Hornbill Classes

AGRICULTURAL ENGINEERING

TOOL KIT SERIES

UPSC

INDIAN FOREST SERVICE

2026 - 27

Linkage of Concepts with PYQs + Infused with Infographics & Maps

Paper - 2

Section - B

Quick Revision

MPPSC STATE FOREST SERVICE 2023



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108 Out of 126 Total Selections in
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AGRICULTURE ENGINEERING

MODULE – 4

EDITION : 2026

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SYLLABUS

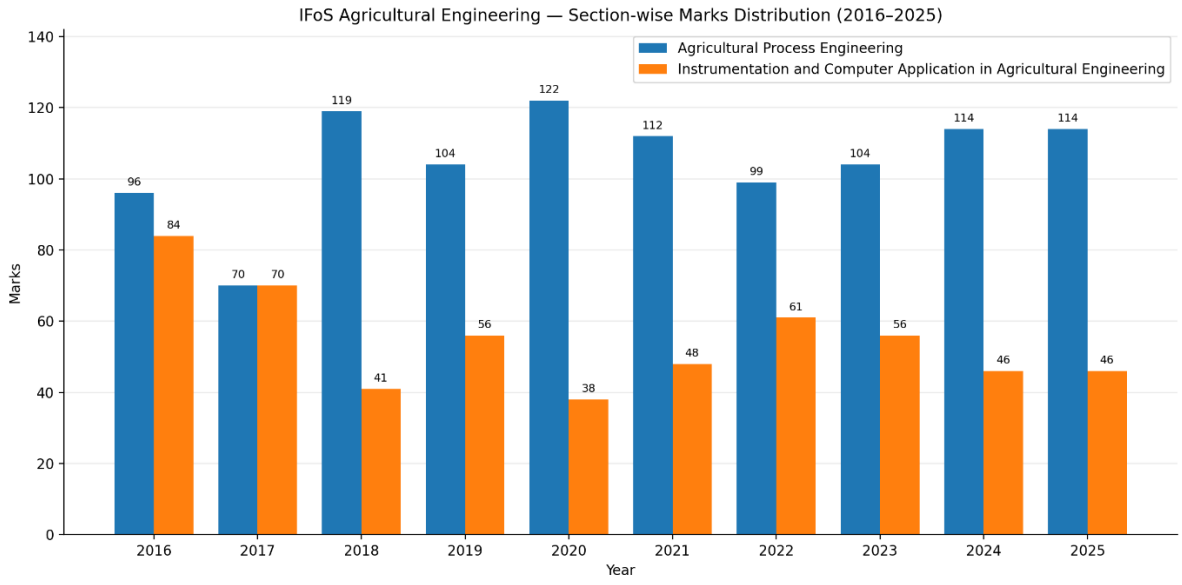
Indian Forest Service (IFoS) [Paper 2 | Section B]	***Farm Power and Machinery:*** Post harvest technology of crops and its scope. Engineering properties of agricultural produces and by-products. Unit operations – clearing grading, size reduction, densification, concentration, drying/dehydration, evaporation, filtration, freezing and packaging of agricultural produces and by-products. Material handling equipment belt and screw conveyors, bucket elevators, their capacity and power requirement. Processing of milk and dairy products - homogenization, cream separation, pasteurization, sterilization, spray and roller drying, butter making, ice cream, cheese and shrikhand manufacture. Waste and by-product utilization - rice husk, rice bran, sugarcane bagasse, plant residues and coir pith. ***Agro-energy:*** Electronic devices and their characteristics-rectifiers, amplifiers, oscillators, multi-vibrators. Digital circuits - sequential and combinational system. Application of microprocessors in data acquisition and control of agricultural engineering processes- measurement systems for level, flow, strain, force, torque, power, pressure, vacuum and temperature. Computers - introduction, input/output devices, central processing unit, memory devices, operating systems, processors, keyboards and printers. Algorithms, flowchart specification, programme translation and problem analysis in Agricultural Engineering. Multimedia and Audio-Visual aids.

Module - 4



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INDIAN FOREST SERVICE (IFoS) PYQs | 2016 – 2025

Post-harvest Technology & Engineering Properties

2024	• Explain the improved paddy parboiling method developed by CFTRI and mention its advantages. [P2/5(a) | 8 M] • Define Equilibrium Moisture Content (EMC) and its usefulness. Mention Henderson's equation for determining EMC. [P2/8(c) | 10 M]
2022	• Explain the design considerations of concrete grain bin. Briefly write the steps and stages of design. [P2/7(b) | 15 M] • Define relative humidity (RH) and humidity ratio with the help of equations. [P2/5(c) | 8 M]
2021	• Write the different types of post-harvest losses which occur at different stages of unit operations in food grains. Explain any one of them. [P2/5(a) | 8 M] • Write the advantages of Rice Parboiling. [P2/5(b) | 8 M] • With the help of process flowchart describe the cottage scale food processing industry for production of fruit jams and juices. [P2/6(a) | 15 M] • Briefly describe the following : (i) Burr mill (ii) Turmeric processing [P2/6(c) | 10 M]
2020	• Define the following properties of agricultural produces : (i) Bulk density (ii) Porosity (iii) Angle of repose (iv) Coefficient of friction Also write the importance of each property in crop processing. [P2/5(a) | 8 M] • Define equilibrium moisture content of grain. Write Henderson's equation for grain isotherm, explaining all its terms. If 10 kg fruit pulp is dried using a drum dryer from 60% (wet basis) to 10% (dry basis) moisture content, how much dried pulp can be obtained? [P2/5(b) | 8 M]
2018	• What is meant by sphericity of a particle? Write the expression for determining sphericity of a body. How does a jaw crusher work? [P2/5(c) | 8 M] • What is meant by dry and wet basis calculations for moisture content in solids? How much water must be removed from parboiled paddy with 45% moisture content (wet basis) to produce 500 kg of dry parboiled paddy with 15% moisture content (wet basis)? [P2/7(b) | 15 M]
2017	• With respect to sterilization of food, define thermal death time and decimal reduction time. What can be the effect if the sterilization is not done. [P2/5(c) | 10 M]
2016	• Differentiate between the following : (i) Osmosis and Dehydration (ii) Equilibrium moisture content and Moisture content (iii) Angle of repose and Angle of internal friction (iv) Specific heat and Thermal conductivity. [P2/5(d) | 8 M]

Unit Operations- Size & Separation

2025	• Define Fineness Modulus. Using fineness modulus, determine the average particle size with the following data : [P2/5(c) | 8 M] • With the help of a line diagram, discuss Vertical Cone Rice Whitener. Also, discuss its

	advantages and disadvantages. [P2/6(a) | 15 M] • What are the objectives of the Tempering-Degerming (TD) method in corn dry milling? Describe the basic operations involved in the TD method. [P2/8(a) | 15 M] • Describe the various steps in modern wheat flour milling. [P2/8(b) | 15 M]
2024	• Derive the effectiveness of screen in a grader through material balance. [P2/7(a) | 15 M] • In wheat milling, it was found that to grind 4·33 mm sized grains to pass sieve of 0·351 mm opening, the power requirement was 8 kW. Calculate the power requirement for milling of the wheat using Rittinger's law and Kick's law by the same mill to pass sieve of 0·157 mm opening. The feed rate of milling is 200 kg/h. [P2/7(b) | 10 M] • Explain the components of a wheat mill. [P2/5(e) | 8 M]
2023	• What are the design considerations for air screen grain cleaner? [P2/5(a) | 8 M]
2021	• (i) Explain the processing and ginning of cotton. [5 M] (ii) Briefly explain about mechanical oil expeller for production of edible oils. [5 M] [P2/7(c) | 10 M]
2020	• Air screen cleaner and specific gravity separators are used in crop processing. Write the basic principle of operation of these equipments. List the components of both the equipments along with the role of each component. Write the importance of cleaning in crop processing. [P2/6(b) | 10 M] • Define filtration. Briefly discuss along with sketch (showing the flow of the feed and the permeate) the cake filter, clarifying filter and the cross-flow filter. If in a slurry there is high solid content, which type of filter will you recommend? Write with proper reasoning. Define screening in food processing. Show mass balance over a screen and find out the ratio of oversize to feed in terms of mass fractions of feed, oversize and undersize. Make suitable assumptions. [P2/7(b) | 15 M]
2019	• State Bond's Law of Crushing. What is Work Index? State the principle of operation of a jaw crusher. [P2/5(a) | 8 M]
2017	• Discuss the criteria and methods of sorting of food materials. Draw sketch of pneumatic method sorting machine. [P2/6(d) | 10 M] • What are the benefits of size reduction in food processing? A crusher requires 10 kW for grinding a material at the rate of 100 kg/h from 2 cm size to 0·5 cm size. How much power would be required if the reduction was to 0·4 cm. Use both Kick's law as well as Rittinger's law to solve the problem. [P2/7(a) | 10 M]
2016	• What are the major differences between a Hammer mill and a Roller mill? [P2/6(a) | 10 M] • Describe the working of a cyclone separator. How is its separation factor related to the weight of a particle? [P2/6(b) | 10 M]

Drying, Dehydration, Evaporation & Freezing

2025	• Write short notes on the following : (i) Specific Humidity (ii) Dew Point (DP) Temperature (iii) Wet Bulb (WB) Temperature (iv) Decortication of Oilseeds [P2/5(a) | 8

	M] • 5000 kg of apples are to be cooled from 25°C to 10°C in 24 hours. Specific heat of apple is 3·25 kJ/kg·°C. The heat of respiration in 24 hours is 3400 kJ per tonne of apples. Due to different sources, the infiltration of heat is 4100 kJ per tonne of apples during 24 hours. The lighting load is 150 W. Calculate the refrigeration capacity [tonne of refrigeration (TR)] of machine required. Note : 1 TR = 3·5 kW = 210 kJ/min. [P2/6(b) | 10 M]
2024	• Find out the evaporation rate in a drum drier for the data given. The steam temperature is 160 °C. The vaporization temperature of milk is 105 °C. The overall heat transfer coefficient is 1200 kcal/h·m2·°C. The drum diameter is 0·7 m. The length of the drum is 105 cm. The latent heat of vaporization is 540 kcal/kg. The product is scrapped at 80% of the revolution of the drum. [P2/5(b) | 8 M] • Explain freeze drying system and its merits. [P2/7(c) | 8 M]
2023	• What are the different parameters which can be determined using psychrometric chart? Give four common uses of psychrometric chart in analysis of the drying process. [P2/5(b) | 8 M] • Differentiate between the following : (i) Thin layer drying and Deep bed drying (ii) Bulk density and True density (iii) Rittinger's law of size reduction and Bond's law of size reduction (iv) Pneumatic separation and Gravity separation (v) Modified Atmosphere packaging and Controlled Atmosphere packaging. [P2/6(a) | 10 M] • What is spray drying and what are its main advantages in food processing industries? Explain spray dryer with the help of a schematic diagram. [P2/7(b) | 15 M]
2022	• Write the advantages of blanching of fruits and vegetables. [P2/5(a) | 8 M] • Write a short note on different quick-freezing methods. What are the advantages of frozen foods? [P2/5(b) | 8 M] • Estimate the steam requirement during the initial stage of heating 120 L of cream in a jacketed pan, if the initial temperature of the cream is 18 °C and the steam used is at 2 kg/cm2 abs. pressure. The pan has a heating surface area of 1 m2 and the overall heat transfer coefficient is assumed to be 250 kcal/m2·h·°C. Data given : Saturation temperature of steam = 119·6 °C Latent heat, L = 526 kcal/kg at 2 kg/cm2 abs. pressure [P2/6(a) | 10 M] • Potatoes are dried from 14% total solids to 93% total solids. What is the product yield from each 1000 kg of raw potatoes assuming that 8% by weight of the original potatoes is lost in peeling? Calculate the product yield (%) along with mass balance. [P2/7(a) | 10 M] • Define and explain the following in relation to drying : (i) Fuel efficiency (ii) Thermal efficiency (iii) Drying efficiency. [P2/8(c) | 10 M]
2021	• Enlist the different types of dryers used for drying agricultural commodities. Explain foam mat drying for liquid juices. [P2/5(d) | 8 M] • (i) Describe the construction and operation of Recirculatory batch dryer (RPEC type) with neat sketch. [10 M] (ii) Explain the mini dal/dhal mill for milling of pulses. [5 M] [P2/7(a) | 15 M]

2020	• Define capacity and economy of an evaporator. A single-effect evaporator is used to concentrate fruit juice from 20% to 50% solid. The feed rate of the juice is 1000 kg per hour. Draw a mass balance diagram of the process and find out the concentrated juice coming out from the evaporator and the amount of vapour being evaporated from the juice. [P2/5(c) | 8 M] • Draw drying curves of a particulate solid. What do you mean by multipass drying? Describe the constructional features and functioning of an LSU type grain dryer. [P2/6(c) | 15 M]
2019	• What is the importance of dehydration in processing of food? State the principle of operation of a tray dryer. [P2/5(b) | 8 M] • What is boiling point elevation? State the principle of operation of a falling film evaporator. Why is this type of evaporator preferred for concentrating heat-sensitive materials like fruit juice and milk? [P2/6(b) | 15 M] • Orange juice needs to be concentrated using an evaporator from an initial moisture content of 80% (wet basis) to a final moisture content of 45% (dry basis). Calculate the amount of moisture to be removed from 100 kg of orange juice. [P2/6(c) | 10 M] • State why freezing can be considered as a method of preservation of food. What are the advantages and disadvantages of quick freezing? [P2/7(c) | 10 M]
2018	• Write the basic mass and energy balance equations for a single effect evaporator, clearly defining each term. [P2/7(a) | 10 M] • What is a filter aid? Name any one material that is used as a filter aid. Describe the operation of any one batch filter used in agricultural processes. [P2/7(c) | 15 M]
2017	• Write the physical and thermal properties of food and their importance in food processing. Apple juice needs to be concentrated using an evaporator from an initial moisture content of 85% (w.b.) to a final moisture content of 50% (d.b.). Calculate the amount of moisture required to be removed from 100 kg of apple juice to achieve the same. Draw a mass balance diagram for the same. [P2/7(b) | 10 M] • Define water activity. Draw a typical drying curve and explain the mechanism of drying. How moisture content could be quickly removed - explain various measures. [P2/7(c) | 10 M] • Discuss the advantages of cold storage in respect of food processing. What is cold food chain? How it works? [P2/5(a) | 10 M]
2016	• Write about the basic drying principle(s) involved in the following : (i) Mechanical drying (ii) Chemical drying (iii) Vacuum drying (iv) Freeze drying. [P2/5(e) | 8 M]

Packaging & Material Handling Equipment

2025	• Explain different types of food packaging materials with their characteristics. [P2/5(b) | 8 M] • A bucket elevator is installed to be used up to a height of 25 m for vertically lifting foodgrains (750 kg/m3). Each bucket has a volume of 3500 cc and spaced 40 cm apart

	on a belt. The centre-to-centre distance between head and foot wheel is 25·30 metres. The head pulley is 30 cm in diameter and rotates on a shaft of 5 cm diameter. The belt and the empty buckets weigh on an average 5 kg per metre length. Assume degree of lifting as 80% and coefficient of friction as 0·4 at the axle of the pulley. Find the speed and power required to lift 4 tonnes of foodgrains (750 kg/m3) per hour. [P2/7(b) | 10 M]
2023	• Explain the working principle of screw conveyor with a neat drawing. List various shapes of screw conveyor trough. [P2/5(c) | 8 M]
2021	• Design a bag storage structure for storing 500 tonnes of wheat. Assume bag size is 70 × 50 × 30 cm to hold 50 kg grain in it. Keep 15 bags in length and 15 bags in width per stack with height/layer of 15 stacks. Assume reasonable data where necessary. [P2/7(b) | 15 M]
2020	• Write the functions of a food packaging material. What is modified atmosphere packaging? Briefly describe how a modified atmosphere packaging works. Differentiate between modified atmosphere storage and controlled atmosphere storage. [P2/8(c) | 10 M]
2019	• Among the two types of conveyors - belt and screw, which type consumes more power and why? With a diagram, explain the operation of a screw conveyor. [P2/6(a) | 15 M]
2018	• With a neat diagram describe the operation of a belt conveyor indicating the placement of valves and motors. [P2/6(a) | 15 M] • The mass of a material on a belt conveyor of length 20 m is 200 kg and the conveyor is moving with a speed of 2 m/min. Calculate the capacity i.e. the flow rate of material on the belt conveyor in kg/s. [P2/6(b) | 10 M]
2017	• What parameters are to be considered while designing a bucket elevator? Describe briefly. [P2/5(b) | 10 M]
2016	• What are the common types of equipment used in grain handling? Discuss in brief the factors considered in their selection. [P2/7(a) | 10 M]

Dairy and Milk Processing

2025	• Discuss various advantages and limitations of ice cream ingredients such as milk fat, milk-solids-not-fat, sugar, stabilizer, emulsifier, total solids, flavour and colour. [P2/7(a) | 15 M] • Define Shrikhand. Discuss the standardised method of preparation of Shrikhand. [P2/8(c) | 10 M]
2024	• Mention the ingredients of ice cream and describe in detail its preparation. [P2/6(a) | 15 M] • If the volume of milk flow in a homogenizer is 1000 L/h, at a pressure of 250 kg/cm2, calculate the horsepower required for homogenization. [P2/6(b) | 10 M] • Discuss the techniques involved in standardization of milk. [P2/8(d) | 10 M]
2023	• What are common types of heat exchangers used in the food industry? How are heat exchangers classified based on relative direction of motions of fluid flow? [P2/6(c) | 15 M]

	• (i) Explain about homogenization. Calculate the horse-power (hp) required for homogenization. Given value of Q is 1000 l/h and p is 250 kg/cm2. [10 M] (ii) Describe In-bottle sterilization of milk. [5 M] [P2/7(a) | 15 M] • Why is freezing of cream done? Explain any two methods of cream freezing. [P2/7(c) | 10 M]
2022	• (i) Why is chilling of milk essential? Write the different types of milk chilling systems. (ii) Write a short note on overrun in ice cream. [P2/8(b) | 15 M]
2021	• Define Ice-cream. Write the method/flowchart of manufacturing, packaging, hardening and storage of ice-cream. [P2/5(c) | 8 M] • How many kg each of 28% cream and 3% milk will be required to make 500 kg of a mixture testing 4% fat? Also do proof showing fat in individual items. [P2/6(b) | 15 M]
2020	• What is pasteurisation of milk? Enlist the methods of pasteurization of milk. Write the advantages of high temperature short time (HTST) pasteurization of milk. [P2/5(d) | 8 M] • Explain the working of centrifugal cream separator. Calculate the power requirement to start up a centrifugal cream separator if the density of the bowl is 7850 kg m-3, revolutions per second 100, outer radius and inner radius of the disk are 0·25 m and 0·225 m, respectively. The length given for the mass is concentrated is 0·35 m and time to reach the running speed is 300 s. [P2/7(a) | 15 M] • How many kg each of cream having 30% fat and milk having 5% fat will be required to make 1000 kg of mixture having 10% fat? [P2/7(c) | 10 M]
2019	• Why is homogenisation of milk important in the dairy industry? With the help of a neat diagram, describe the operation of a cream separator. [P2/7(a) | 15 M] • Describe how milk powder can be produced from liquid milk slurry in a spray dryer. [P2/7(b) | 15 M]
2018	• What are the reasons for fouling of heat exchangers during milk processing? [P2/5(a) | 8 M] • Draw the flowchart of making butter from milk in a continuous process. [P2/8(a) | 15 M] • What is the difference between sterilisation and pasteurisation? What are the steps involved in making cheddar cheese from milk? [P2/8(b) | 15 M]
2016	• Differentiate between the working principle and application of Spray and Roller driers in Milk Powder manufacture. [P2/7(c) | 10 M]

Waste & By-Product utilization

2024	• Explain the process of extracting crude bran oil through batch type solvent extraction method. [P2/8(b) | 12 M]
2023	• (i) What are the different methods of stabilization of rice bran? [8 M] (ii) Explain the process of extraction and refining of rice bran oil. [7 M] [P2/6(b) | 15 M]
2022	• Explain the by-products generation from sugarcane in sugar and jaggery industries. Show potential utilization of sugarcane industry waste for generation of wealth from waste through process flowchart. [P2/6(b) | 15 M]

2020	• The biomass generated from various crops have usually low bulk density and thus pose huge problem in transportation and storage. State how this problem can be solved. List the technologies available for this. Describe any one technology in detail. Calculate the percent saving per kg in transportation cost of chopped wheat straw if it is transported by a truck from city A to city B in two different forms, i.e., loose form and densified form. The bulk density of loose straw may be assumed as 80 kg/m3 whereas that of densified straw as 400 kg/m3. The transportation cost may be considered as ₹ 2000 per truck from city A to city B. Consider the volume of one truck as 10 m3. [P2/6(a) | 15 M]
2019	• What is rice husk? Describe how energy can be generated from rice husk. [P2/5(c) | 8 M]
2018	• What are the steps involved in producing alcohol from sugarcane bagasse? [P2/5(d) | 8 M]
2016	• Which are the by-products generated during milling of paddy? Describe how the by-products can be profitably used. [P2/6(d) | 10 M] • Describe how sugarcane bagasse can be utilized, not going as waste. [P2/7(d) | 10 M]
	• Write different technological solutions available for utilization of rice husk. [P2/8(c) | 10 M] • Write the problem associated with storage of rice bran and its possible reasons. Explain with the help of suitable flow diagram the extraction of oil from rice bran. [P2/8(d) | 10 M]

Electronic Devices

2025	• Define electrical amplifying elements and discuss their voltage amplification, current amplification and gain. [P2/5(d) | 8 M]
2022	• Discuss in detail about (i) amplifiers and (ii) multivibrators. [P2/5(e) | 8 M]

Digital Circuits & Microprocessors

2019	• State how microprocessors can be utilised in acquisition of data and can subsequently be used in agricultural engineering. [P2/5(d) | 8 M] • Differentiate between the working principles of sequential and combination systems of digital circuits. [P2/8(b) | 15 M]
2016	• How are Microprocessors used in data acquisition and control of Agricultural Engineering processes? [P2/8(a) | 10 M] • Differentiate between the working principle of sequential and combination systems of Digital circuits. [P2/8(d) | 10 M]

Measuremet System in Agriculture Engineering

2025	• Write the principle of operation of the following transducer elements and mention their input and output variables : (i) Bourdon gauge (ii) Venturimeter/Orifice meter (iii) Piezo-electric device (iv) Solar cell [P2/6(c) | 8 M] • With a neat sketch, explain the cistern-type manometer used for measuring static pressure. [P2/7(d) | 7 M]
2024	• Write the principle of operation of the following and mention their input and output variables : (i) Thermocouple (ii) Resistance strain gauge (iii) Hot wire anemometer (iv) Resistance thermometer [P2/5(d) | 8 M] • Write short note on precision, resolution and threshold of an instrument. [P2/6(c) | 8 M] • Discuss the use of U-tube manometer. What are the desirable characteristics of manometric fluid? [P2/8(a) | 8 M]
2023	• Differentiate between the following : (i) Analog Signal and Digital Signal (ii) Force and Torque (iii) Accuracy and Precision (iv) Stress and Strain [P2/5(d) | 8 M] • (i) Write in brief about the instrumentation used in measurement of temperature. [5 M] (ii) Calculate the steam requirement during the initial stage of heating of 120 l of cream in a pan, if the initial temperature of the cream is 18°C and the steam used is at 2·00 kg/cm2 abs. pressure. Heating surface area of pan is 1 m2 and overall heat transfer coefficient is 250 kcal/m2·h·°C. Given data from steam tables are : Saturation temperature of steam = 119·6°C; Latent heat = 526 kcal/kg at 2 kg/cm2 abs. pressure. [5 M] [P2/8(a) | 10 M] • Explain with the help of neat figures : (i) Orifice meter (ii) Venturimeter [P2/8(b) | 10 M] • Write the working principles involved in hydraulic load cell and pneumatic load cell in force measurements. [P2/8(c) | 10 M]
2022	• Explain the classification of the following analog instruments : (i) Indicating instruments (ii) Recording instruments [P2/5(d) | 8 M] • Draw a figure of generalized measurement system and write about its functional elements. [P2/7(c) | 15 M] • Write the principle of operations of thermocouple. Draw the common forms of thermocouple construction and explain. [P2/8(a) | 15 M]
2021	• What is an amplifier and what are their different types? With the help of neat sketch, explain the hydraulic amplifying element. [P2/8(a) | 15 M] • Write in brief about the following : (i) Transmission Dynamometer (ii) Driving type Dynamometer (iii) Absorption Dynamometer [P2/8(b) | 15 M] • For a certain thermistor, β = 3140 K and the resistance at 27°C is known to be 1050 Ω. The thermistor is used for temperature measurement and the resistance is measured as 2330 Ω. Find the measured temperature using equation of the temperature-resistance characteristics of the thermistor. [P2/8(c) | 10 M]
2020	• Write the types of instrumentation systems being used in food processing. Explain the elements of an analog data acquisition system. [P2/5(e) | 8 M] • Describe the working principle of strain gauge torque meters. Write the methods of

	measurement of liquid level in a glass tube. What are the advantages and disadvantages of resistive method? [P2/8(a) | 15 M] • Describe the two basic methods for measurement of low pressure in a food processing equipment. Draw a diagram of the thermocouple vacuum gauge and explain the heater element. [P2/8(b) | 15 M]
2019	• What is meant by strain? Draw the typical stress – strain curve showing linear, necking and eventual break regions. What is the principle of operation of a metal strain-gauge? [P2/5(e) | 8 M] • What is the basic difference between sensors and transducers? For what purpose is a rotameter used in fluid flow? How does it operate? [P2/8(a) | 15 M] • What is Seebeck effect? Find the Seebeck emf, in mV, for a material with $\alpha = 60\ \mu V/°C$ if the junction temperatures are 30°C and 100°C, where α is a proportionality constant. [P2/8(c) | 10 M]
2018	• Explain with a neat diagram how a diaphragm can be used for measuring pressure difference in a system. [P2/5(b) | 8 M] • What is Seebeck effect? How is this principle applied in the operation of a thermocouple used for measuring temperature? [P2/6(c) | 15 M]
2017	• Write basic principles involved in working of thermocouples. How law of intermediate temperature and metals is used in design of thermocouples? Also explain the construction and advantages of thermopiles. [P2/5(d) | 10 M] • Classify flow meters. Explain the functioning of a hot wire anemometer. Draw a neat sketch. [P2/6(a) | 10 M] • Write the working principle of the following : (i) Piezoelectric transducer (ii) Pyrometer (iii) Semi conductor resistance sensors (iv) Signal conditioning (v) Vibration meter [P2/6(b) | 10 M] • Describe different types of torque sensors along with their working principles. How the torque of PTO pulley can be measured? [P2/6(c) | 10 M] • Explain five important static characteristic parameters of a simplified measuring system. Derive an expression for output of a first order instrument. [P2/7(d) | 10 M] • Define precision and accuracy of an instrument with suitable examples. [P2/8(a) | 10 M]
2016	• Differentiate between the following : (i) Analog and Digital signals (ii) Readability and Span (iii) True value and Accuracy (iv) Force and Torque. [P2/5(a) | 8 M] • Describe in brief the method of measurement calibration of the following : (i) Draft requirement of an animal drawn plough (ii) Draft requirement of a tractor drawn trailed disc harrow. [P2/5(b) | 8 M] • How are the following measurements done? (i) Brake Horse Power of an engine using hydraulic brake dynamometer (ii) Calibration of a hydraulic tension dynamometer. [P2/5(c) | 8 M] • Describe the basic methods of force measurement. [P2/6(c) | 10 M] • Name the different types of strain measuring equipment and describe in brief the techniques adopted using strain gauges. [P2/7(b) | 10 M]

Computer Algorithms & Multimedia

2025	• Explain in ascending order the data storage hierarchy in a computer. [P2/5(e) | 8 M] • Write the algorithm and flowchart to find the sum of two numbers. [P2/6(d) | 7 M] • What is Data? Describe the procedure of data processing to obtain information for decision-making. [P2/7(c) | 8 M]
2024	• Explain about Random Access Memory (RAM) and Read Only Memory (ROM) in a computer. [P2/5(c) | 8 M] • Explain the major characters of computers that made them powerful and useful in agriculture. [P2/6(d) | 7 M] • Explain the Central Processing Unit (CPU) of a computer. Also explain the main operations accomplished using CPU cycle. [P2/7(d) | 7 M]
2023	• Explain various steps involved in developing a programme using a computer. [P2/5(e) | 8 M] • Explain the role of digital marketing using multimedia and audio-visual aids in Agro/Food Processing Industry. [P2/8(d) | 10 M]
2022	• What are the different components used in CPU? Explain in brief each of them. Discuss the primary memory and secondary memory units used in computers. [P2/6(c) | 15 M]
2021	• Write about digital computers. Draw digital computer system showing input and output devices. [P2/5(e) | 8 M]
2018	• Name any two input devices and two output devices of a computer. What are the primary and secondary storage of a computer system? What is the function of the central processing unit of a computer? [P2/5(e) | 8 M] • Write the algorithm in any programming language for calculating the Reynolds number when various sets of values of diameter of a pipe (D), linear velocity of a fluid through the pipe (v), density of the fluid (ρ) and viscosity of the fluid (μ) are given. [P2/8(c) | 10 M]
2017	• Discuss the functions of CPU and memory devices in computers. How microprocessor helps in acquisition of data related to agriculture? [P2/8(b) | 10 M]
2016	• Describe in brief the application of Multimedia and Audio-Visual aids in propagation of forestation. [P2/8(b) | 10 M] • Explain in brief the role of C.P.U. and memory devices in modern computers. [P2/8(c) | 10 M]

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CHAPTER

1

POST-HARVEST TECHNOLOGY & ENGINEERING PROPERTIES

Post-harvest scope & losses · Engineering, physical & thermal properties · Moisture content & EMC · Paddy parboiling

SYLLABUS : Agricultural Process Engineering — Post harvest technology of crops and its scope. Engineering properties of agricultural produces and by-products. (Paper II, Section B, Topic 3)

Chapter Outline

1. **Scope of Post-Harvest Technology**
2. **Post-Harvest Losses**
3. **Engineering Properties: Meaning and Classification**
4. **Physical Properties**
5. **Frictional Properties**
6. **Thermal Properties**
7. **Aerodynamic, Mechanical, Rheological, Electrical and Optical Properties**
8. **Moisture Content: Bases, Conversion and Measurement**
9. **Water Activity, EMC and Sorption Isotherms**
10. **Worked Numericals on Moisture Mass Balance**
11. **Paddy Parboiling**
12. **Physical Properties of Fruits and Vegetables**
13. **Formula Sheet · Summary · Last-Night Revision**

1 SCOPE OF POST-HARVEST TECHNOLOGY

1.1 Meaning, Scope and the Post-Harvest System

Post-harvest technology (PHT) covers every operation performed on a crop after it is detached from the plant and before it reaches the consumer — handling, threshing, cleaning, grading, drying, storage, milling, processing, packaging, transport and by-product utilisation. Its premise is examinable in one line: ***food supply can be raised either by producing more or by losing less***, and the second route needs no extra land, water or fertiliser.

> **Agricultural processing :** *any activity performed to maintain or improve the quality, or to change the form or characteristics, of an agricultural product after production, so as to add value and minimise qualitative and quantitative deterioration.*

A processing job is a **series of unit operations**, each with its own loss risk:

Unit operation	Purpose	Consequence of doing it badly
Cleaning, grading, sorting	Remove straw, chaff, weed seeds, stones, mud, iron pieces	Lower price, higher bulk and handling cost, machine wear, higher storage loss
Drying / dehydration	Bring moisture to a safe level; the principal preservation method for grain	Breakage in maize and soybean; loss of milling quality in rice and wheat
Storage	Hold the surplus between glut and scarcity	The bulk of all post-harvest loss occurs here
Milling	Remove indigestible hull and enzymatically active germ; recover endosperm	Broken rice, low head yield, rancidity
Handling, packaging, transport	Move and protect the produce	Spillage, mechanical damage, moisture regain
By-product utilisation	Convert husk, bran and residues to fuel, oil, feed	Revenue forgone; this alone can finance mill modernisation

1.2 Objectives, Opportunities and Challenges in India

Objective	Achieved by	Benefit
Conservation of produce	Timely drying, scientific storage, pest management	Quantity loss falls, availability rises
Quality preservation	Control of moisture, temperature, mechanical damage	Higher price, export acceptability
Value addition	Milling, parboiling, processing, packaging	Farmer becomes producer-cum-processor
By-product utilisation	Husk as fuel, bran for oil, residues for feed and biogas	New revenue; less environmental burden
Price stabilisation	Storage evens out glut and scarcity	Distress sale avoided

Rising yields create a marketable surplus that must be conserved, moved and converted, so the importance of PHT grows with productivity — it became critical in India once high-yielding varieties carried agriculture from subsistence to commercial enterprise. **Opportunities**: value addition, export-grade quality through controlled moisture and uniform grading, and a by-product economy in husk, bran, bagasse and coir pith. ***Challenges***: more than 75 % of farmers are marginal or small so individual investment in drying and storage is unviable; drying capacity is short, forcing road-side sun-drying; storage is largely bag storage in unscientific godowns; the cold chain for perishables is thin; and weak market linkage forces distress sale during glut.

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PREVIOUS YEAR QUESTIONS

- *How does post-harvest technology contribute to optimizing the handling, storage and processing of agricultural produce?*

  [OPSC·CSE (Main) 2023–24 · Paper-II, Q.13(a) · 20M]

- *What are the key challenges and opportunities in post-harvest handling of crops and how do they impact the agricultural supply chain and farmers' livelihoods?*

  [OPSC·CSE (Main) 2023–24 · Paper-II, Q.13(b) · 20M]

2 POST-HARVEST LOSSES

Post-harvest loss : *the measurable reduction in the quantity or the quality of a harvested crop between harvest and consumption.*

- ***Quantitative loss*** : actual disappearance of dry matter — grain eaten by rodents, birds and insects, spillage, shattering, broken and powdered grain in milling. It is weighable.
- ***Qualitative loss*** : loss of nutritive value, viability, colour, flavour, milling quality or market grade without loss of weight — mould-discoloured grain, rancid bran, loss of germination, off-flavour in over-soaked parboiled paddy. Often the larger economic loss, but under-reported because it does not show on the weighbridge.

Losses are ***5–20 % in cereals and 20–50 % in fruits and vegetables***, the difference explained by the high moisture, active respiration and soft texture of perishables.

2.1 Stage-wise Losses in Food Grains

Stage where loss is caused	*Wheat*	*Rice*	*Maize*	*Pulses*	*All grains*
Threshing yard	1.0	2.5	0.5	0.5	1.68
Transport	0.5	0.5	0.5	0.5	0.15
Processing	2.0	—	—	0.20	—
Storage — rodents	2.5	2.5	2.5	2.5	2.50
Storage — birds	0.5	1.0	0.5	0.5	0.85
Storage — insects	3.0	2.0	3.0	5.0	2.55
Storage — moisture	0.5	0.5	0.5	0.5	0.68
TOTAL	8.0	11.0	7.5	9.5	9.33

Table 1.1 Stage-wise percentage loss.

Two conclusions must reach the answer sheet: ***storage accounts for about two-thirds of the total***, and within storage ***insects and rodents dominate***.

2.2 Losses at Each Unit Operation, and Their Causes

Unit operation	*Nature of loss*	*Principal causes*
Harvesting	Shattering, un-gathered grain	Delayed or premature harvest; over-ripeness; rough handling
Threshing	Un-threshed ears, broken and cracked grain	Wrong cylinder speed and concave clearance; high grain moisture
Cleaning &	Good grain blown away with	Air velocity set above the terminal velocity of sound

winnowing	the chaff	grain
Drying	Cracking, case-hardening, discolouration, scorching	Too rapid drying; excessive air temperature; uneven bed
Storage	Weight loss, contamination, germination loss, caking	Insects, rodents, birds, moulds; moisture migration; high RH
Handling & transport	Spillage, bag tearing, mechanical damage	Poor conveyor choice, excess drop height, bad roads
Milling	Broken rice, low head yield, bran loss	Un-parboiled brittle grain; wrong huller clearance; over-polishing
Packaging & marketing	Moisture regain, insect re-infestation	Permeable packs; unhygienic godowns; long market chains

▶ ***Explaining one loss in full — storage loss***

Stored grain is a ***living, respiring ecosystem***. Deterioration arises from interaction among physical, chemical, physiological and biological variables — temperature, moisture, oxygen and carbon dioxide, the storage structure, the properties of the grain bulk, micro-organisms, insects, mites, rodents and birds. These seldom act alone. Initially deterioration is slow; once a favourable combination is established and storage is prolonged, loss in both quantity and quality becomes severe. Respiration of the grain and of the infesting organisms liberates heat, moisture and carbon dioxide; the released moisture raises the local equilibrium relative humidity, which accelerates mould growth, which liberates more heat — an ***autocatalytic cycle*** ending in hot-spot formation and caking.

PREVIOUS YEAR QUESTIONS

Write the different types of post-harvest losses which occur at different stages of unit operations in food grains. Explain any one of them.

[IFoS 2021 · P2/5(a) · 8M]

MODEL Q Open with the quantitative/qualitative split, give the stage-wise table as the 'different types', then take storage loss as the 'any one' and develop the respiration–heat–moisture cycle. One line of figures from Table 1.1 earns the marks a purely descriptive answer loses.***

3 ENGINEERING PROPERTIES: MEANING AND CLASSIFICATION

Engineering properties : *those properties of an agricultural material which are useful and necessary in the design and operation of processing equipment and in the development of farm machinery.*

Every unit operation is designed around a short list of measurable properties. Three illustrations fix the idea. ***Air-screen cleaner***: grain shape and size fix the screen opening, inclination and vibration; density fixes the screening area; frontal area with density fixes the terminal velocity and hence the winnowing air velocity. ***Storage bin***: bulk density fixes the volume, angle of internal friction the lateral wall pressure, angle of repose the hopper slope. ***Grain drier***: specific heat and thermal conductivity fix the heat load, porosity fixes the fan duty, EMC fixes the attainable final moisture.

Class	*Properties included*	*Chief design application*
Physical	Size, shape, sphericity, roundness, volume, surface area, bulk and true density, specific	Cleaning, grading, separation; sizing of bins and conveyors

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	gravity, porosity, colour, 1000-grain weight	
Frictional	Coefficient of static and kinetic friction, angle of repose, angle of internal friction, rolling resistance	Bins, hoppers, chutes, screw conveyors, threshers, forage harvesters
Aerodynamic / hydrodynamic	Terminal velocity, drag coefficient, resistance of the grain bed to airflow	Pneumatic conveying, aspiration, winnowing, fan and blower selection
Thermal	Specific heat, thermal conductivity, thermal diffusivity, enthalpy, latent heat	Drying, cooling, freezing, thermal disinfestation, heat exchangers
Mechanical	Hardness, compressive strength, impact and shear resistance, modulus of elasticity	Size reduction, milling, threshing, dehulling, handling damage
Rheological	Elasticity, plasticity, viscosity; firmness, crispness, fibrousness	Handling of pulps and liquid foods, texture evaluation, extrusion
Electrical	Resistance, dielectric constant, loss factor	Moisture meters, dielectric and microwave heating, electrostatic separation
Optical	Colour, reflectance, transmittance, gloss	Colour sorters, maturity indices, quality grading

PREVIOUS YEAR QUESTIONS

- *What do you understand by engineering properties of agricultural materials? Enlist all properties and also give its importance.*

  [UK·PSC ACF/RFO (Mains) 2025 · Q.7(iv) · 10M]

- *Explain the engineering properties of agricultural produces and by-products, affecting its handling and processing.*

  [OPSC·CSE (Main) 2016–17 · Paper-II, Q.5(d) · 20M · also OPSC·Forest 2015–16 · Q.5(c) · 20M]

MODEL Q Reproduce the classification table, then add the three design illustrations above. The table is the answer; the illustrations separate a pass from a good score. Never list property names without the design use against each.***

4 PHYSICAL PROPERTIES

4.1 *Size and Shape: Sphericity and Roundness*

A grain is described by three mutually perpendicular intercepts — l the major intercept, b the largest perpendicular to it, and t the largest perpendicular to both; they need not intersect at a common point.

$$D_g = (l \cdot b \cdot t)^{(1/3)} \qquad D_a = (l + b + t)/3$$

D_g = geometric mean or equivalent diameter, mm ; D_a = arithmetic mean diameter, mm

Sphericity : *the ratio of the diameter of a sphere of the same volume as the particle to the diameter of the smallest circumscribing sphere; it expresses the shape of the particle relative to a sphere of equal volume.*

Taking the grain as an ellipsoid of intercepts l, b, t and the circumscribed sphere as having diameter equal to the largest intercept:

$$\varphi = [\ (\pi/6)\cdot l\cdot b\cdot t \div (\pi/6)\cdot l^3\ ]^{(1/3)} = (l\cdot b\cdot t)^{(1/3)} / l$$

Working form — geometric mean diameter divided by the major intercept

Two further definitions are acceptable if the symbols are defined: $\varphi = D_i / D_c$, the largest inscribed circle over the smallest circumscribed circle; and Chakraverty's surface-area form, the surface area of an equal-volume sphere over the actual surface area of the particle.

Roundness : *a measure of the sharpness of the corners of the solid.*

$$\textit{Roundness} = A_p / A_c \qquad \textit{Roundness ratio} = r / R$$

Ap = largest projected area in the natural rest position ; A_c = area of the smallest circumscribing circle ; r = radius of curvature of the sharpest corner ; R = mean radius

Basis	Sphericity	Roundness
What it measures	How closely the whole particle approaches a sphere in volume	How sharp or blunt the corners and edges are
Quantity compared	Volumes or diameters — three-dimensional	Projected areas or radii of curvature — two-dimensional
Defining ratio	ϕ = (l·b·t)$^{(1/3)}$/l, or D_i/D_c	A_p/A_c, or r/R
Rest position	Not required	Particle must be in its natural rest position
Value for a sphere	1.0	1.0
Chief use	Flow and rolling behaviour, terminal velocity, screen design	Abrasion, polishing, wear, grading of nuts and fruits

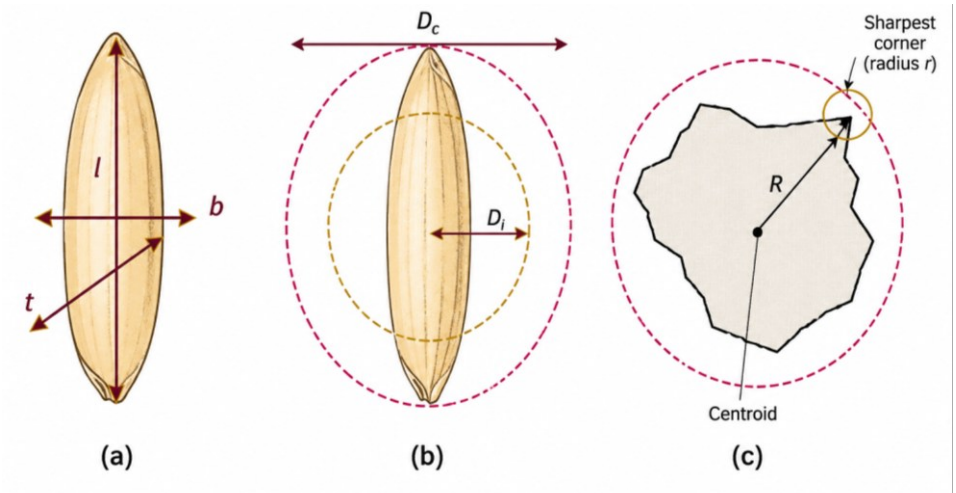


Fig. 1.1 (a) Characteristic intercepts, (b) inscribed and circumscribed circles, (c) roundness parameters.

◆ **WORKED NUMERICAL — *Sphericity of an apple*** **[MH·PSC Forest Services (Mains) 2024 · Q.5(g)(ii) · 8M]**

Problem. *Determine the sphericity of an apple using three mutually perpendicular axes A = 85 mm, B = 58 mm and C = 41 mm.*

Given. A = l = 85 mm ; B = b = 58 mm ; C = t = 41 mm. **Find.** Sphericity ϕ.

Formula (first principles). Treating the apple as an ellipsoid of semi-axes A/2, B/2, C/2, its volume is (π/6)ABC, so an equal-volume sphere has diameter D_e = (ABC)$^{(1/3)}$. The smallest circumscribing sphere has diameter equal to the largest intercept A. Hence

$$\varphi = (A \cdot B \cdot C)^{(1/3)} / A$$

Substitution. A·B·C = 85 × 58 × 41 = 202 130 mm³

$$D_e = (202\,130)^{(1/3)} = 58.687 \text{ mm} \qquad \varphi = 58.687 / 85 = 0.6904$$

Result. ϕ = 0.690, i.e. 69.0 %.

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Check. mm ÷ mm — dimensionless, as sphericity must be, and 0 < 0.690 < 1. A perfect sphere gives 1.0; 0.69 reflects the flattened fruit.

PREVIOUS YEAR QUESTIONS

- *What is meant by sphericity of a particle? Write the expression for determining sphericity of a body.*

  [IFoS 2018 · P2/5(c) · 8M]

- *Differentiate between: Static and Dynamic friction; Sphericity and roundness.*

  [OPSC·Forest (Main) 2023–24 · Paper-II, Q.5(c) · 20M]

4.2 Bulk Density, True Density, Specific Gravity and Porosity

Bulk density : *mass of grain per unit volume of the bulk,* ***including*** *the inter-granular voids; found by weighing a known volume filled uniformly into a measuring cylinder.*

True density : *mass per unit volume of the material* ***excluding*** *the void space; also called particle or unit density.*

Porosity : *the percentage of the volume of inter-grain space to the total volume of the grain bulk.*

$$\rho_B = W / V \qquad \varepsilon = (1 - \rho_B/\rho_t) \times 100$$

ρ_B = bulk density, kg/m³ ; ρ_t = true density, kg/m³ ; ε = porosity, %

▶ ***Determination of true volume***

- ***Platform-scale displacement*** : for fruits and vegetables. Weigh in air, force fully under water with a rod; the submerged reading minus the weight of container and water is the weight of displaced water. Then $V = W_{dw}/\rho_w$ and $G = W_{air}/W_{dw}$.
- ***Pycnometer with toluene*** : toluene ($C_6H_5CH_3$) is preferred to water because grain does not absorb it and it wets well. Weigh the empty bottle and the bottle full of water at 20 °C; obtain the specific gravity of toluene as the weight ratio of toluene to distilled water; place a 10 g sample and cover with toluene; exhaust entrapped air with a vacuum pump; top up, bring to 20 °C, weigh. Then $G_{grain} = G_{toluene} \times W_{grain} / W_{toluene}$ displaced.
- ***Air-comparison pycnometer*** : measures true volume of any shape without wetting the sample; the modern preference.

▶ ***Importance***

Density and specific gravity are used in the design of bins and silos; in separating produce from impurities; in cleaning and grading; in evaluating grain maturity and the texture and softness of fruits; and in computing thermal diffusivity and the Reynolds number. Porosity depends on grain shape, dimensions and surface roughness, and governs the resistance of the bed to airflow — hence fan power in drying and aeration — and heat and mass transfer through the bulk.

Grain	*Bulk density, kg/m³ (m.c. % w.b.)*	*Porosity, %*
Paddy	587.9 (14.0) · 615.2 (18.0)	48–50
Wheat	789.8 (11.0) · 756.1 (14.1)	50–55
Corn, shelled	736.9 (13.0) · 720.9 (16.2)	40–45
Barley	576.7 (10.8) · 592.7 (16.8)	—

Sorghum	752.9 (12.0)	—
Oats	—	65–70

◆ **WORKED NUMERICAL — *Porosity of paddy from bulk and true density*** [Author-set, from book data]

Problem. *Paddy at 14 % moisture (w.b.) has a bulk density of 587.9 kg/m³. Taking the true density of the kernel as 1150 kg/m³, determine the porosity of the bulk and comment.*

Given. ρ_B = 587.9 kg/m³ ; ρ_t = 1150 kg/m³. **Find.** Porosity ε, %.

Formula (first principles). For a bulk of mass m the solid occupies m/ρ_t while the bulk occupies m/ρ_B; the void volume is the difference, so

$$\varepsilon = [\,(m/\rho_B) - (m/\rho_t)] \div (m/\rho_B) \times 100 = (1 - \rho_B/\rho_t) \times 100$$

Substitution. ρ_B/ρ_t = 587.9 / 1150 = 0.51122

$$\varepsilon = (1 - 0.51122) \times 100 = 48.88\ \%$$

Result. ε = 48.9 %.

Check. kg/m³ ÷ kg/m³ is dimensionless, so ε is a pure percentage; the value falls inside the tabulated 48–50 % band for paddy, confirming the assumed true density.

PREVIOUS YEAR QUESTIONS

- *Define the following properties of agricultural produces : (i) Bulk density (ii) Porosity (iii) Angle of repose (iv) Coefficient of friction. Also write the importance of each property in crop processing.*

  [IFoS 2020 · P2/5(a) · 8M]

- *Define the following properties of agricultural produce: Bulk density; Porosity; Angle of repose; Roundness.*

  [MH·PSC Forest Services (Mains) 2024 · Q.5(g)(i) · 8M]

MODEL Q This four-part definition question recurs almost every year. Write each part as definition + formula + one design use, in three lines. The marks are split equally — do not write a paragraph on one and a line on the rest.***

5 FRICTIONAL PROPERTIES

Needed for bins, hoppers, chutes, pneumatic conveying, screw conveyors, forage harvesters and threshers. In conveying, the material slides against the trough and casing, so frictional loss enters the drive-power calculation directly.

5.1 *Coefficient of Friction and Angle of Repose*

Static friction : *the frictional force between surfaces of contact at rest with respect to each other;* ***kinetic (dynamic) friction*** *is that between surfaces in relative motion.*

$$f = F / W = \tan\theta$$

f = coefficient of friction ; F = friction force ; W = force normal to the surface of contact ; θ = angle of the inclined surface at which sliding just begins

Basis	*Static friction*	*Kinetic (dynamic) friction*
Condition of surfaces	At rest relative to each other	In relative motion
Magnitude	Higher — must be overcome to start motion	Lower — sustains motion once started
Design use	Starting torque of conveyors; whether material	Running power of belt and screw

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	will begin to slide on a chute	conveyors; steady chute flow
Measurement	Tilting table — angle at which motion just begins	Force to keep the sample sliding at constant speed

Angle of repose : *the angle between the base and the slope of the cone formed on a free vertical fall of granular material to a horizontal plane. The* ***static*** *angle is that at which the material just slides upon itself; the* ***dynamic*** *angle obtains when the bulk is in motion, as in discharge from bins and hoppers, and is the more important for design.*

▶ ***Measurement***

- ***Method I — tilting table*** : A wooden frame full of grain is mounted on a tilting-top drafting table; the top is tilted until the grain just starts to move, and the angle of inclination is read.
- ***Method II — cone on platform*** : A circular platform on three adjustable screw legs stands inside a glass-windowed box of grain, surrounded by a funnel leading to a discharge hole. Grain escapes, leaving a free-standing cone on the platform; a travelling microscope measures the heights and the angle follows from the cone geometry.

$$\varphi = \tan^{-1}\left[\, 2\,(H_c - H_p) \,/\, D_p \,\right]$$

H_c = height of the cone ; H_p = height of the platform ; D_p = diameter of the platform

Grain	*Wheat*	*Paddy*	*Maize*	*Barley*	*Millets*	*Rye*
Angle of repose, degrees	23–28	30–45	30–40	28–40	20–25	23–28

The angle of repose ***increases as moisture content increases***, because the surface film of moisture binds the particles by surface tension and the heap stands at a steeper slope. Practical consequence: a hopper designed for dry grain may bridge and refuse to flow when the grain is damp.

5.2 *Angle of Internal Friction and Rolling Resistance*

Angle of internal friction : *the angle whose tangent is the coefficient of friction between grain and grain; used to estimate the lateral pressure in silos and to design bins and hoppers for gravity discharge.*

Basis	*Angle of repose*	*Angle of internal friction*
Definition	Angle of the free-standing cone formed when grain falls freely on a horizontal plane	Angle whose tangent equals the coefficient of friction between grain and grain
Friction involved	Grain sliding upon the heap surface	Grain shearing against grain within the mass
Measurement	Tilting table or cone-on-platform	Direct shear or triaxial test on the grain mass
Design use	Hopper slope, chute angle, heap volume, conveyor trough angle	Lateral pressure on silo walls; deep- and shallow-bin design
Relative magnitude	Generally the larger at comparable moisture and density	Generally the smaller
Interrelation	The two curves run almost parallel with moisture content, but no reliable relation exists — one cannot be estimated from the other	Substituting one for the other in design leads to error

Engineers commonly ***assume the two angles equal***. Work on sorghum shows they are not, and the substitution causes design error — a favourite examination point. ***Rolling resistance***: when a round object rolls and the surface deforms, taking moments about the reaction and neglecting acceleration gives F·a − W·c = 0; with small deformation a ≈ r, so F = c·W/r, where c is the coefficient of rolling resistance. Resistance is proportional to weight and to c and inversely to the effective radius — the basis of the mechanical ***separation of potatoes from stones***.

PREVIOUS YEAR QUESTIONS

- *Differentiate between the following : (i) Osmosis and Dehydration (ii) Equilibrium moisture content and Moisture content (iii) Angle of repose and Angle of internal friction (iv) Specific heat and Thermal conductivity.*

[IFoS 2016 · P2/5(d) · 8M]

MODEL Q A four-part 'differentiate' carries two marks each — answer each as a four- or five-row table, never as prose. The tables in §4.1, §5.1, §5.2, §6 and §9 of this chapter cover every pair the examiner has asked for.***

6 THERMAL PROPERTIES

Raw foods are heated, cooled, dried and frozen; the temperature response depends on the thermal properties. They are needed to design driers, coolers, freezers and heat exchangers, to compute heat loads for thermal disinfestation of stored grain, and for fruit-fly quarantine treatment.

Specific heat : *the heat that must be added to or removed from 1 kg of a substance to change its temperature by 1 °C.*

$$c = (m/100)\cdot c_w + [(100 - m)/100]\cdot c_d$$

c = specific heat of wet grain ; c_w = of water ; c_d = of bone-dry grain ; m = moisture content, % w.b.

Bone-dry grain has c_d = ***0.35–0.45 kcal/(kg·°C)*** (1.46–1.88 kJ/(kg·°C)). The linear relation holds only ***above about 8 % moisture***. Measurement is by the method of mixtures in a thermos-flask calorimeter, or by differential scanning calorimeter (DSC).

Thermal conductivity : *the rate of heat flow through unit thickness per unit area normal to the flow, per unit time, for unit temperature difference — the ability of the material to conduct heat.*

$$Q = K \cdot A \cdot \Delta T / L \qquad K_{wheat\ bulk} = 0.060 + 0.002\ M$$

K in kcal/(m·h·°C) or W/(m·°C) ; M = moisture content, % d.b., valid 10–20 % for wheat bulk

Material	*Single grain kernel*	*Grain in bulk*	*Air*
Thermal conductivity, kcal/(m·h·°C)	0.30 – 0.60	0.10 – 0.15	0.02

A single kernel conducts three to four times better than the bulk, because of the ***interstitial air*** — which is why a grain bulk heats slowly, cools slowly, and holds hot-spots. Other book relations: sorghum K = 0.564 + 0.0858 w; fruits and vegetables K = 0.148 + 0.493 w, with w the moisture fraction. Measurement is by the transient ***line heat-source probe***: a needle carrying a constantan heater and a chromel–constantan thermocouple is inserted in a sample at uniform temperature and heated at constant rate; after a short transient, temperature against ln(time) is a straight line of slope Q/4πK. Constantan is used because its resistance barely varies with temperature.

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Thermal diffusivity : *The normal conductivity divided by the product of specific heat and mass density; it expresses the ratio of the material's ability to conduct heat to its ability to store heat.*

$$\alpha = K / (\rho \cdot c_p) \qquad h_2 - h_1 = m \cdot c_p (T_2 - T_1) + m \cdot X_w \cdot L$$

α = thermal diffusivity, m²/s ; h = enthalpy ; X_w = water fraction ; L = latent heat of fusion of water

Basis	Thermal conductivity, K	Thermal diffusivity, α
Physical meaning	Ability of the material to transmit heat	Ability to transmit heat relative to its ability to store heat
Governs	Steady-state heat transfer — how much heat flows	Unsteady-state heat transfer — how fast the temperature front moves
Defining relation	Q = K·A·ΔT/L	α = K/(ρ·c_p)
SI unit	W/(m·°C)	m²/s
Composed of	A single transport property	A group of three — K, ρ and c_p
Design use	Insulation thickness, heat-exchanger area, steady heat load	Time–temperature history in drying, cooling, freezing and thermal processing

Basis	Specific heat, c	Thermal conductivity, K
Physical meaning	Heat stored per unit mass per unit temperature rise — a heat-storage property	Rate of heat flow per unit area per unit temperature gradient — a heat-transport property
Governs	How much heat a mass absorbs or releases when its temperature changes	How fast heat conducts through the material under a steady temperature difference
Defining relation	c = (m/100)·c_w + [(100 − m)/100]·c_d	Q = K·A·ΔT/L
SI unit	kJ/(kg·°C)	W/(m·°C)
Depends on	Moisture content and composition	Moisture, bulk density and interstitial air in the bulk
Design use	Heat load in heating, cooling and drying; enthalpy of frozen foods	Insulation, steady heat load; slow heating and hot-spot formation in stored grain

Enthalpy is the total heat content; enthalpy data are needed for frozen foods, which freeze over a ***range*** of temperature below 0 °C rather than at a single point.

◆ **WORKED NUMERICAL — *Specific heat of wheat at storage moisture*** **[Author-set, from book data]**

Problem. *Compute the specific heat of wheat at 14 % moisture (w.b.), taking c_d = 0.40 and c_w = 1.0 kcal/(kg·°C). Express in SI units.*

Given. m = 14 % w.b. ; c_d = 0.40 ; c_w = 1.0 kcal/(kg·°C). **Find.** c of the wet grain.

Formula (first principles). Heat is extensive, so the heat to raise 1 kg of wet grain by 1 °C is the sum for its water and dry fractions. With m % w.b., 1 kg holds m/100 kg water and (100 − m)/100 kg dry matter:

$$c = (m/100) \cdot c_w + [(100 - m)/100] \cdot c_d$$

Substitution. c = (14/100)(1.0) + (86/100)(0.40) = 0.140 + 0.344 = 0.484 kcal/(kg·°C)

Conversion. 1 kcal = 4.1868 kJ, so c = 0.484 × 4.1868 = 2.026 kJ/(kg·°C)

Result. c = 0.484 kcal/(kg·°C) = 2.03 kJ/(kg·°C).

Check. The value lies between c_d = 0.40 and c_w = 1.0, nearer the dry-matter value because dry matter is 86 % of the mass. m = 14 % > 8 %, so the linear relation is valid.

PREVIOUS YEAR QUESTIONS

- *Differentiate between: Thermal conductivity and Thermal diffusivity*

[HP·PSC RFO (Mains) 2021 · Q.7(c) · 10M]

7 AERODYNAMIC, MECHANICAL, RHEOLOGICAL, ELECTRICAL AND OPTICAL PROPERTIES

Terminal velocity: *the air velocity at which a particle remains suspended in a vertical pipe; equivalently the constant velocity attained in free fall when the gravitational force equals the upward drag.*

$$F_D = C \cdot A_p \cdot \rho_f \cdot V^2 / 2 \qquad V_t = [\, 2W(\rho_p - \rho_f) / (C \cdot A_p \cdot \rho_p \cdot \rho_f) \,]^{(1/2)}$$

C = overall drag coefficient ; A_p = projected area normal to motion ; ρ_p , ρ_f = densities of particle and fluid ; W = weight of particle

In separating a wheat–chaff mixture by an air stream the ***terminal velocities of the components fix the air velocity***: it is set above that of the chaff but below that of sound grain. Drag and bed resistance depend on bed thickness, grain type, shape and size, air velocity, and the orientation and packing of the material. Typical terminal velocities: wheat 9–11.5, rye 8.5–10.0, oats 8.0–9.0, corn 10–11, soybean 12–14 m/s.

Property group	*Key parameters*	*Significance in processing*
Mechanical	Hardness, compressive strength, impact and shear resistance, modulus of elasticity	Hardness governs milling behaviour and is used by feeders and plant breeders; impact and shear resistance govern size reduction; mechanical damage in threshing lowers germination and viability and invites insect attack
Rheological	Elasticity, plasticity, viscosity; firmness, yielding quality, crispness, fibrousness	Deformation and flow under load — handling systems, liquid foods (milk, syrups, filtered juices and vegetable oils are Newtonian, so viscosity with its temperature and concentration dependence suffices), texture evaluation. The three ideal reference bodies are the Hookean (elastic), St. Venant (plastic) and Newtonian (viscous); no real biomaterial is Hookean even at very small strains — the loading curve shows residual deformation
Electrical	Resistance, dielectric constant, dielectric loss factor	Resistance- and capacitance-type moisture meters; dielectric and microwave heating; electrostatic separation
Optical	Colour, reflectance, transmittance, gloss	Colour sorters, maturity index, detection of mould and discolouration, market grading

8 MOISTURE CONTENT: BASES, CONVERSION AND MEASUREMENT

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Moisture content fixes safe storage life, respiration rate, susceptibility to mould and insects, milling recovery, drying energy and the procurement price. The respiration rate of paddy at 25 °C rises sharply between **14 % and 15 % moisture** — the **critical point**.

Crop	Optimum m.c. at harvest, % w.b.	Safe storage 6–12 months	Safe storage over 1 year
Wheat	16–18	12	10
Paddy	20–22	12	10
Maize	20–23	12	10
Sorghum	20–22	12	10
Pigeonpea / Bengalgram / Soybean	—	10	8
Groundnut	10–12	8	7
Mustard	—	8	6

8.1 Wet Basis and Dry Basis

Moisture content, wet basis : *weight of moisture as a percentage of the* ***total weight*** *of wet material — the basis used in trade and in all statutory specifications.* ***Dry basis*** *expresses it as a percentage of the* ***bone-dry matter****, and is preferred in drying calculations because the moisture present is then directly proportional to the moisture content.*

$$m = W_m/(W_m + W_d) \times 100 \qquad M = W_m/W_d \times 100$$

m = % wet basis ; M = % dry basis ; W_m = weight of moisture ; W_d = weight of bone-dry matter

$$M = 100\ m\ /\ (100 - m) \qquad m = 100\ M\ /\ (100 + M)$$

The two conversions that must be memorised

m can never exceed 100 % while M has no upper limit — a pulp at 60 % w.b. is 150 % d.b. Confusing the bases is the commonest source of lost marks; the examiner deliberately mixes them inside a single question, as in 2018, 2020 and 2024. In drying, the **bone-dry matter is conserved** — every numerical follows from that one statement.

$$W_d = W_1(100 - m_1)/100 = W_2(100 - m_2)/100 \qquad W_{evap} = W_1(m_1 - m_2)/(100 - m_2) = W_2(m_1 - m_2)/(100 - m_1)$$

W_1 , W_2 = initial and final weights ; m_1 , m_2 = initial and final moisture contents, % w.b. ; W_evap = moisture evaporated, kg

8.2 Measurement of Moisture Content

Class	Method	Procedure and remarks
Direct	Air-oven, single stage	Grind 2–3 g; hold about 1 h at 130 ± 2 °C; cool in a desiccator and weigh. For grain below about 13 % moisture
Direct	Air-oven, double stage	Hold 25–30 g whole grain at 130 ± 2 °C for 14–16 h to bring it to about 13 %, then follow the single-stage procedure. Avoids case-hardening and loss of volatiles
Direct	Low-temperature and vacuum oven	Whole grain at 100 ± 2 °C for 24–36 h; the vacuum oven suits sugar-rich materials that would decompose
Direct	Brown–Duvel distillation	100 g grain with 150 cc oil heated at 200 °C for 30–40 min; moisture distils over and is read directly as cc. Toluene distillation is similar

Indirect	Electrical resistance type	Resistance of a fixed quantity at given compaction and temperature; all three must be controlled. Universal, Tag–Heppenstall, Kett meters; about 30 s
Indirect	Dielectric (capacitance) type	200 g between condenser plates, capacitance measured. Motomco, Burrows meters; about 1 min. Called safe crop moisture testers — the sample is undamaged and can be returned

Direct methods are simple and accurate but slow; indirect methods are quick but less accurate and need calibration. Determination must follow the standard procedure laid down for that grain by the Government or the Association of Official Agricultural Chemists.

▶ ***Steps in a moisture determination***

(i) Draw a representative sample from several points of the lot and reduce it by quartering or with a Boerner divider. (ii) Store it in an airtight container so that it neither gains nor loses moisture in transit. (iii) Weigh the empty moisture dish and the dish plus sample to 0.1 mg. (iv) Grind if the standard requires it. (v) Dry at the prescribed temperature for the prescribed time. (vi) Cool in a desiccator to room temperature so the hot sample does not reabsorb atmospheric moisture. (vii) Reweigh and repeat to constant weight. (viii) Compute on the required basis and ***state the basis explicitly***.

PREVIOUS YEAR QUESTIONS

- *Describe the key steps in determining moisture content in agricultural products and its importance in post-harvest technology.*

  [OPSC·CSE (Main) 2023–24 · Paper-II, Q.14(b) · 20M]

- *Explain moisture content and its measurement. Also give moisture content representation.*

  [UK·PSC ACF/RFO (Mains) 2025 · Q.7(ii)(a) · 5M]

9 WATER ACTIVITY, EMC AND SORPTION ISOTHERMS

Equilibrium moisture content (EMC) : *when a solid is exposed to a continual supply of air at constant temperature and humidity, it loses or gains moisture until the vapour pressure of the moisture in the solid equals that of the air. The moisture content at that equilibrium is the EMC. The relative humidity of the air with which the material is then in equilibrium is the* ***equilibrium relative humidity (ERH)*** *— the same equilibrium seen from the other side.*

▶ ***Usefulness of EMC***

- ***Gain or lose?*** : EMC states directly whether produce placed in a given ambient will pick up or give off moisture — the basic decision in aeration and godown ventilation.
- ***Limit of drying*** : no drier can dry below the EMC corresponding to the temperature and humidity of the exhaust air, so EMC fixes the ***minimum attainable final moisture*** and hence the drying air condition to select.
- ***Safe storage moisture*** : mould growth begins near 70 % ERH; the moisture in equilibrium with 70 % RH at storage temperature is the safe storage moisture — the origin of the 12 % w.b. figure for cereals.
- ***Packaging*** : the water-vapour permeability required of a pack is fixed by the EMC of the contents relative to ambient RH.
- ***Drying-rate modelling*** : the driving force in thin-layer drying is the moisture ratio MR = (M − M_e)/(M_o − M_e); the EMC term is indispensable.

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Basis	Moisture content	Equilibrium moisture content
What it is	The moisture actually present at that instant	The moisture the material would finally reach in that air
Depends on	Past history — harvest condition, drying done so far	Only the temperature and RH of the air, and the material
Changes with time	Yes, continuously during drying or wetting	No — a fixed end-point for that air condition
Role in drying	M is the state variable	M_e is the asymptote M approaches; drying stops at $M = M_e$

9.1 Sorption Isotherms, Hysteresis and the Temperature Effect

A plot of EMC against ERH at constant temperature is a ***sorption isotherm***, sigmoid in shape. Wetting an initially dry sample gives the ***adsorption*** curve; drying an initially wet sample gives the ***desorption*** curve. They do not coincide — at any ERH the desorption curve lies ***above*** the adsorption curve, and the gap is called ***hysteresis***. Consequence: grain dried down to a given moisture and grain that has picked up moisture to the same value are not in the same condition; the dried grain is in equilibrium with a lower RH and is safer in storage.

At ***constant RH the EMC falls as temperature rises***, because the sorbed water molecules gain kinetic energy and less water is retained at the same vapour pressure; equivalently, at constant moisture content the ERH rises with temperature. This is the mechanism of ***moisture migration***: grain warmed at a sun-facing bin wall or in the warm centre of a bulk equilibrates with a higher RH, the interstitial air becomes damp, migrates to a cooler region and deposits its moisture there because the cool grain has a higher EMC — producing hot-spots and caking even when the average moisture of the lot is perfectly safe.

9.2 Henderson's Equation and Other EMC Models

Several models exist — BET (1938), Harkins and Jura (1944), Henderson (1952), Chung and Pfost (1967), Haynes (1961). Of these, ***Henderson's equation is the one the examiner asks for***.

$$1 - RH = \exp(-c \cdot T \cdot M_e{}^{n})$$

RH = equilibrium relative humidity, decimal ; M_e = EMC, % dry basis ; T = absolute temperature ; c , n = product constants varying with the material

Henderson's original form is inadequate for many cereal grains; the widely used correction is the ***modified Henderson equation***, $1 - RH = \exp[-A(t + C)\cdot M_e{}^{B}]$, with t in °C and A, B, C material constants. Other established models: **Chung–Pfost** $\ln[-\ln(RH)] = \ln A - B\cdot M_e$; **Halsey** $\ln[-\ln(RH)] = \ln A - B \ln M_e$; **Oswin** $M_e = A[RH/(1 - RH)]^{B}$; and the three-parameter GAB equation, the international reference model. EMC is determined by the ***static*** method, the grain equilibrating with still air, or the faster and preferred ***dynamic*** method with mechanically moved air; a thermostat controls temperature and acid or salt solutions control the humidity.

◆ **WORKED NUMERICAL — EMC of paddy by the modified Henderson equation** [Author-set; constants from ASAE D245.5]

Problem. *Determine the EMC of rough rice held at 30 °C and 70 % RH. For rough rice $A = 1.9187 \times 10^{-5}$, $B = 2.4451$ and $C = 51.161$, with t in °C and M_e in per cent dry basis. Express the answer on both bases.*

Given. t = 30 °C ; RH = 0.70 ; $A = 1.9187 \times 10^{-5}$; B = 2.4451 ; C = 51.161.

Formula. $1 - RH = \exp[-A\,(t + C) \cdot M_e{}^{B}]$

Step 1 — rearrange. Taking natural logarithms of both sides and changing sign,

$$-\ln(1 - RH) = A\,(t + C) \cdot M_e{}^{B} \quad \Rightarrow \quad M_e = [-\ln(1 - RH) \div A\,(t + C)]\text{^}(1/B)$$

Step 2 — evaluate A(t + C). t + C = 30 + 51.161 = 81.161

$$A\,(t + C) = 1.9187 \times 10^{-5} \times 81.161 = 1.55724 \times 10^{-3}$$

Step 3 — evaluate the logarithm. 1 − RH = 0.30 ; − ln(0.30) = 1.20397

Step 4 — substitute. M_e ^{B} = 1.20397 ÷ 1.55724 × 10^{-3} = 773.13

$$M_e = (773.13)^{(1/2.4451)} = \exp(6.6506 \div 2.4451) = \exp(2.7199) = 15.18$$

Step 5 — convert. m = 100 M/(100 + M) = 100 × 15.18 ÷ 115.18 = 13.18

Result. EMC = 15.2 % dry basis = 13.2 % wet basis.

Check. Back-substituting, 1 − exp(−1.55724 × 10^{-3} × 15.18^2.4451) = 0.700, recovering the given RH exactly. 13.2 % w.b. sits just above the 12 % safe-storage figure — consistent with 70 % RH being the mould threshold.

Note. Table A.2 of Chakraverty & Singh lists classical Henderson constants, so the ASAE modified-Henderson constants (ASAE D245.5) are used here as the standard reference.

PREVIOUS YEAR QUESTIONS

- *Define Equilibrium Moisture Content (EMC) and its usefulness. Mention Henderson's equation for determining EMC.*

  [IFoS 2024 · P2/8(c) · 10M]

- *Explain the significance of Equilibrium Moisture Content (EMC) of grain. How does temperature affect the EMC-ERH relationship? · Explain the phenomenon of moisture migration in stored grain bulk.*

  [OPSC·CSE (Main) 2022–23 · Paper-II, Q.5(b) · 5M · also Q.6(b) · 5M and OPSC 2016–17 Q.8(c)]

MODEL Q For the 10-mark IFoS question the structure is fixed: definition box, the five uses, the isotherm sketch with hysteresis, Henderson's equation with every symbol defined, and one line on the temperature effect. Nothing else is needed and nothing less will do.***

9.3 *Water Activity; Osmosis versus Dehydration*

Water activity, a_w : *The ratio of the vapour pressure of water in the food to that of pure water at the same temperature; numerically equal to ERH/100. It, and not total moisture, controls microbial growth: most bacteria are inhibited below 0.90, most yeasts below 0.88, most moulds below 0.80, and below about 0.60 nothing grows. Two foods at the same moisture content can have very different water activities and shelf lives.*

Basis	*Osmosis (osmotic dehydration)*	*Dehydration (thermal drying)*
Driving force	Difference in osmotic pressure / water activity across the cell membrane	Difference in vapour pressure between the product surface and the drying air
Medium	Concentrated solution — sugar syrup or brine	Heated air, or contact with a hot surface
Energy input	Little or none; near ambient temperature	Substantial — the latent heat of vaporisation must be supplied

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Phase change	None — water leaves as liquid	Yes — water leaves as vapour
Extent	Partial, typically to 50 % of original weight; a pre-treatment	Can be carried to any desired final moisture
Effect on product	Solute gain; colour, flavour and vitamins retained; sweeter	Risk of shrinkage, case-hardening, browning, vitamin loss
Typical use	Pre-treatment before drying or freezing of fruit slices; candied fruit	Grain drying; dehydrated vegetables; milk powder

10 WORKED NUMERICALS ON MOISTURE MASS BALANCE

Every numerical in this family turns on one idea — ***the bone-dry matter does not change during drying***. Compute the dry matter from the initial condition, impose the final moisture condition on that same dry matter, and every unknown falls out. Read the basis of each figure with care: the examiner routinely gives the initial moisture on the wet basis and the final on the dry basis in the same sentence.

◆ **WORKED NUMERICAL — *Drum-dried fruit pulp*** **[IFoS 2020 · P2/5(b) · 8M]**

Problem. *If 10 kg fruit pulp is dried using a drum dryer from 60 % (wet basis) to 10 % (dry basis) moisture content, how much dried pulp can be obtained?*

Given. $W_1 = 10$ kg ; $m_1 = 60$ % w.b. ; $M_2 = 10$ % d.b. **Find.** W_2, the dried pulp.

Basis check. Initial figure wet basis, final dry basis — do not subtract them.

Step 1 — bone-dry solids. On the wet basis, dry matter is $(100 - m_1)$ per cent of the total.

$$W_d = W_1(100 - m_1)/100 = 10 \times 40/100 = 4.0 \text{ kg}$$

Step 2 — water in the dried product. On the dry basis, moisture is M_2 per cent of the dry matter.

$$W_{m2} = 4.0 \times 10/100 = 0.4 \text{ kg} \qquad W_2 = 4.0 + 0.4 = 4.4 \text{ kg}$$

Result. Dried pulp = 4.40 kg (water evaporated = 10 – 4.4 = 5.60 kg).

Check. Final moisture on the wet basis = 0.4/4.4 × 100 = 9.09 %, the correct equivalent of 10 % d.b. Reading 10 % as wet basis would give 4.44 kg — that is the trap.

◆ **WORKED NUMERICAL — *Water to be removed from parboiled paddy*** **[IFoS 2018 · P2/7(b) · 15M]**

Problem. *What is meant by dry and wet basis calculations for moisture content in solids? How much water must be removed from parboiled paddy with 45 % moisture content (wet basis) to produce 500 kg of dry parboiled paddy with 15 % moisture content (wet basis)?*

Given. $m_1 = 45$ % w.b. ; $W_2 = 500$ kg ; $m_2 = 15$ % w.b. The theory part is answered in §8.1.

Step 1 — dry matter in the product. $W_d = W_2(100 - m_2)/100 = 500 \times 85/100 = 425$ kg ; water in product $= 75$ kg

Step 2 — initial weight, W_d being unchanged. $W_1 = W_d \times 100/(100 - m_1) = 425 \times 100/55 = 772.727$ kg

Step 3 — water removed. $W_{evap} = W_1 - W_2 = 772.727 - 500 = 272.727$ kg

Result. Water removed = 272.7 kg (initial wet paddy = 772.7 kg).

Cross-check. W_evap = $W_2(m_1 - m_2)/(100 - m_1)$ = 500 × 30/55 = 272.727 kg — identical.

◆ **WORKED NUMERICAL — *Drying of wheat — dry matter, water evaporated, final weight*** **[MH·PSC Forest Services (Mains) 2024 · Q.5(c) · 8M · also OPSC·CSE 2023–24 · Q.14(a) · 20M on paddy]**

Problem. *Two tons of wheat with 22 per cent moisture content on wet basis are to be dried to 13 per cent moisture content on dry basis. Calculate: (i) weight of bone dry matter; (ii) amount of water evaporated; (iii) final weight of grain after drying.*

Given. $W_1 = 2000$ kg ; $m_1 = 22$ % w.b. ; $M_2 = 13$ % d.b.

Step 1 — bone-dry matter. $W_d = 2000 \times 78/100 = 1560$ kg ; initial water $= 440$ kg $(= 28.21$ % d.b.)

Step 2 — water retained. $W_{m2} = 1560 \times 13/100 = 202.8$ kg

Step 3 — final weight and evaporation. $W_2 = 1560 + 202.8 = 1762.8$ kg ; $W_{evap} = 2000 - 1762.8 = 237.2$ kg

Result. (i) 1560 kg (ii) 237.2 kg (iii) 1762.8 kg.

Check. Final moisture on the wet basis = 202.8/1762.8 × 100 = 11.50 %, the correct equivalent of 13 % d.b. OPSC sets the identical problem on paddy asking only (i) and (ii); the arithmetic is unchanged.

◆ **WORKED NUMERICAL — *Moisture removed in drying one tonne of grain*** **[OPSC·CSE (Main) 2016–17 · Paper-II, Q.6(c) · 20M]**

Problem. *Find the amount of moisture to be removed in drying 1 tonne of grain, initially at 24 % moisture (wet basis) to 12 % moisture (wet basis). Also calculate the weight of dried grain.*

Given. $W_1 = 1000$ kg ; $m_1 = 24$ % w.b. ; $m_2 = 12$ % w.b. — both on the same basis this time.

Step 1 — bone-dry matter. $W_d = 1000 \times 76/100 = 760$ kg

Step 2 — final weight. $W_2 = 760 \times 100/88 = 863.636$ kg

Step 3 — moisture removed. $W_{evap} = 1000 - 863.636 = 136.364$ kg

Result. Moisture removed = 136.4 kg ; dried grain = 863.6 kg.

Check. $W_1(m_1 - m_2)/(100 - m_2) = 1000 \times 12/88 = 136.364$ kg — identical. Removing 12 percentage points of wet-basis moisture removes 13.6 % of the weight, not 12 % — which is why the wet basis must never be subtracted naively.

◆ **WORKED NUMERICAL — *Bin of wet grain — both bases and water removed*** **[UK·PSC RFO (Mains) 2015 · Q.8(iii) · 10M]**

Problem. *A bin holds 2000 kg of wet grain containing 500 kg of water. This grain is to be dried to a final moisture content of 14 per cent (wet basis). What are the initial and final moisture contents of grain on dry basis? How much water is removed during drying?*

Given. $W_1 = 2000$ kg ; water = 500 kg ; $m_2 = 14$ % w.b.

Step 1 — dry matter and initial moisture. $W_d = 1500$ kg ; $m_1 = 500/2000 \times 100 = 25$ % w.b. ; $M_1 = 500/1500 \times 100 = 33.33$ % d.b.

Step 2 — final moisture, dry basis. $M_2 = 100\, m_2/(100 - m_2) = 1400/86 = 16.28$ % d.b.

Step 3 — final weight and water removed. $W_2 = 1500 \times 100/86 = 1744.186$ kg ; $W_{evap} = 2000 - 1744.186 = 255.814$ kg

Result. Initial 33.3 % d.b. ; final 16.3 % d.b. ; water removed 255.8 kg.

Check. Final water = 1744.186 − 1500 = 244.186 kg, and 244.186/1500 × 100 = 16.28 % d.b. — consistent with Step 2.

11 PADDY PARBOILING

Parboiling : *A hydrothermal premilling treatment given to paddy to gelatinise the starch within the*

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grain and so improve its milling quality; practically, parboiled rice is rice partially precooked in the paddy form. The process is ***soaking to saturation, steaming to gelatinise, and drying before milling****. It originated in ancient India and about 20 % of world rice production is parboiled.*

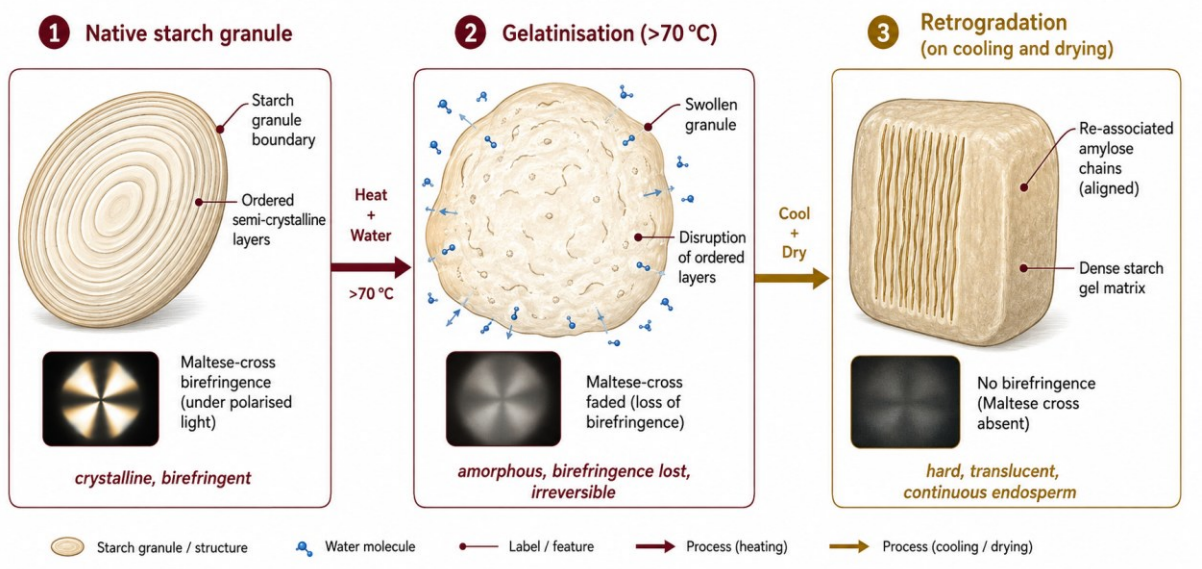
11.1 Principle: Why Gelatinisation Improves Milling

Rice starch has two components — ***amylose***, a simple chain soluble in hot water, and ***amylopectin***, a branched chain that is insoluble and forms a viscous suspension on heating. In the native granule the starch layers lie in an ordered crystalline arrangement which under plane-polarised light shows ***birefringence***. Hydrothermal treatment breaks the granule down in three phases:

- ***Swelling*** : During hydration the granule takes up water and expands reversibly.
- ***Gelatinisation*** : Above the gelatinisation temperature — about 70 °C, varying from 68–75 °C with variety — the hydrogen bonds between amylose and amylopectin rupture; the granules swell suddenly, absorb a large amount of water, lose their crystalline structure and hence their birefringence, and viscosity rises sharply. This phase change is ***irreversible***.
- ***Pasting and retrogradation : Above about 75 °C the granules become formless sacs and the soluble fraction dissolves (pasting); then on slow cooling and drying the simple-chain amylose molecules realign closely into a hard gel-like starch (retrogradation)***.

The net effect is that the loose, chalky, fissured endosperm becomes a ***hard, translucent, continuous mass***. A hard kernel resists the impact and shear of shelling and polishing, so breakage falls and head-rice yield rises. That single sentence answers 'why parboil'.

Fig. 1.3 — Principle of parboiling: starch transformation



11.2 The Three Unit Operations

- ***Soaking (steeping, imbibition)*** : water absorption with swelling — essentially a ***diffusion*** operation combining molecular absorption, capillary absorption and hydration; water enters until the internal vapour pressure equals that of the soak water. Absorption has two phases: the first continues until the grain reaches 24–43 % moisture (d.b.) depending on temperature, at which point the grain bursts and the rate becomes very fast — the ***critical moisture content in soaking***. The initial high rate is due to rapid wetting of the hull and filling of the hull–kernel space. Higher temperature raises the diffusion coefficient

and the soaking rate, but discolours the milled product. Soaking is exothermic. Steeping time is cut by removing interstitial air under vacuum and then applying pneumatic pressure at moderate temperature.

- ***Steaming*** : supplies the heat that carries the hydrated starch through gelatinisation. ***Splitting of the husk*** is the practical signal that parboiling is complete.
- ***Drying*** : parboiled paddy leaves the vessel at 30–35 % moisture and must reach about 14 % before milling. Drying must be gradual with tempering rests, or the hot kernel develops internal stresses and fissures — undoing the benefit parboiling was meant to give.

11.3 Methods of Parboiling

Method	Origin	Distinguishing feature
Single boiling / steaming	India — traditional	Cold-water soak at ambient for 2–3 days in ~5 t cement tanks; steamed once for a few minutes in mild-steel kettles; sun-dried. Prolonged soak ferments — foul odour
Double boiling / steaming	India — traditional	Raw paddy steamed first at 6–7 kg/cm² in vertical kettles (700–900 mm dia, 1.2–2.0 m tall, conical bottom with sliding gate); dumped into a masonry soak tank, water falling to 40–45 °C; soaked 36–72 h; steamed a second time for gelatinisation; sun-dried. Light-yellow rice of good cooking quality, but the odour persists
Rice conversion process	United Kingdom / USA	Deaeration under vacuum, then hydrostatic pressure by compressed air on the steeping water; steaming in a rotating steam-jacketed autoclave at ~1 kg/cm²; vacuum drying then rotary drying
Schule process	Germany	Soak 2–3 h in a pressure vessel with circulating warm water; hydrostatic pressure 4–6 kg/cm²; cooking by releasing pressure and re-admitting very hot water; vibratory semi-fluidised drying then columnar drying with tempering
Crystallo process	Italy	Cold-water pre-soak to float off impurities and light grains; steeping in a stationary autoclave under vacuum, then hot water at ~6 kg/cm²; steaming and vacuum drying in a rotary autoclave
Malek process	United States	Continuous; amber, fully gelatinised, hard grain; steam-heated rotary drier then through-flow columnar drier
Jadavpur University method	India	Semi-continuous. Steeping at ~70 °C within 3½ h in vertical batch tanks; steaming a few minutes in the same tank through perforated pipes; rapid cooling in cup-and-cone air coolers to keep the colour light; steam-tube rotary drying at ~90 °C; tempering before milling
CFTRI method	India	Batch; soaking and steaming in the same tank; low capital cost — see §11.4
Pressure parboiling	India, 1969	Soaking only ~40 min at 80–90 °C, then steaming under pressure ~18 min; short drying; very short total cycle; deep-yellow rice needing longer cooking is the drawback

Limitations of the traditional methods, which the improved ones were designed to remove: very long soaking; fermentation and off-odour; non-uniform or incomplete gelatinisation; dependence on sun-drying and therefore on weather; large tank inventory and floor space; risk of mycotoxin development; and high labour requirement.

11.4 The CFTRI Method

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The CFTRI (Central Food Technological Research Institute, Mysore) batch method was aimed specifically at ***improving the yield and quality of rice at lower capital investment***. Both soaking and steaming are done in the ***same*** upright mild-steel cylindrical tank, each holding 3–4 t of paddy. Steam enters through a perforated pipe at the centre and through other perforated pipes. The base is cone-shaped, closed by a watertight bottom hatch, with a valve beside it for draining the steep water.

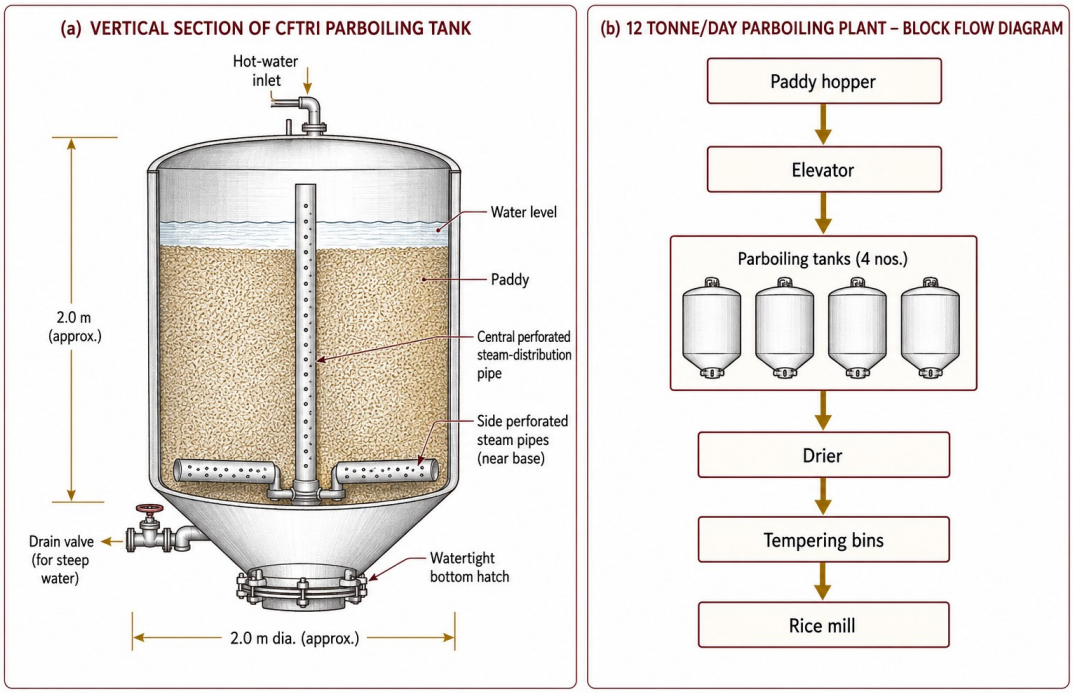
▶ ***Procedure***

(1) The tank is filled with water heated by direct steam injection to **85–90 °C**. (2) Paddy is fed in as quickly as possible; the mixture settles at **70–75 °C**. (3) Soaking continues about **3½ h** with occasional recirculation of the hot water to hold 70 °C. (4) The steep water is drained, the discharge valve left open to remove condensate formed during steaming. (5) Steam at about **4 kg/cm²** is passed through the perforated pipes until the husks just begin to crack open, signalling complete gelatinisation. (6) The hot paddy is unloaded through the bottom hatch and dried in the sun, or discharged to a belt conveyor and elevated to the drier.

CFTRI cycle	Fill paddy	Fill hot water 90 °C	Soak at 70 °C	Drain	Steam	Unload	Total
Time, min	30	30	210	30	30	30	360 = 6 h

For a 2 t/h rice mill the batch is 2 × 6 = 12 t, met by four 3 t tanks. Design data: bulk density of raw paddy 560 kg/m³; allowance for swelling of soaked paddy 33 %.

Fig. 1.4 — CFTRI parboiling tank and plant layout



▶ ***Advantages of the CFTRI method***

(i) ***Short cycle*** — 6 h against 2–3 days for traditional single boiling, so tank inventory and floor space fall sharply. (ii) ***No fermentation*** — hot-water steeping at 70 °C prevents microbial growth, eliminating the off-odour of traditional parboiled rice. (iii) ***Low capital cost*** — soaking and steaming in one vessel halves the equipment; suited to small and medium mills. (iv) ***Better nutrient retention*** — as much as ***70 % of vitamin B is retained*** against about 30 % by the traditional process. (v) ***Uniform gelatinisation*** — controlled temperature and steam pressure give a consistent colour and complete gelatinisation. (vi)

Higher milling outturn — husk splitting during steaming raises shelling efficiency and the hardened kernel resists breakage.

PREVIOUS YEAR QUESTIONS

- *Explain the improved paddy parboiling method developed by CFTRI and mention its advantages.* [IFoS 2024 · P2/5(a) · 8M]
- *Enlist various methods of paddy parboiling.* [UK·PSC ACF/RFO (Mains) 2025 · Q.7(ii)(b) · 5M]

MODEL Q For the IFoS 8-marker: one line of definition, the labelled tank sketch, the six procedure steps with their temperatures and the 4 kg/cm² steam pressure, the cycle-time table, then the six advantages. The numbers — 85–90 °C, 70 °C, 3½ h, 4 kg/cm², 6 h, 70 % vitamin B — are what separate this answer from a generic one. For UKPSC, give the classification table of §11.3.***

11.5 *Advantages and Disadvantages of Parboiling*

Advantages	*Disadvantages*
Fewer broken grains owing to the hard texture	Relatively darker-coloured rice
Increase in total milling yield (head-rice recovery)	Off-flavour from the traditional process due to prolonged soaking
Greater nutrient status, particularly B-vitamins, which diffuse inward and survive polishing	Longer cooking — 30–40 min against 15–20 min for raw rice
Translucent kernels	Risk of mycotoxin development in the long traditional soak
Less loss of solids into the gruel during cooking	Destruction of some natural antioxidants during heat treatment
Less susceptible to insect attack in storage	More power required for polishing the harder grain
Non-glutinous, non-sticky cooked rice	Additional initial capital investment
Higher oil in parboiled bran, 25–28 %, and the bran is relatively stabilised	—
Easier husking, hence higher husking efficiency	—

Despite the disadvantages, the higher milling outturn and the higher return from high-oil parboiled bran ensure a ***higher net return to the miller*** — the concluding line a complete answer should carry.

PREVIOUS YEAR QUESTIONS

- *Write the advantages of Rice Parboiling.* · *What are the advantages of parboiling the paddy?* [IFoS 2021 · P2/5(b) · 8M · also AP·PSC RFO (Mains) 2012 · Q.2(G) · 5M]

12 PHYSICAL PROPERTIES OF FRUITS AND VEGETABLES IN SORTING, WASHING AND PRESERVATION

Fruits and vegetables hold ***70–85 % water*** against 10–15 % in cereals; they respire and transpire after harvest, bruise easily and are seasonal. Loss is 20–50 % against 5–20 % for grain. Their engineering properties therefore serve a different purpose — not to design a mill, but to ***separate, clean and grade a living, fragile commodity without damaging it***. Sorting, washing and preservation equipment can only discriminate on a ***measurable property***, so the choice of property fixes the choice of machine.

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Property	*Operation it governs*	*How it is used*
Size — length, diameter, geometric mean diameter	Grading and sizing	Diverging-belt, roller and screen sizers separate by the largest dimension; the size grade fixes market price and the count per carton
Shape — sphericity, roundness	Sorting and conveying	High-sphericity produce rolls freely on inclined and roller graders; irregular produce must be belt-handled. Shape uniformity is itself a grade attribute
Density and specific gravity	Washing, flotation sorting, maturity grading	Flotation in water or brine separates hollow, pithy, insect-damaged and immature units, which float, from sound heavy ones, which sink — peas, potatoes, cherries. Specific gravity is a maturity index in peas and potatoes
Surface area and volume	Washing, coating, cooling, drying	Fix the water and detergent requirement, the wax pick-up in coating, and the heat- and mass-transfer area in pre-cooling and dehydration; hence slicing and dicing precede drying
Coefficient of friction, angle of repose	Conveying, chute and bin design	Fix the slope of gravity chutes and the maximum drop height; excessive slope causes rolling impact bruising
Firmness, texture, rheology	Sorting, maturity judgement, handling damage	Penetrometer firmness is the commonest maturity index; low firmness limits permissible drop height and stacking depth
Colour and optical properties	Optical and electronic sorting	Reflectance sorters remove discoloured, mouldy and unripe units at high speed; colour is the leading consumer grade attribute
Thermal properties	Pre-cooling, cold storage, freezing, blanching	Specific heat and diffusivity fix pre-cooling time and refrigeration load; conductivity fixes freezing time

Preservation works by suppressing the very physiology that makes perishables perishable, and each route is chosen using the properties above. ***Freezing*** — frozen at about −38 °C, stored at −18 °C; thermal properties fix the freezing time and texture decides whether the thawed product holds its shape. ***Dehydration*** — moisture removed under controlled temperature, humidity and airflow; FPO limits are 20 % for dehydrated fruits and 24 % for vegetables. ***Canning*** — heating and sealing in a hermetically sealed container; FPO head space not more than 1.6 cm and drained weight not less than 50 %. ***Osmotic treatment and coating*** — water activity lowered by sugar or salt, or a wax coating applied to cut transpiration and respiration, the quantity set by surface area.

PREVIOUS YEAR QUESTIONS

Discuss the physical properties of fruits and vegetables and their relevance in sorting, washing and preservation technology.

[OPSC·CSE (Main) 2023–24 · Paper-II, Q.16(b) · 20M]

13 FORMULA SHEET

Quantity	*Formula*	*Symbols and units*
Geometric mean diameter	$D_g = (l \cdot b \cdot t)^{(1/3)}$	l, b, t = three mutually

		perpendicular intercepts, mm
Sphericity	$\phi = (l \cdot b \cdot t)^{(1/3)}/l = D_e/D_c = D_i/D_c$	dimensionless, $0 < \phi \leq 1$
Roundness	A_p/A_c ; roundness ratio = r/R	A_p = projected area at rest; A_c = circumscribing circle
Bulk density · porosity	$\rho_B = W/V$; $\varepsilon = (1 - \rho_B/\rho_t) \times 100$	kg/m³ ; % — ρ_t = true density
Specific gravity (displacement)	$G = W_{air} \times G_{water} / W_{displaced\ water}$	dimensionless
Coefficient of friction	$f = F/W = \tan\theta$	F = friction force; W = normal force
Angle of repose (cone method)	$\phi = \tan^{-1}[2(H_c - H_p)/D_p]$	degrees
Rolling resistance	$F = c \cdot W/r$	c = coefficient of rolling resistance
Specific heat of wet grain	$c = (m/100)c_w + [(100 - m)/100]c_d$	kcal/(kg·°C); valid above m = 8 %
Fourier conduction	$Q = K \cdot A \cdot \Delta T/L$	K in kcal/(m·h·°C) or W/(m·°C)
Thermal conductivity, wheat bulk	$K = 0.060 + 0.002\ M$	M in % d.b., 10–20 % range
Thermal diffusivity	$\alpha = K/(\rho \cdot c_p)$	m²/s
Enthalpy of moist material	$h_2 - h_1 = m \cdot c_p(T_2 - T_1) + m \cdot X_w \cdot L$	X_w = water fraction; L = latent heat of fusion
Drag force · terminal velocity	$F_D = C \cdot A_p \cdot \rho_f \cdot V^2/2$; $V_t = [2W(\rho_p - \rho_f)/(C \cdot A_p \cdot \rho_p \cdot \rho_f)]^{(1/2)}$	C = drag coefficient; V_t in m/s
Moisture content	$m = W_m/(W_m + W_d) \times 100$; $M = W_m/W_d \times 100$	m = % wet basis (≤100) ; M = % dry basis (no limit)
Basis conversion	$M = 100m/(100 - m)$; $m = 100M/(100 + M)$	%
Conservation of dry matter	$W_1(100 - m_1) = W_2(100 - m_2)$	kg
Water evaporated	$W_{evap} = W_1(m_1 - m_2)/(100 - m_2) = W_2(m_1 - m_2)/(100 - m_1)$	kg
Water activity	$a_w = p/p_o = ERH/100$	dimensionless
Henderson · modified Henderson	$1 - RH = \exp(-c \cdot T \cdot M_e{}^{n})$; $1 - RH = \exp[-A(t + C) \cdot M_e{}^{B}]$	RH decimal; M_e in % d.b.; T absolute; t in °C
Moisture ratio, thin-layer drying	$MR = (M - M_e)/(M_o - M_e)$	dimensionless

14 SUMMARY

- ***Scope & losses*** : PHT conserves what is already grown; cutting loss needs no extra land, water or fertiliser. Cereals lose 5–20 %, fruits and vegetables 20–50 %; storage is about two-thirds of grain loss, with insects and rodents dominant.
- ***Engineering properties*** : Eight classes — physical, frictional, aerodynamic, thermal, mechanical, rheological, electrical, optical. Each unit operation is designed around a specific short list.
- ***Shape & density*** : Sphericity compares volumes (3-D); roundness compares projected areas or radii of curvature (2-D); both are 1.0 for a sphere. Bulk density includes voids, true density excludes them, porosity is the gap — 40–45 % corn, 48–50 % paddy, 50–55 % wheat.

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- ***Friction*** : Angle of repose is generally larger than the angle of internal friction and the two are not interchangeable. Repose increases with moisture because surface tension binds the particles.
- ***Thermal*** : A single kernel conducts three to four times better than the bulk because of interstitial air. Conductivity governs steady-state heat flow; diffusivity governs the speed of temperature change.
- ***Moisture*** : Wet basis for trade, dry basis for drying calculations. Every numerical is solved by conserving bone-dry matter. Never subtract wet-basis percentages.
- ***EMC*** : The end-point drying can reach and the criterion of safe storage. Falls as temperature rises at constant RH — the mechanism of moisture migration. Desorption lies above adsorption: hysteresis.
- ***Parboiling*** : Soak, steam, dry. Gelatinisation hardens the endosperm, so breakage falls and head-rice yield rises; B-vitamins diffuse inward and survive polishing. CFTRI: 85–90 °C water, soak 3½ h at 70 °C, steam at 4 kg/cm², 6 h cycle, 70 % vitamin B retained.

15 LAST-NIGHT REVISION

▶ ***Numbers that must be on your fingertips***

Item	Value	Item	Value
Loss — cereals / F&V	5–20 % / 20–50 %	Gelatinisation temperature of rice starch	68–75 °C (~70 °C)
Total grain loss, all stages	≈ 9.3 % (storage ≈ ⅔)	CFTRI water / soak temperature	85–90 °C / 70 °C
Safe storage, cereals 6–12 mo / >1 yr	12 % / 10 % w.b.	CFTRI soak time / steam pressure / cycle	3½ h / 4 kg/cm² / 6 h
Critical respiration point, paddy at 25 °C	14 → 15 % moisture	Vitamin B retained — improved / traditional	70 % / 30 %
Specific heat, bone-dry grain	0.35–0.45 kcal/(kg·°C)	Oil content of parboiled bran	25–28 %
Thermal conductivity — kernel / bulk / air	0.3–0.6 / 0.10–0.15 / 0.02	Cooking time — raw / parboiled rice	15–20 / 30–40 min
Porosity — corn / paddy / wheat / oats	40–45 / 48–50 / 50–55 / 65–70 %	Mould growth threshold	≈ 70 % ERH (a_w ≈ 0.70)
Angle of repose — wheat / paddy / maize	23–28° / 30–45° / 30–40°	Oven method for moisture	130 ± 2 °C, 1 h single stage
Terminal velocity — wheat / corn / soybean	9–11.5 / 10–11 / 12–14 m/s	FPO moisture — dehydrated fruit / vegetable	20 % / 24 %
Bulk density of raw paddy (design)	560 kg/m³	Swelling allowance, soaked paddy	33 %

▶ ***Comparison tables the examiner keeps asking for***

Sphericity vs roundness (§4.1) · static vs dynamic friction (§5.1) · angle of repose vs angle of internal friction (§5.2) · thermal conductivity vs thermal diffusivity (§6) · specific heat vs thermal conductivity (§6) · moisture content vs EMC (§9) · osmosis vs dehydration (§9.3) · advantages vs disadvantages of parboiling (§11.5).

CHAPTER

2

UNIT OPERATIONS — SIZE & SEPARATION

Size reduction & crushing laws · Screening & fineness modulus · Cleaning, grading, sorting · Separators · Milling · Oil extraction · Filtration

SYLLABUS : Agricultural Process Engineering — Unit operations: cleaning, grading, size reduction and filtration of agricultural produces and by-products. (Paper II, Section B, Topic 3)

Chapter Outline

1. **Unit Operations in Agricultural Processing**
2. **Size Reduction: Principles and Forces**
3. **Energy and Power: Rittinger, Kick and Bond**
4. **Worked Numerical on Crushing Laws**
5. **Size-Reduction Machinery**
6. **Screen Analysis, Fineness Modulus and Uniformity Index**
7. **Screening: Ideal and Actual Screens; Effectiveness**
8. **Cleaning, Grading and Sorting**
9. **Separators**
10. **Seed Processing Plant**
11. **Rice Milling**
12. **Wheat, Corn and Pulse Milling**
13. **Oil Extraction, Ginning and Juice Extraction**
14. **Filtration and Membrane Separation**
15. **Formula Sheet · Summary · Last-Night Revision**

1 UNIT OPERATIONS IN AGRICULTURAL PROCESSING

A processing job is a ***series of unit operations***. The sequence differs with the crop, but the operations themselves are common to all —same question of cereals, pulses, oilseeds and paddy appears in turn. The table below is the skeleton of every such answer; each operation is developed in the sections that follow.

Unit operation	*Purpose*	*Governing property*
Cleaning	Remove straw, chaff, weed seed, stones, mud, iron	Size, aerodynamic, sp. gravity, magnetic
Grading & sorting	Segregate into quality or size classes	Size, shape, density, colour
Size reduction	Flour, grits, meal; aids extraction and mixing	Hardness, impact and shear resistance
Separation / screening	Split a stream into oversize and undersize	Width and thickness
Hulling / shelling	Remove husk with the kernel shape retained	Bond strength between hull and kernel
Whitening / polishing	Remove bran and germ from husked kernel	Abrasion and friction resistance
Milling / flour milling	Reduce endosperm to flour, bran and germ separated	Differential friability of endosperm and bran
Expression & extraction	Recover oil or juice	Cell rupture, solubility in solvent
Filtration	Separate solids from a liquid stream	Particle size relative to medium pore

For a specific crop the order is what changes. ***Paddy***: cleaning → parboiling (optional) → drying → shelling → paddy separation → whitening → polishing → grading → packaging. ***Wheat***: cleaning → conditioning → break rolls → sifting and purification → reduction rolls → flour. ***Pulses***: cleaning → pitting → oil/water treatment → conditioning → dehulling → splitting → grading. ***Oilseeds***: cleaning → dehulling → flaking → cooking → expression or solvent extraction → refining.

PREVIOUS YEAR QUESTIONS

- *Explain various unit operations in processing of agricultural produce (cereals, pulses and oilseeds).*
  [OPSC·CSE 2020-21 · Q.5(b)(i) · 12M · OPSC·CSE 2017-18 · Q.5(c) · 20M · OPSC·Forest 2015-16 · Q.5(a) · 20M]
- *What are the key unit operations involved in processing cereals and how do they contribute to producing safe, nutritious and marketable cereal products?*
  [OPSC·CSE 2023-24 · Paper-II, Q.15(a) · 20M · also OPSC·CSE 2016-17 · Q.5(b) · 20M on paddy]

2 SIZE REDUCTION: PRINCIPLES AND FORCES

Comminution : *the generic term for size reduction, covering crushing, grinding, milling, mincing and dicing. The mechanism is to deform the piece until it breaks or tears; breaking of hard materials occurs along cracks or defects already present in the structure.*

▶ ***Objectives — why we reduce size***

(a) To increase the surface area, which raises the rate of drying, heating, cooling, dissolution and ***solvent extraction*** through greater solid–solvent contact area. (b) To separate two constituents where one is dispersed in small isolated pockets — the basis of milling. (c) To meet specifications on the size of commercial products. (d) To permit intimate mixing of solids, which is more complete when particles are small. (e) To

improve dissolution rate, solubility, binding strength and dispersion. (f) To shorten heat treatments such as blanching and cooking.

Force	How it acts	Product character	Typical application
Compression / crushing	External force exceeds the strength; the material ruptures in many directions	Irregular particles, coarse, few fines	Flour, grits, meal, livestock feed; oil from oilseeds; juice from sugarcane
Impact	Sudden blow in excess of strength	Coarse, medium or fine	Hammer mill; cracking a nut
Attrition / rubbing	Material pulverised between two toothed discs rotating in opposite directions	Very fine product from soft, non-abrasive materials	Disc and pin mills; whitening of rice
Cutting	Sharp thin knife forced through the material	Definite size and often definite shape, few or no fines	Slicing and dicing fruits and vegetables; chaff cutter
Shearing	Combines cutting and crushing; a knife works against a bar	Between cutting and crushing depending on edge thickness	Forage cutting; dehulling

More than one force always acts in a real machine. As a general rule, ***compression suits coarse reduction of hard solids, impact gives coarse to fine, attrition gives very fine product from soft materials, and cutting gives a definite size with few fines***.

- ***Mechanical resistance and the role of moisture***

  Deformation is elastic below the elastic limit E and inelastic beyond it, passing through the yield point Y into the region of ductility and finally the breaking point B. Breaking occurs along existing cracks, so a ***large piece with many defects breaks under a small stress***, while smaller pieces have fewer defects and need higher stress — in the limit only intermolecular forces remain, which is why grinding below a certain size becomes so difficult that fine grinding of roasted coffee below 50 µm is done cryogenically. Moisture matters both ways: a small amount on the surface of fines causes ***agglomeration*** and can rapidly block a mill, but moisture also suppresses dust and prevents dust explosions, which is exploited in wet milling of corn.

Reduction ratio : *the ratio of the average size of feed to the average size of product; used to judge the performance of a comminution operation. As a rule, the coarser the reduction the smaller the ratio.*

Degree of grinding : *the ratio of the overall surface area of the ground product to the overall surface area of the feed, $d_g = S_p / S_f$.*

Fig. 2.1 — Forces in size reduction and the stress–strain curve

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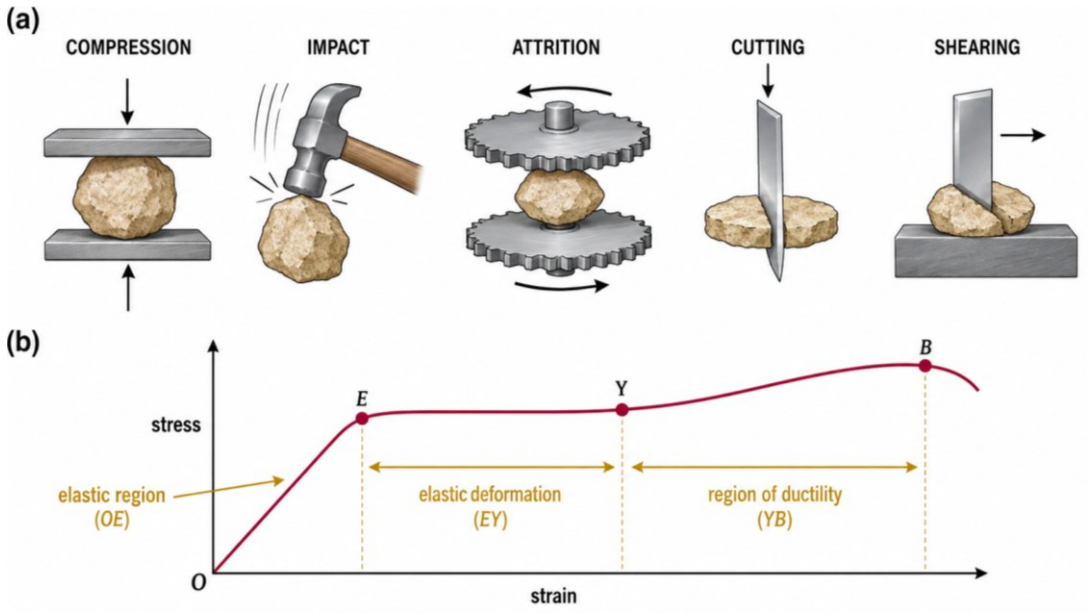


Fig. 2.1 (a) The five forces used in size reduction; (b) stress–strain behaviour up to fracture.

PREVIOUS YEAR QUESTIONS

- *What are the benefits of size reduction in food processing? · Discuss the size reduction procedures of agricultural produces. Also give the name of machines.*

  [IFoS 2017 · P2/7(a) · 10M (first part) · UK·PSC 2025 · Q.8(iv) · 10M]

- *Briefly explain: Degree of grinding*

  [HP·PSC RFO (Mains) 2021 · Q.7(d) · 10M]

3 ENERGY AND POWER: RITTINGER, KICK AND BOND

Grinding is the ***most inefficient of the traditional unit operations***: only about ***1 % of the energy supplied actually creates new surface***. The rest is spent deforming particles within their elastic limits and in inter-particle friction, and is dissipated as heat — which raises product temperature and can damage nutrients. Because power is the major operating cost of crushing and grinding, estimating it accurately is central to equipment selection.

▶ *Derivation of the general law of comminution*

Work is stored in the solid as mechanical energy of stress; when the particle ruptures, that stress energy is released and new surface appears. Since unit area of solid carries a definite surface energy e_s, the energy E required is

$$E = e_s\,(A_p - A_f) \,/\, (\eta_m \cdot \eta_c)$$

A_p , A_f = surface area per unit mass of product and feed ; η_m = mechanical efficiency ; η_c = crushing efficiency

For particles of sphericity ϕ and density ρ_s, the specific surface is A = 6/(ϕ ρ_s x), so

$$E = [\, e_s \,/\, (\eta_m\, \eta_c)\,] \cdot [\, 6/(\varphi\, \rho_s)\,] \cdot (\, 1/x_p - 1/x_f\,)$$

x_f , x_p = surface-volume mean particle size of feed and product

Energy input is therefore a function of initial and final size alone. Generalising, the energy dE for a small change dx in unit mass is expressed as a power function of size — the ***general law of comminution***:

$$dE/dx = -\,C \,/\, x^n$$

C = constant ; n = power index ; x = particle size

Integrating between x_f and x_p at n = 2, 1 and 1.5 gives the three empirical laws.

Law	*n*	*Integrated form*	*Assumption and range of validity*
Rittinger (1867)	2	E = C_R (1/x_p − 1/x_f)	Particles do not deform before breaking, i.e. infinitely brittle; energy is proportional to the new surface created. Holds better for FINE grinding, where the surface increase is large. C_R in J·m/kg
Kick (1885)	1	E = C_K ln (x_f/x_p)	Energy is proportional to the size-reduction ratio. Holds better for COARSE crushing, where most energy fractures along existing cracks. Implies the same energy for 1 cm → 1 mm as for 100 → 10 µm. C_K in J/kg
Bond (1952)	1.5	E = 2C_B (1/√x_p − 1/√x_f), with C_B = 5W_i	A compromise; holds reasonably for coarse, medium and fine reduction. In working units E = 0.3162 W_i (1/√D_p − 1/√D_f), with D in mm and E in kWh/tonne

Bond work index, W_i : *the gross energy in kWh per tonne of feed required to reduce unit mass of material from an infinite particle size to a size such that 80 % of the product passes a 100 µm sieve. It is material-specific and obtained from laboratory crushing tests. Hard, brittle materials have W_i of the order of 4×10^4 to 8×10^4 J/kg.*

A comparison the examiner rewards: for the same duty, ***Rittinger's law tends to overestimate the energy required and Kick's law to underestimate it***, with Bond's value lying between the two. In one book case the three gave 215.6, 98.2 and 137.9 kW respectively for the same grinding duty.

PREVIOUS YEAR QUESTIONS

- *State Bond's Law of Crushing. What is Work Index? State the principle of operation of a jaw crusher.*

  [IFoS 2019 · P2/5(a) · 8M]

- *What are the principles of size reduction? Derive an equation for energy and power requirement in size reduction.*

  [UK·PSC RFO (Mains) 2015 · Q.7(iii) · 10M]

MODEL Q For the UKPSC derivation, start from surface energy, reach $dE/dx = -C/x^n$, then integrate at n = 2, 1 and 1.5. Do not merely quote the three laws — the mark is for the integration.***

4 WORKED NUMERICALS ON CRUSHING LAWS

Every problem in this family is a two-step: use the first condition to evaluate the constant, then apply the same constant to the second condition. Work in ***P/f*** — power divided by feed rate — so that the constant carries the units of specific energy.

◆ **WORKED NUMERICAL — *Wheat milling — Rittinger and Kick*** **[IFoS 2024 · P2/7(b) · 10M · MH·PSC 2024 · Q.8(a) · 15M · OPSC·CSE 2018-19 · Q.7(c) · 20M]**

Problem. *In wheat milling, it was found that to grind 4.33 mm sized grains to pass a sieve of 0.351 mm opening, the power requirement was 8 kW. Calculate the power requirement for milling of the wheat using Rittinger's law and Kick's law by the same mill to pass a sieve of 0.157 mm opening. The feed rate of milling is 200 kg/h.*

Given. x_f = 4.33 mm ; x_p1 = 0.351 mm ; P_1 = 8 kW ; f = 200 kg/h = 0.2 t/h ; x_p2 = 0.157 mm.

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(i) Rittinger's law. $P/f = C_R\,(1/x_p - 1/x_f)$

$$8/0.2 = C_R\,(1/0.351 - 1/4.33) = C_R\,(2.8490 - 0.2309) = 2.6181\,C_R$$

$$C_R = 40 / 2.6181 = 15.279$$

$$P_2 = 0.2 \times 15.279\,(1/0.157 - 1/4.33) = 0.2 \times 15.279 \times 6.1381 = 18.76\ \text{kW}$$

(ii) Kick's law. $P/f = C_K \ln (x_f/x_p)$

$$40 = C_K \ln (4.33/0.351) = C_K \times 2.5125 \quad \Rightarrow \quad C_K = 15.92$$

$$P_2 = 0.2 \times 15.92 \times \ln (4.33/0.157) = 0.2 \times 15.92 \times 3.3170 = 10.56\ \text{kW}$$

Result. Rittinger 18.8 kW ; Kick 10.6 kW.

Comment. Rittinger predicts nearly twice Kick — expected, since this is a fine grind where surface creation dominates and Rittinger overestimates while Kick underestimates.

◆ **WORKED NUMERICAL — *Crusher — benefits of size reduction and power for a finer product*** **[IFoS 2017 · P2/7(a) · 10M]**

Problem. *A crusher requires 10 kW for grinding a material at the rate of 100 kg/h from 2 cm size to 0.5 cm size. How much power would be required if the reduction was to 0.4 cm? Use both Kick's law as well as Rittinger's law.*

Given. x_f = 2 cm ; x_p1 = 0.5 cm ; P_1 = 10 kW ; f = 100 kg/h ; x_p2 = 0.4 cm. Since f is unchanged throughout, it cancels and we may work directly in P.

(i) Rittinger. $10 = C_R\,(1/0.5 - 1/2) = C_R\,(2 - 0.5) = 1.5\,C_R \quad \Rightarrow \quad C_R = 6.667$

$$P_2 = 6.667\,(1/0.4 - 1/2) = 6.667 \times 2.0 = 13.33\ \text{kW}$$

(ii) Kick. $10 = C_K \ln (2/0.5) = C_K \times 1.3863 \quad \Rightarrow \quad C_K = 7.213$

$$P_2 = 7.213 \times \ln (2/0.4) = 7.213 \times 1.6094 = 11.61\ \text{kW}$$

Result. Rittinger 13.3 kW ; Kick 11.6 kW.

Check. Both exceed the original 10 kW, as they must for a finer product, and Rittinger again gives the higher figure.

◆ **WORKED NUMERICAL — *Sugar crystals — Sauter diameter*** **[OPSC·CSE 2023-24 · Paper-II, Q.15(b) · 20M]**

Problem. *Sugar crystals were ground from an average Sauter diameter of 500 µm to a powder with an average Sauter diameter of 100 µm. The net energy consumption was 0.5 kWh per ton. What would be the net energy consumption for grinding the crystals to 50 µm powder, (a) according to Rittinger's law and (b) according to Kick's law?*

Given. x_f = 500 µm ; x_p1 = 100 µm ; E_1 = 0.5 kWh/t ; x_p2 = 50 µm.

(a) Rittinger. $0.5 = C_R\,(1/100 - 1/500) = C_R \times 0.008 \quad \Rightarrow \quad C_R = 62.5$

$$E_2 = 62.5\,(1/50 - 1/500) = 62.5 \times 0.018 = 1.125\ \text{kWh/t}$$

(b) Kick. $0.5 = C_K \ln (500/100) = C_K \times 1.6094 \quad \Rightarrow \quad C_K = 0.3107$

$$E_2 = 0.3107 \times \ln (500/50) = 0.3107 \times 2.3026 = 0.715\ \text{kWh/t}$$

Result. Rittinger 1.13 kWh/t ; Kick 0.715 kWh/t.

Note. Halving the product size from 100 to 50 µm more than doubles the Rittinger energy but raises the Kick energy by only 43 % — a clean illustration of why Rittinger is preferred for fine grinding.

◆ **WORKED NUMERICAL — *Green gram — Bond's law*** **[OPSC·CSE 2022-23 · Paper-II, Q.17(b) · 10M]**

Problem. *Grinding green gram with a hammer mill required 8.3 kWh of energy per tonne of material for reducing its size from 6.25 mm to 0.75 mm. Assuming that Bond's law holds good for the material, estimate the amount of energy required for reducing the size down to 0.1 mm.*

Given. D_f = 6.25 mm ; D_p1 = 0.75 mm ; E_1 = 8.3 kWh/t ; D_p2 = 0.1 mm.

Formula. $E = C_B\,(1/\sqrt{D_p} - 1/\sqrt{D_f})$, where C_B absorbs 0.3162 W_i

Step 1 — evaluate C_B. 1/√0.75 = 1.15470 ; 1/√6.25 = 0.40000

$$8.3 = C_B\,(1.15470 - 0.40000) = 0.75470\,C_B \quad \Rightarrow \quad C_B = 10.998$$

Step 2 — apply to 0.1 mm. 1/√0.1 = 3.16228

$$E_2 = 10.998\,(3.16228 - 0.40000) = 10.998 \times 2.76228 = 30.38 \text{ kWh/t}$$

Result. Energy required = 30.4 kWh/tonne.

Check. Implied work index W_i = C_B/0.3162 = 34.8 kWh/t, a plausible order for a pulse.

◆ **WORKED NUMERICAL — *Rittinger scaling*** **[UK·PSC RFO (Mains) 2015 · Q.7(iv) · 10M]**

Problem. *It is found that the energy required to reduce particles from a mean diameter of 10 mm to 3 mm is 10 kJ/kg. Using Rittinger's law, calculate the energy required to reduce the same material from a diameter of 1 mm to 0.3 mm.*

Given. First duty 10 → 3 mm at E_1 = 10 kJ/kg ; second duty 1 → 0.3 mm.

Step 1 — evaluate C_R. $10 = C_R\,(1/3 - 1/10) = C_R\,(0.33333 - 0.10000) = 0.23333\,C_R$

$$C_R = 42.857 \text{ kJ·mm/kg}$$

Step 2 — second duty. $E_2 = 42.857\,(1/0.3 - 1/1) = 42.857\,(3.33333 - 1.00000) = 42.857 \times 2.33333$

$$E_2 = 100.0 \text{ kJ/kg}$$

Result. Energy required = 100 kJ/kg.

Insight worth writing. Both sizes were divided by 10, and the energy rose exactly ten-fold. Under Rittinger's law energy scales inversely with size, so geometrically similar reductions at one-tenth the size cost ten times the energy.

5 SIZE-REDUCTION MACHINERY

Group	*Machine*	*Principle and construction*	*Product / use*
Crushers	Jaw crusher	Two jaws open at the top like a V; one fixed and near-vertical, the other swinging at 20–30° to it, driven by an eccentric imparting great compressive force. Lumps caught in the upper part break and drop into the narrower space below, to be reduced again as the jaws close. 250–400 strokes/min	Coarse crushing of hard solids; limited agricultural use
Crushers	Gyratory crusher	Circular jaws; solids caught in the V between head and casing; head rotated by an eccentric at 125–425 gyrations/min. Crushing occurs somewhere at all times, so discharge is continuous	Continuous duty; lower power and maintenance than jaw crusher
Crushers	Crushing rolls	Compression between rolls ~0.6 m dia at up to 300 rpm, designed to nip lumps. Smooth rolls for flaking corn and semi-liquids, corrugated for coarse grinding of grain; a series with decreasing gaps grinds progressively finer	Flaked corn, chocolate; sugarcane juice extraction

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Grinders	Hammer mill	Hinged or fixed hammers on a high-speed shaft — peripheral speed to 100 m/s, shaft to 4000 rpm. Solids impacted between hammer and a toughened breaker plate; fineness set by the screen mesh below. Simple, high capacity	Hard and brittle materials — pepper, sugar, dried milk, dried vegetables, spices; also fibrous matter
Grinders	Burr / plate mill	Shearing between two corrugated chilled-iron plates, one driven and one stationary; fineness set by plate roughness and clearance via a hand screw. A spring prevents contact when no grain passes. Popular size 30 cm at 650–750 rpm	Wheat, sorghum flour; farm feed grinding
Fine grinders	Disc and pin mill	Rotating disc against a stationary plate, or two counter-rotating discs — largely attrition. Pin mill has pins or teeth, axial feed and radial flow, impaction to 160 m/s	Sugar, nuts, cocoa, nutmeg, cereals, rice
Fine grinders	Ball and rod mills	Horizontal rotating drum with free metal or ceramic balls 25–150 mm dia; the rod mill uses rods the length of the drum, adding attrition	Fine grinding; rod mill avoids the clogging of ball mills with sticky material

Basis	*Hammer mill*	*Roller mill*
Principal force	Impact, with some attrition	Compression, with shear from differential roll speed
Working element	Swinging or fixed hammers on a high-speed rotor	Pairs of rolls, smooth or corrugated, with a set nip
Size control	By the screen mesh fitted below the grinding chamber	By the gap between rolls; no screen needed
Particle size distribution	Wide, with a substantial proportion of fines	Narrow and uniform, few fines
Selectivity	Non-selective — bran and endosperm reduced together	Selective — friable endosperm reduced while tough bran flattens and stays coarse, permitting separation
Energy	Higher per unit product; much lost as heat	Lower; more efficient
Heat and moisture loss	Significant	Low
Suitability	Hard, brittle and fibrous materials; feed milling	Wheat flour milling, flaking, chocolate refining
Maintenance	Hammers and screens wear and are replaced cheaply	Roll re-corrugation is costly and infrequent

▶ ***Open-circuit versus closed-circuit grinding***

In ***open circuit*** the material passes the mill once with no rework of oversize; the distribution is wide, energy is wasted and too many fines are made, because the largest particle leaving must already be below the product limit. In ***closed circuit*** a classifier removes the undersize as product and returns the oversize to the mill; the investment is greater but the operation is far more efficient and the product more homogeneous.

Fig. 2.2 — Size-reduction machinery

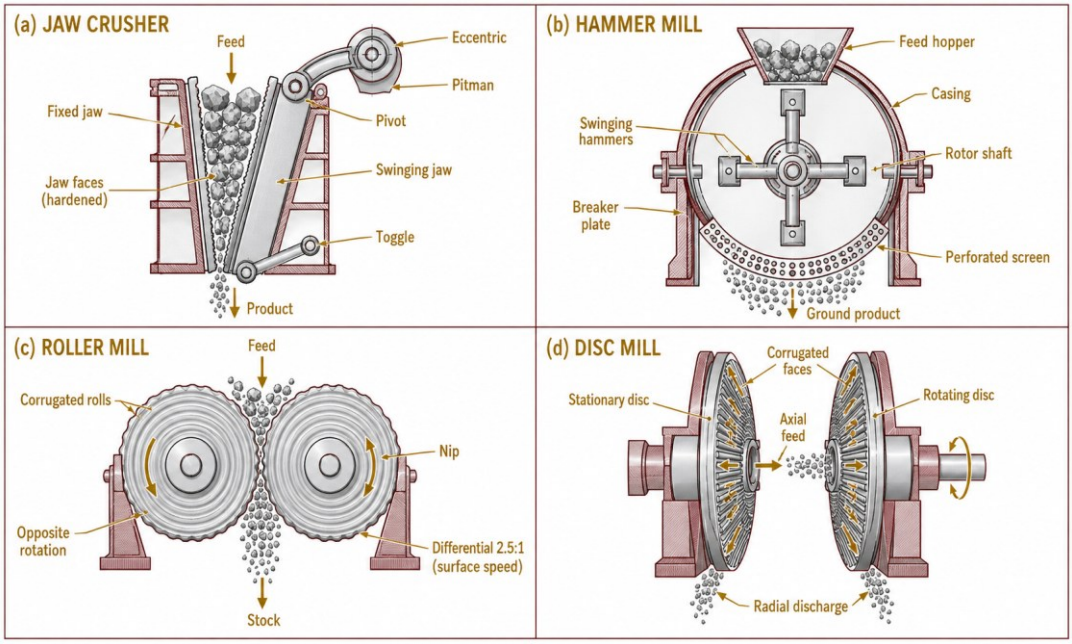


Fig. 2.2 (a) Jaw crusher, (b) hammer mill, (c) roller mill, (d) disc mill.

PREVIOUS YEAR QUESTIONS

- *What are the major differences between a Hammer mill and a Roller mill?*
  [IFoS 2016 · P2/6(a) · 10M]
- *Explain the construction and working principle of hammer mill for size reduction operations.* · *What is grain milling? Describe the working principle of a hammer mill.*
  [OPSC·CSE 2022-23 · Q.17(a) · 10M · UK·PSC RFO 2021 · Q.7(ii) · 10M · UK·PSC ACF 2019 · Q.7(ii) · 10M]

6 SCREEN ANALYSIS, FINENESS MODULUS AND UNIFORMITY INDEX

Screen analysis

A set of standard sieves is stacked coarsest at the top, finest at the bottom, the sample placed on top and shaken for a fixed time; the material retained on each sieve is weighed and expressed as a weight fraction. Because particles retained on one screen have passed the screen above, two numbers specify a fraction — the notation ***8/10*** or −8 +10 means material passing 8 mesh and retained on 10 mesh. Reporting the individual fractions is a ***differential analysis***; adding them cumulatively from the coarsest downward gives the ***cumulative analysis***, in which ϕ is the weight fraction larger than a given opening and 1 − ϕ the fraction passing.

Fineness modulus (FM) : *an empirical index of the uniformity of grind, obtained by adding the cumulative percentage weight fraction of material retained on each of a specified series of standard sieves and dividing the sum by 100. A small value indicates fine material, a large value coarse.*

$$FM = (\Sigma \text{ cumulative \% weight retained}) / 100 \qquad D_p = 0.135\,(1.366)^{FM}$$

D_p = average particle size, mm — the relation used to convert a fineness modulus into an average size

Uniformity index : *an index indicating the* ***distribution*** *of fines, mediums and coarses in the sample, expressed as their relative proportions. It is needed because the same fineness modulus can arise from several quite different particle-size distributions; the recommended practice is therefore to quote both indices.*

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For food-grain flour analysis a set of IS sieves numbered 100, 70, 50, 40, 30, 20 and 15 mesh is used with a pan and cover; the standard procedure specifies a **250 g sample** oven-dried to constant weight at 105 °C, shaken in a RoTap sieve shaker for 5 minutes. In the multiplier method the sieves are weighted 7, 6, 5, 4, 3, 2, 1 and 0 from the coarsest downward.

◆ **WORKED NUMERICAL — *Fineness modulus and average particle size*** **[IFoS 2025 · P2/5(c) · 8M · UK·PSC 2021 & 2019 · Q.7(i) · 10M]**

Problem. *Define Fineness Modulus. Using fineness modulus, determine the average particle size with the following data (250 g sorghum flour sample, IS sieves).*

Given. Mass retained, g — IS 70: 10.1 ; IS 50: 16.7 ; IS 40: 36.0 ; IS 30: 83.2 ; IS 20: 96.0 ; IS 15: 8.0 ; pan: nil. Total 250.0 g.

Step 1 — percentage retained on each sieve. 10.1/250 × 100 = 4.04 ; 16.7 → 6.68 ; 36.0 → 14.40 ; 83.2 → 33.28 ; 96.0 → 38.40 ; 8.0 → 3.20 %.

Step 2 — apply the IS multipliers 6, 5, 4, 3, 2, 1 (the 100-mesh retains nothing, multiplier 7).

$$6(4.04) + 5(6.68) + 4(14.40) + 3(33.28) + 2(38.40) + 1(3.20)$$

$$= 24.24 + 33.40 + 57.60 + 99.84 + 76.80 + 3.20 = 295.08$$

Step 3 — fineness modulus. $FM = 295.08 / 100 = 2.9508$

Step 4 — average particle size. $D_p = 0.135\ (1.366)^{2}.9508 = 0.135 \times 2.510 = 0.3389$ mm

Result. FM = 2.95 ; average particle size D_p = 0.339 mm.

Comment. FM alone does not fix the distribution — the same 2.95 could arise from a quite different spread — which is why the uniformity index must be quoted alongside it.

7 SCREENING: IDEAL AND ACTUAL SCREENS; EFFECTIVENESS

Ideal and actual screens : *An **ideal screen** separates the feed so that the largest particle of the underflow is just smaller than the screen opening while the smallest particle of the overflow is just larger. No real screen achieves this: in an **actual screen** the underflow may contain material coarser than the aperture and the overflow finer material.*

Effectiveness of a screen : *the ability of a screen to separate the feed closely into overflow and underflow according to size.*

▶ ***Derivation through material balance***

Let F, O and U be the mass flow rates of feed, oversize and undersize, kg/h, and m_F, m_O and m_U the mass fractions of oversize material in each stream. The fractions of undersize material are then 1 − m_F, 1 − m_O and 1 − m_U.

Overall balance: $F = O + U$

Balance on oversize material: $F \cdot m_F = O \cdot m_O + U \cdot m_U$

Substituting U = F − O into the second equation, F·m_F = O·m_O + (F − O) m_U, so F(m_F − m_U) = O(m_O − m_U), and eliminating O instead gives the companion result:

$$O/F = (m_F - m_U)/(m_O - m_U) \qquad U/F = (m_O - m_F)/(m_O - m_U)$$

The recovery ratios of oversize and undersize — the answer to 'find the ratio of oversize to feed in terms of mass fractions'

Effectiveness based on the ***oversize*** is the ratio of the oversize actually present in the overflow to the oversize entering with the feed; that based on the ***undersize*** is defined correspondingly:

$$E_O = O\cdot m_O / (F\cdot m_F) \qquad E_U = U(1 - m_U) / [\, F(1 - m_F)\,]$$

$$\text{Overall effectiveness} \quad E = E_O \times E_U$$

Substituting the ratios O/F and U/F obtained above eliminates the flow rates entirely and leaves an expression in the three mass fractions alone — the form used in practice, because only a screen analysis is needed and no stream need be weighed:

$$E = [\, (m_F - m_U)(m_O - m_F)(1 - m_U)\, m_O\,] \div [\, (m_O - m_U)^2\,(1 - m_F)\, m_F\,]$$

Fig. 2.3 — Material balance over a screen

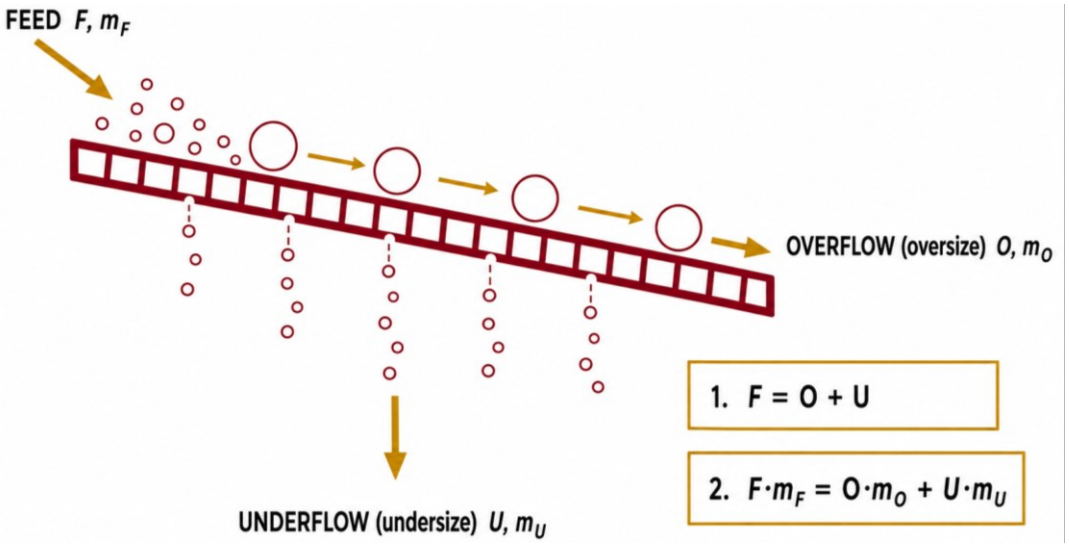


Fig. 2.3 Streams and mass fractions in a screening operation.

◆ **WORKED NUMERICAL — *Screen effectiveness from a screen analysis*** **[IFoS 2024 · P2/7(a) · 15M (application)]**

Problem. *Wheat was milled in a burr mill and the ground product analysed on a set of IS screens. From the cumulative mass fractions smaller than the screen opening — feed 0.16, overflow 0.615, underflow 0.030 for IS 50 mesh — calculate the screen effectiveness. Repeat for IS 30 mesh, where the values are 0.75, 0.955 and 0.610.*

Given (IS 50). m_F = 0.16 ; m_O = 0.615 ; m_U = 0.030.

Formula. $E = (m_F - m_U)(m_O - m_F)(1 - m_U)\, m_O \div [\, (m_O - m_U)^2\,(1 - m_F)\, m_F\,]$

Substitution. numerator = (0.130)(0.455)(0.970)(0.615) = 0.035293

$$\text{denominator} = (0.585)^2\,(0.840)(0.160) = 0.342225 \times 0.1344 = 0.046003$$

$$E = 0.035293 / 0.046003 = 0.767$$

For IS 30. m_F = 0.75 ; m_O = 0.955 ; m_U = 0.610

$$E = (0.140)(0.205)(0.390)(0.955) \div [\, (0.345)^2\,(0.250)(0.750)\,] = 0.010690 / 0.022317 = 0.479$$

Result. E = 0.767 at IS 50 mesh ; E = 0.479 at IS 30 mesh.

Comment. Effectiveness falls sharply at the coarser screen because the feed there is close to the aperture size, promoting blinding and interference.

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▶ ***Capacity, effectiveness and the factors that govern them***

Capacity — mass fed per unit time per unit screen area — and effectiveness are ***opposing***: maximum effectiveness goes with small capacity, and large capacity is bought at the expense of efficiency. An overloaded screen gives each particle few contacts and particle interference reduces the chance of passage at each contact. The probability of passage depends on (i) the fraction of the total surface represented by openings, (ii) the ratio of particle diameter to aperture width, and (iii) the number of particle–screen contacts. In a mixture the large particles ***segregate in a layer next to the screen*** and prevent the small ones reaching the surface. Damp particles stick to the surface and to each other; and a particle of critical dimension, close to the aperture, wedges in and causes ***blinding***.

PREVIOUS YEAR QUESTIONS

- *Derive the effectiveness of screen in a grader through material balance.*

  [IFoS 2024 · P2/7(a) · 15M]

- *Define screening in food processing. Show mass balance over a screen and find out the ratio of oversize to feed in terms of mass fractions of feed, oversize and undersize. Make suitable assumptions.*

  [IFoS 2020 · P2/7(b) · 15M (second part)]

MODEL Q The 2024 question wants the derivation, not the answer — write F = O + U, the oversize balance, the elimination of U and then of O, the two definitions of E_O and E_U, and the combined form, stating the assumptions: steady state, no accumulation on the deck, and only two size classes present. The 2020 question stops at O/F = (m_F − m_U)/(m_O − m_U).***

8 CLEANING, GRADING AND SORTING

Crops after harvesting and threshing carry organic and inorganic impurities — straw, chaff, weed seeds, iron pieces, stones and mud. Impure grain fetches a lower price, increases bulk and hence handling and transport cost, causes high storage loss, and wears processing machinery. Cleaning is therefore the first operation in every processing line.

Term	*Definition*	*Basis of separation*
Cleaning	Removal of foreign matter, dust, chaff, stones and damaged seed from the produce	Difference in any physical property between the produce and the contaminant
Grading	Segregation of the cleaned produce into parcels of defined quality or size, to establish a price relation	Usually a single measurable attribute — size, weight or density
Sorting	Separation into categories on the basis of a quality attribute such as colour, maturity, shape or freedom from defect	Attributes judged individually for each unit, often by machine vision or reflectance

▶ ***The eight bases of separation — the framework for any 'principles' answer***

Physical property exploited	*Equipment*
Width and thickness of the grain	Sieves, screen cleaners, sifters, thickness graders, grading reels, inclined sifters
Length of the grain	Indented cylinder and disc-type pocket separators
Aerodynamic properties (terminal velocity)	Husk aspirators, pneumatic separators, cyclone separators

Form and state of the surface	Spiral separators, inclined belt (draper) separators, roll separators
Specific gravity and coefficient of friction	Specific gravity separating tables, destoners
Ferromagnetic properties	Magnetic and electromagnetic separators
Electrical properties	Electrostatic separators
Colour and reflectance	Electronic and optical colour sorters

- ***Criteria and methods of sorting food materials***

  Sorting criteria reduce to five: ***size*** (screens, roller and diverging-belt sizers), ***shape*** (spiral, disc and indented cylinder, belt separators), ***density*** (flotation in water or brine, gravity tables, destoners, pneumatic sorting), ***colour*** (photoelectric sorters comparing reflectance with a reference and ejecting off-colour units by an air jet) and ***freedom from defect*** (X-ray, machine vision, inspection belts). Pneumatic sorting is commonest in grain: the mixture enters a rising air column whose velocity lies between the terminal velocities of the two fractions, so light material rises and heavy material falls against the stream.

- ***Pneumatic sorting machine — construction and working***

  Construction. A vertical rectangular aspiration channel (air column); a feed hopper with a metering gate at the top of the column; a fan at the base, either suction type drawing air up the channel or blower type forcing it; a damper or variable-speed drive to set the air velocity; an expansion chamber and cyclone above the column to recover the light fraction; and spouts for the heavy fraction at the bottom and the light fraction at the cyclone apex.

  Working. The air velocity is set between the terminal velocities of the two fractions. Metered feed entering the column is met by the rising stream: particles whose terminal velocity is lower than the air velocity are carried upward into the expansion chamber and cyclone, while those whose terminal velocity is higher fall against the stream and discharge at the bottom. Separation is therefore on terminal velocity, which combines size, shape and density in one property. Effectiveness depends on the air velocity setting, the uniformity of the velocity profile across the channel, the feed rate — overloading causes particle interference and carry-over of good grain — and the moisture content, since damp light material becomes heavier. The sketch is Fig. 2.4(d).

- ***Criteria for selecting a cleaning or grading machine***

  (i) The property in which produce and contaminant differ most, which fixes the machine type; (ii) required capacity and the acceptable capacity–effectiveness trade-off; (iii) permissible mechanical damage, which rules out aggressive machines for seed; (iv) number of fractions required; (v) feed moisture, since damp material blinds screens; (vi) seed versus food end-use, seed needing gentler handling and higher purity; (vii) power cost; (viii) capital cost, floor space and maintenance.

PREVIOUS YEAR QUESTIONS

- *What are the principles applied for cleaning and grading of grains and seeds?*

  [OPSC·CSE 2018-19 · Paper-II, Q.5(a) · 20M]

- *Discuss the criteria and methods of sorting of food materials. Draw sketch of pneumatic method sorting machine.*

  [IFoS 2017 · P2/6(d) · 10M]

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Differentiate between: Grading and Sorting. · What are the criteria for selection of cleaning and grading machines? · How sorting and grading is useful in fruits and vegetables? Explain, in detail, various processes and equipments used for sorting and grading.

[HP·PSC RFO 2021 · Q.7(c) · 10M · OPSC·CSE 2020-21 · Q.5(b)(ii) · 8M and Q.6(b) · 20M]

MODEL Q For the 20-mark 'principles' question, the eight-row table is the answer — every principle with its machine. For the fruits-and-vegetables version, keep the same skeleton but substitute the perishable-specific equipment: diverging-belt and roller sizers, flotation in brine, penetrometer firmness and reflectance colour sorters.***

9 SEPARATORS

9.1 Air-Screen Cleaner

The air-screen cleaner is the ***basic machine of seed and grain processing***. It combines two principles — ***aspiration***, which separates on terminal velocity, and ***screening***, which separates on width and thickness. A typical unit uses ***two air blasts and four screens***: the first air blast lifts dust and light chaff from the feed; the first (scalping) screen passes the good seed and scalps off large trash; the second screen removes material smaller than the seed; the third is a grading screen; the fourth is a cleaning screen through which the good seed drops; and the second air blast at the discharge removes any remaining light material.

▶ ***Components and the role of each***

Component	Role
Feed hopper and feed-gate	Holds the incoming stock and meters it at a uniform rate across the full screen width; local overloading destroys effectiveness
First (upper) aspiration — fan, duct, settling chamber	Draws air through the falling feed before screening to lift dust, chaff and light immature grain; velocity set above their terminal velocity but below that of sound grain
Scalping screen (top)	Largest aperture: good seed passes through while oversize trash — straw, clods, pods, stalks — is scalped off the surface and discharged separately
Grading screen (middle)	Intermediate aperture: splits the through-stock into size grades where graded output is required
Cleaning screen (bottom)	Aperture smaller than the seed: sand, dust, weed seeds and broken grain drop through as undersize while clean seed travels over it to the outlet
Screen frames and shoe assembly	Carry the screen stack at the set inclination and transmit the oscillation; inclination fixes residence time and the travel of the stock
Eccentric shaker drive (crank and connecting rod)	Imparts reciprocating or gyratory motion of set amplitude and frequency, giving repeated particle–screen contacts and keeping the bed moving
Screen-cleaning devices — rubber balls, brushes or knockers	Housed in trays beneath each screen; dislodge grain wedged in the apertures and so prevent blinding
Second (lower) aspiration at discharge	Final air blast that removes any light material still travelling with the cleaned seed
Fan, ducting and damper	Supply and regulate the air; the damper setting is the operator's working control over aspiration intensity

Discharge spouts	Separate outlets for clean seed, oversize, undersize and light fraction, keeping the four fractions apart
Frame, motor and V-belt drive	Support the assembly and power the shaker and the fans

▶ ***Design considerations***

(i) ***Screen aperture — shape and size***: round perforations separate on width, oblong perforations on thickness; the aperture is chosen from the dimensional distribution of the grain and the contaminant. (ii) ***Screen area***, fixed by the required capacity and by the bulk density of the grain, since capacity is expressed per unit area. (iii) ***Angle of inclination***, which controls residence time and the travel of the stock. (iv) ***Amplitude and frequency of oscillation***, which govern the number of particle–screen contacts and hence effectiveness, and must avoid resonance. (v) ***Air velocity***, set above the terminal velocity of chaff and dust but below that of sound grain — hence the aerodynamic data of §8 are a design input. (vi) ***Uniform feed distribution*** across the full screen width, since local overloading destroys effectiveness. (vii) ***Number of screens and their sequence***, set by the number of fractions required. (viii) Provision for ***screen cleaning*** — rubber balls, brushes or knockers — to prevent blinding. (ix) Power requirement of fan and shaker, and (x) accessibility for changing screens.

◆ **WORKED NUMERICAL — *Cleaning efficiency of an air-screen cleaner*** **[BIS IS 5817:1980 · applies to IFoS 2023 and 2020]**

Problem. *During evaluation of an air-screen grain cleaner with two screens, 250 g samples were collected from each outlet. Clean seed: feed 231.25 g, clean-grain outlet 246.5 g, blower outlet 1.25 g, oversize outlet 4.5 g, undersize outlet 2.0 g. Calculate the cleaning efficiency.*

Formula (BIS IS 5817:1980). $\eta = E(F-G)(E-F)(1-G) \div [\, F(E-G)^2(1-F)\,]$

E = fraction of clean seed at the clean-seed outlet ; F = fraction of clean seed in the feed ; G = fraction of clean seed at the foreign-matter outlets

Step 1. E = 246.5/250 = 0.986 ; F = 231.25/250 = 0.925

$$G = (1.25 + 4.5 + 2.0)/250 = 7.75/250 = 0.031$$

Step 2 — substitute. numerator = 0.986 (0.894)(0.061)(0.969) = 0.052106

$$\text{denominator} = 0.925\ (0.955)^2\ (0.075) = 0.925 \times 0.912025 \times 0.075 = 0.063272$$

$$\eta = 0.052106 \,/\, 0.063272 = 0.8235$$

Result. Cleaning efficiency = 82.35 %.

Editor's note. Sahay & Singh work a companion problem with E = 0.995, F = 0.935, G = 0.017 and print 91.18 %. Recomputation of that data by the same formula gives 92.68 %; the printed figure carries an arithmetic slip. The corrected value is used here.

9.2 *Specific Gravity Separator, Spiral Separator and Cyclone*

Separator	*Principle*	*Construction and working*	*Use*
Specific gravity separator	Difference in density, combined with the tendency of grain to flow down an inclined surface and to float in a rising air stream	Triangular perforated deck, baffled underneath for uniform air distribution, reciprocating; air stratifies the bed while the deck motion conveys the heavy fraction up-slope. Controlled by feed rate, deck slope, deck vibration and air flow	Separating insect-damaged, immature, mouldy and hollow grain from sound grain; seed upgrading

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Destoner	A form of specific gravity separator	Mixture fed to the centre of a perforated deck; air stratifies, reciprocation separates. Heavy stones travel to the high end, grain discharges at the low end, with no middling fraction	Removal of stones, mud balls and metal from grain
Spiral separator	Difference in roundness — round grains roll, non-round grains slide	A stationary open screw conveyor standing on end, no moving parts; round material accelerates down the incline until centrifugal force throws it into the outer helix, while non-round material is caught in the inner helix. Only the feed rate is adjustable	Separating mustard, rape, soybean and other round seeds from wheat, flax and oats. Simple and inexpensive but inflexible
Cyclone separator	Centrifugal force generated by a tangential vortex	Air and material enter tangentially at the top; a vortex forms, the lighter air leaves through the top opening while heavier material slides down the wall and discharges at the bottom. Effective turns usually taken as two	Collecting dust and light waste from aspirators and pneumatic conveyors

▶ *Specific gravity separator: components and the role of each*

Component	Role
Feed hopper and feed-rate control	Meters the stock onto the deck; the setting fixes bed depth, and bed depth governs how completely the layers stratify
Perforated deck, triangular	The working surface, inclined in two planes (end slope and side slope); air passes upward through the perforations to fluidise the grain bed
Plenum chamber with baffles, beneath the deck	Distributes the air uniformly over the whole deck area; uneven air flow leaves parts of the bed unfluidised and destroys the separation
Fan with air-volume control	Supplies the upward air stream that fluidises the bed and stratifies it by density, light and unsound grain floating to the top
Eccentric reciprocating drive, variable speed	Shakes the deck longitudinally; the heavy bottom layer, still in contact with the deck, is conveyed up-slope while the fluidised light layer flows down-slope
Deck-slope adjustment — end tilt and side tilt	Sets the balance between gravity flow and the conveying action of the shake; the operator's primary control over separation sharpness
Adjustable discharge lips or splitters at the deck edge	Cut the stratified stream into heavy, middling and light fractions and fix the boundaries between them
Frame with springs or vibration isolators	Carries the oscillating deck and prevents the vibration from being transmitted to the floor
Dust hood and aspiration duct	Collects dust and chaff lifted off the fluidised bed by the air stream

▶ *Cyclone: separation factor and its relation to particle weight*

A particle in a cyclone is acted on by two forces — the centrifugal force and its own weight:

$$C = W V^2 / (g R) \qquad \text{Separation factor } S = C / W = V^2 / (g R)$$

C = centrifugal force ; W = weight of particle ; V = tangential velocity, m/s ; R = radius of rotation, m ; g = 9.81 m/s²

This is the point the examiner is testing. The centrifugal force is ***directly proportional to the weight*** of the particle, but the separation factor — being their ratio — is ***independent of the weight*** and depends only on tangential velocity and radius of rotation. A cyclone therefore develops the same separation factor for a heavy particle as for a light one; what differs is the settling rate, lighter particles taking longer to reach the wall. Separation improves as S increases, so a smaller radius and a higher inlet velocity give sharper separation.

◆ **WORKED NUMERICAL — *Cyclone separation factor*** **[IFoS 2016 · P2/6(b) · 10M (application)]**

Problem. *Air carrying particles of density 1200 kg/m³ and average diameter 25 micron enters a cyclone of 600 mm diameter at a linear velocity of 20 m/s. Calculate the centrifugal force acting radially and the separation factor.*

Given. ρ_p = 1200 kg/m³ ; d = 25 μm so r = 12.5 × 10⁻⁶ m ; D = 0.6 m so R = 0.3 m ; V = 20 m/s.

Step 1 — weight of one particle. $W = \rho_p \times (4/3)\pi r^3 = 1200 \times (4/3)\pi(12.5 \times 10^{-6})^3$

$$W = 9.82 \times 10^{-12}\ \text{kg}$$

Step 2 — centrifugal force. $C = W\,V^2/(gR) = 9.82 \times 10^{-12} \times 400 \div (9.81 \times 0.3)$

$$C = 1.334 \times 10^{-9}\ \text{kg}$$

Step 3 — separation factor. $S = C/W = V^2/(gR) = 400 \div 2.943 = 135.9$

Result. C = 1.33 × 10⁻⁹ kg ; S = 136.

Check. S computed as C/W and as V²/(gR) agree, confirming that the particle weight cancels — the separation factor is a property of the cyclone geometry and the inlet velocity, not of the particle.

Fig. 2.4 — Separators and pneumatic sorter

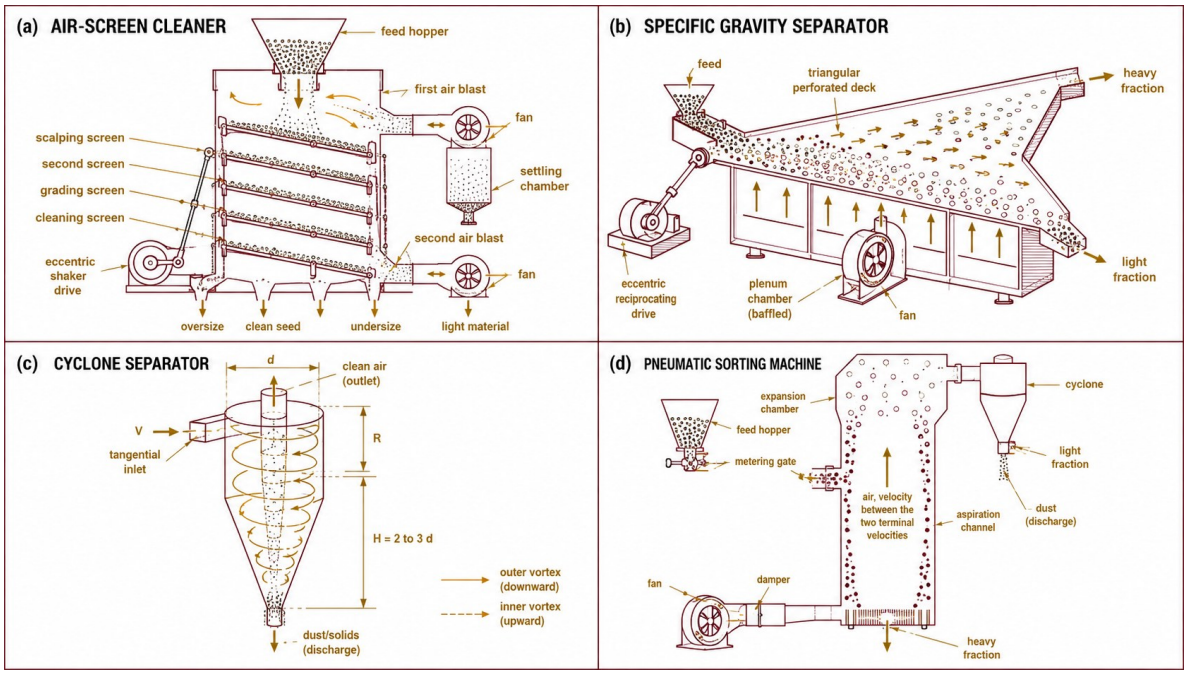


Fig. 2.4 (a) Air-screen cleaner, (b) specific gravity separator, (c) cyclone separator, (d) pneumatic sorting machine.

Basis	*Spiral separator*	*Specific gravity separator*
Property exploited	Roundness — ability to roll	Density or specific gravity
Moving parts	None; gravity alone	Reciprocating deck plus a fan
Adjustment available	Feed rate only	Feed rate, deck slope, vibration, air flow
Fractions produced	Two — round and non-round	Two, and grades in between

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Typical duty	Mustard or soybean from wheat, flax, oats	Insect-damaged, immature or mouldy grain from sound grain; destoning
Cost and flexibility	Simple and inexpensive but inflexible	Costly and power-using but versatile

PREVIOUS YEAR QUESTIONS

- *What are the design considerations for air screen grain cleaner?*

  [IFoS 2023 · P2/5(a) · 8M]

- *Air screen cleaner and specific gravity separators are used in crop processing. Write the basic principle of operation of these equipments. List the components of both the equipments along with the role of each component. Write the importance of cleaning in crop processing.*

  [IFoS 2020 · P2/6(b) · 10M]

- *Describe the working of a cyclone separator. How is its separation factor related to the weight of a particle?* · *Explain the functioning of specific gravity separator and its uses.* · *Differentiate between: Spiral separator and Specific gravity separator*

  [IFoS 2016 · P2/6(b) · 10M · OPSC·Forest 2019-20 · Q.5(a) · 20M · HP·PSC 2021 · Q.7(c)]

10 SEED PROCESSING PLANT

Seed processing aims at ***upgrading the quality of seed by removing foreign material and undesirable seed***. The justification is economic: the entire crop depends on seed quality, and seed of mixed variety contaminates the whole production plot.

Seed processing eliminates seven categories — inert material, weed seeds, other crop seeds, other varieties, damaged seeds, diseased seeds and off-size seeds — through five operations: ***cleaning, grading, treating, testing and packaging***. These fall into three phases: the first is scalping, debearding and hulling; the second is removal of inert material, weed seed, other crop seed and broken seed, generally by the air-screen cleaner; the third is drying, treating and bagging.

Component	*Function*
Prime mover	IC engine or electric motor supplying power to all components
Seed moving equipment	Bucket elevators (commonest), belt, mass-flow and vibrating conveyors; belts must run at the designed speed, as excess speed damages seed
Scalper	Vibrating or rotating screen removing the bulk of trash; perforations pass the seed while large inert matter is scalped off
Debearder	Steel cylinder with stationary internal bars and a shaft carrying beater arms; rubbing removes awns, hairs and appendages from oats, barley and some vegetable seeds
Scarifier–huller	Scratches the hard seed coat of lucerne, berseem and sweet clover so that moisture can penetrate and the seed can germinate
Air-screen cleaner	The basic machine — aspiration plus screening; two air blasts and four screens (see §9.1)
Aspirators and pneumatic separators	Separate on terminal velocity, upgrading the fraction the screens cannot
Seed treater	Applies a metered quantity of chemical uniformly over each seed; comprises metering devices for seed and chemical, an applicator, a mixing chamber and a discharge

Bagger weigher	Mounted beneath a bin; fills and weighs a bag in one operation, followed by closing and labelling

PREVIOUS YEAR QUESTIONS

- *Describe the working and important features of a seed processing plant.* · *Explain the main features and important components of seed processing plant.*

[OPSC·CSE 2017-18 · Paper-II, Q.5(b) · 20M · OPSC·Forest 2015-16 · Q.5(b) · 20M]

11 RICE MILLING

Milling is ***size reduction and separation applied to convert food grain into edible form by removing the inedible parts***. In ***grain milling*** the husk and bran are removed with the grain shape retained; in ***flour milling*** flour is produced without retaining the shape. Rice milling comprises cleaning, parboiling (optional), shelling (dehusking), paddy separation, whitening, polishing, grading and packaging.

▶ *Importance of rice processing*

Paddy as harvested is not edible: the husk is fibrous and indigestible and must be removed before the kernel can be cooked. Processing is therefore a precondition of consumption rather than a value addition, and the way it is carried out decides both how much rice and how much value the crop yields.

(i) **Edibility** : shelling removes the husk and whitening pares off the bran layers, converting an inedible grain into a cookable one.

(ii) **Recovery and food security** : paddy yields roughly 70 % rice, 20 % husk and 8–10 % bran; because the crop is milled on a national scale, a few percentage points of extra breakage is a loss of lakhs of tonnes of food grain. Head-rice yield is therefore a food-supply variable, not merely a mill-economics one.

(iii) **Price realisation** : head rice commands a large premium over brokens, so mill margin tracks head-rice yield directly, and grading into defined size and quality classes allows the produce to be priced to quality.

(iv) **By-product value** : only processing releases the by-product streams: husk as boiler fuel and a source of silica, bran carrying 15–20 % oil for rice bran oil and de-oiled cake, and brokens for flour, starch and brewing.

(v) **Storability** : bran lipids turn rancid under the action of lipase, so brown rice keeps poorly; removing the bran, or parboiling before milling, gives a grain that stores for months. Cleaning and drying the paddy first cuts insect and mould losses in store.

(vi) **Nutrition** : the degree of milling governs the loss of B vitamins and minerals held in the aleurone, which is why whitening is controlled and why parboiling is used to fix those nutrients in the endosperm before the bran is removed.

Term	*Meaning*
Hulling / shelling / dehusking	Removal of the husk from paddy
Brown rice	The kernel obtained after the husk is removed — pericarp, tegmen, aleurone and germ still present
Whitening / polishing / pearling	Removal of germ, pericarp, tegmen and aleurone layers from the husked kernel
Huller / sheller / paddy separator	The huller hulls and whitens in one pass; a sheller only hulls — disc or rubber roll. The paddy separator, gravity type, splits unhulled paddy from brown rice

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Head rice	Whole milled kernels; the head-rice yield is the commercial measure of milling quality

▶ ***Parboiling of paddy – purpose and effect***

Parboiling is a hydrothermal treatment given to paddy before shelling: the grain is soaked to about 30 % moisture, steamed, and dried back to about 14 %. Soaking and steaming gelatinise the starch inside the intact husk; on drying it retrogrades into a hard, translucent, homogeneous mass.

The purpose is fivefold.

(i) **Milling quality** : gelatinisation seals the cracks and air spaces in the endosperm and cements the kernel into a single hard body, so breakage during shelling and whitening falls sharply and the head-rice yield rises.

(ii) **Nutrition** : water-soluble B vitamins and minerals held in the aleurone and germ migrate inward with the soak water and are fixed in the endosperm, so thiamine and niacin survive whitening instead of being lost with the bran.

(iii) **Easier dehusking** : the husk splits along the suture and the bran loosens from the kernel, reducing shelling resistance and milling energy.

(iv) **Storage** : insects, moulds and the lipase that turns raw bran rancid are inactivated, so both the rice and the bran keep better, and the bran is a more stable feedstock for oil extraction.

(v) **Cooking behaviour** : the harder grain absorbs less water, cooks firm and non-sticky, and loses less solid matter to the cooking water.

The costs are a darker colour and a characteristic odour, higher capital and fuel cost for the soaking, steaming and drying plant, and the risk of off-flavour if the soak water is allowed to ferment. Parboiling is therefore optional in the milling line — standard for most of eastern and southern India, omitted where a white raw rice is wanted.

11.1 *Shelling: Huller and Rubber Roll Sheller*

The ***Engelberg huller*** hulls and whitens in a single operation between a ribbed steel roller and a perforated cage. It is simple and cheap, but the combined action means high breakage and low head-rice yield, the bran is contaminated with husk, and the milling quality is poor. Disc and roller type hullers share the same defect.

The ***rubber roll sheller*** replaced it in modern mills. Two rubber-covered rolls rotate in opposite directions at ***different speeds***, one faster than the other. Paddy fed evenly from a hopper passes into the nip; the differential speed produces a shearing action that strips the husk without abrading the kernel. Husk is removed by an aspirator and the mixture of brown rice and unhulled paddy passes to the paddy separator. Shelling efficiency is high and breakage low, so the head-rice yield is markedly better than with a huller.

Basis	*Engelberg huller*	*Rubber roll sheller*
Action	Hulling and whitening together, by abrasion between a ribbed steel roller and a cage	Hulling only, by shear between two rubber rolls at differential speed
Breakage	High	Low
Head-rice yield	Low	High
Bran quality	Contaminated with husk; unfit for oil extraction	Clean bran, suitable for rice bran oil

Wear and cost	Rugged, cheap, low maintenance	Rubber rolls wear and must be replaced; higher cost
Suitability	Village-level custom milling	Modern commercial rice mills

11.2 *Whitening: the Vertical Cone Rice Whitener*

Three kinds of whitening machine are used in modern rice mills — the ***vertical abrasive whitening cone***, the horizontal abrasive whitening roll, and the horizontal metallic friction roll. The vertical cone, of European origin, is the one the examiner asks for.

- ***Construction***

  An inverted cast-iron frustoconical rotor covered with abrasive material is mounted on a vertical spindle and revolves inside a fixed ***crib*** of steel wire cloth or perforated metal sheet. The gap between abrasive surface and crib is about ***10 mm***. Rubber brakes are placed vertically, spaced equally around the crib, protruding into the gap, with a clearance of ***2–3 mm*** from the crib. The pressure inside the whitening chamber is adjusted by pushing the brakes in or drawing them out, and the whole cone can be raised or lowered to reset the clearance as the brakes wear. The number of brakes follows $n = (D/100) - 2$, D being the cone diameter in mm, and the peripheral speed of the cone is about ***13 m/s***.

- ***Working***

  Husked rice enters the gap and is dragged round by the rough surface of the rotating cone. The rubber brakes retard it, so the grain piles up against them and, being oval and smooth, undergoes a strong swirling and revolving movement. Each grain is scoured by the abrasive cone and also rubs against neighbouring grains and the crib lining. The grains sink lower by gravity and discharge at the bottom; the bran, ground fine by scouring, escapes through the crib and is removed continuously. Because the rotor is an inverted truncated cone, ***peripheral speed is higher at the top while density and pressure are higher at the bottom***, so grinding predominates in the upper part and friction in the lower — strictly, the machine is a combination of abrasive and friction types. Two to four cones in series are normally used to whiten rice in successive passes.

Advantages	*Disadvantages*
Wearing parts — abrasive surface, crib lining and rubber brakes — can be made and replaced locally	The machine is big and heavy
Handles any variety of rice; performance is excellent with parboiled rice	Requires skilled operators and constant attention
Degree of whitening is adjustable through the brakes	Power requirement is high
Very long machine life	Power transmission system is troublesome
Low operational cost	The abrasive roll is not vitrified, so the abrasive particles are not very sharp
—	Pressure distribution along the vertical line is not uniform

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Fig. 2.5 — Vertical cone rice whitener (line diagram)

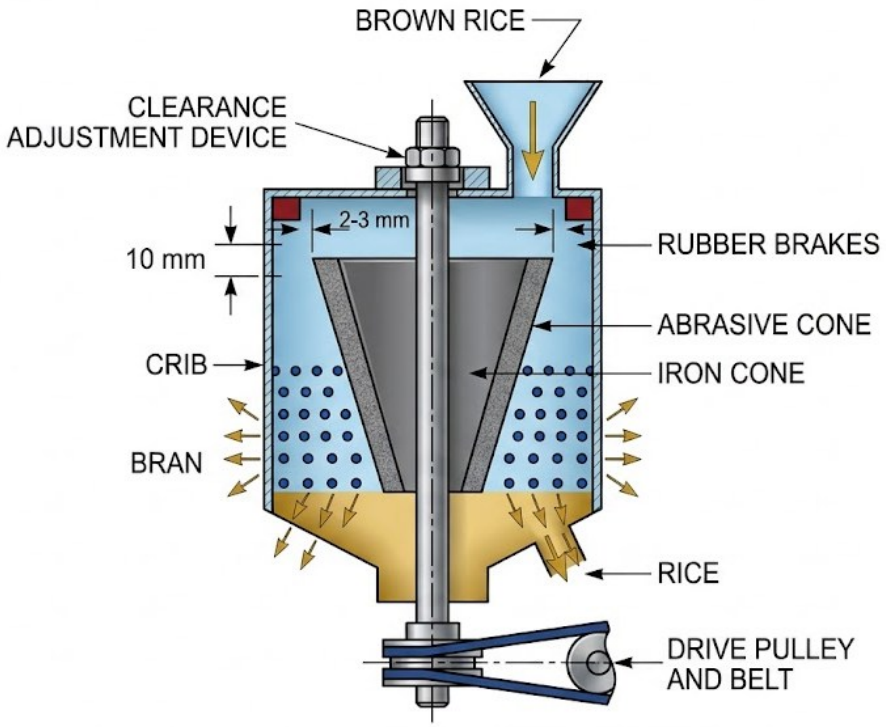


Fig. 2.5 Vertical abrasive whitening cone — construction and flow of rice and bran.

PREVIOUS YEAR QUESTIONS

- *With the help of a line diagram, discuss Vertical Cone Rice Whitener. Also, discuss its advantages and disadvantages.*

  [IFoS 2025 · P2/6(a) · 15M]

- *Explain the importance of rice processing. Describe the working of a rubber roll sheller.* · *Discuss working of huller. Also discuss advantages and disadvantages of huller.* · *Briefly explain the major operations performed by any modern rice milling plant. What is the purpose of parboiling of rice?*

  [OPSC·CSE 2017-18 · Q.5(a) · 20M · AP·PSC RFO 2012 · Q.5(B) · 20M · OPSC·CSE 2015-16 · Q.7(a) · 20M]

MODEL Q The 2025 question is worth 15 marks and names the line diagram first — draw it, label all nine parts, and only then write the construction, working, five advantages and six disadvantages. The numbers that earn marks are the 10 mm gap, the 2–3 mm brake clearance, n = (D/100) − 2 and 13 m/s.***

12 WHEAT, CORN AND PULSE MILLING

12.1 Modern Wheat Flour Milling

The objective is to obtain ***the maximum white flour from the endosperm with no bran or germ***. Wheat is 85 % endosperm, 12 % bran and 3 % germ; white flour milling yields about 70 % flour and 30 % mill feed, the latter composed of 12 % bran, 3 % germ and 15 % shorts. Modern flour milling has ***seven steps***: (1) receiving, drying and storage; (2) cleaning; (3) conditioning; (4) milling into flour and by-products; (5) packaging and storage; (6) blending; and (7) handling of milling by-products.

- ***Cleaning*** : Sieving removes sticks, stones and sand and aspiration removes chaff; powerful magnetic separators take out ferromagnetic pieces; disc separators remove other grains, defective grain and weed seed. Scouring then drives the wheat by paddles against a stationary emery surface to remove adhering dirt, and the scratches formed increase the rate of moisture absorption during conditioning. Finally washing sinks the dirt and metal and raises the moisture by about 1 %.
- ***Conditioning*** : Hydrothermal treatment makes bran and germ rubber-like while the endosperm becomes soft, and evens out the difference between hard and soft wheat. Soft wheat is raised to 15–17 % and hard wheat to 16–19 % moisture, then tempered **18–72 h**. The grain temperature must not exceed **47 °C**, or gluten quality and hence baking quality suffer. Modern conditioners work in preheating, moistening and cooling sections; direct steaming heats the grain to 47 °C within 20–30 s.
- ***Milling*** : A series of grinding and sifting operations with purification in between. When conditioned wheat is sheared by the corrugations of the first break roll it splits open, releasing endosperm and exposing the rest to be scraped off the bran in successive breaks. Generally four sets of break rolls are used; after each break the mixture of free bran, free endosperm, free germ and endosperm still adhering to bran is sifted. Middlings go to the reduction rolls, and as many as 12–14 reduction rolls are used in most mills.

▶ ***Components of a wheat mill***

Component	Description and function
Break roll	Twin pairs of corrugated steel rolls; one roll of each pair revolves faster than the other, the differential speed being about 2.5 : 1. Cracks the bran and opens the kernel, producing middlings
Break sifting system — plan sifter	A scalping system: the top sieve removes large bran pieces with adhering endosperm, the next finer series removes bran and germ, a still finer layer removes the endosperm middlings, and the bottom carries the rough flour
Break sifting system — purifier	Removes finer bran particles from the middlings before they pass to the reduction rolls
Reduction roll	Smooth-surfaced rolls that grind free middlings to flour size by gradual reduction; high pressure must be avoided or the starch is ruptured
Reduction sifting system	The same plan-sifter arrangement; after each reduction the finished flour is sifted through a 120-mesh silk and the oversize returns to the reduction rolls
Scratch system	An extension of the break system used to maintain release of endosperm from bran; a standby only, bypassed when the break rolls are releasing well

12.2 *Corn Dry Milling — the Tempering–Degerming Method*

Corn dry milling divides into the traditional ***non-degerming*** system, in which whole corn is stone-ground into a high-fibre, high-protein meal, and the modern ***degerming*** system. Yields from the degerming route are about 70 % endosperm products and 30 % hominy feed.

▶ ***Objectives of the TD method***

(a) To remove essentially all germ and hull so that the endosperm contains as little fat and fibre as possible; (b) to recover the maximum amount of endosperm as ***large clean grits without dark specks***; and (c) to recover the maximum amount of germ as large, pure particles — the germ then going for oil extraction, with de-oiled germ and hull sold as hominy feed.

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▶ ***Basic operations***

(1) Cleaning — magnetic separators for iron, dry cleaners of sieves and aspirators, and sometimes a wet cleaner with a washer-destoner and a mechanical dewatering whizzer. (2) Hydrothermal treatment — cold or hot water or steam added in one to three stages with tempering rests after each; tempering temperatures from room temperature to about 50 °C. Optimum moisture for degerming in the Beall degermer is **21–25 %**. (3) Degerming in the ***Beall degermer*** — a rotating cast-iron conical roller on a horizontal shaft inside a conical cage, part perforated screen and part plate with conical projections; the feed end of the cone has spiral corrugations to move corn forward and the large end has reversed corrugations to retard flow. Germ, husk, fines and some grits pass the screens while tail stock rich in grits escapes at the large end, a hinged weighted gate controlling the pressure. (4) Drying and cooling — degermer stock dried from 15–18 % moisture in rotary steam-tube dryers, stock heated to about 50 °C, then cooled. (5) Fractionation by multistep milling through roller mills, sifters, aspirators, gravity table separators and purifiers. (6) Further drying as required. (7) Blending and packaging.

12.3 *Pulse Milling*

Pulse milling removes the fibrous seed coat and splits the cotyledons. This reduces fibre and improves appearance, texture, quality, palatability and digestibility, and shortens cooking time. The seed is **7–15 % hull, about 85 % cotyledons and 1–4 % embryo**, and the two cotyledons are attached only at the axis, so the seed is unusually vulnerable to breakage — which is why dehulling yield is the central problem.

Dehulling efficiency depends on grain type and properties, bond strength between kernel and hull, hull proportion, size and uniformity, moisture content and the moisture difference between hull and kernel, extent of hydrothermal treatment, and ease of classifying kernels from hulls. The ***wet method*** is cleaning and grading, pitting, soaking, sun-drying, dehulling and splitting, grading; the ***dry method*** substitutes oil application and conditioning for soaking and is quicker with less loss. Dal mill equipment: cleaner-grader, pitting machine, oil or water applicator, dryer, dehuller (emery roller or under-runner disc sheller), aspirator, splitting rollers, polisher and grader-bagger.

Fig. 2.6 — Milling flowcharts

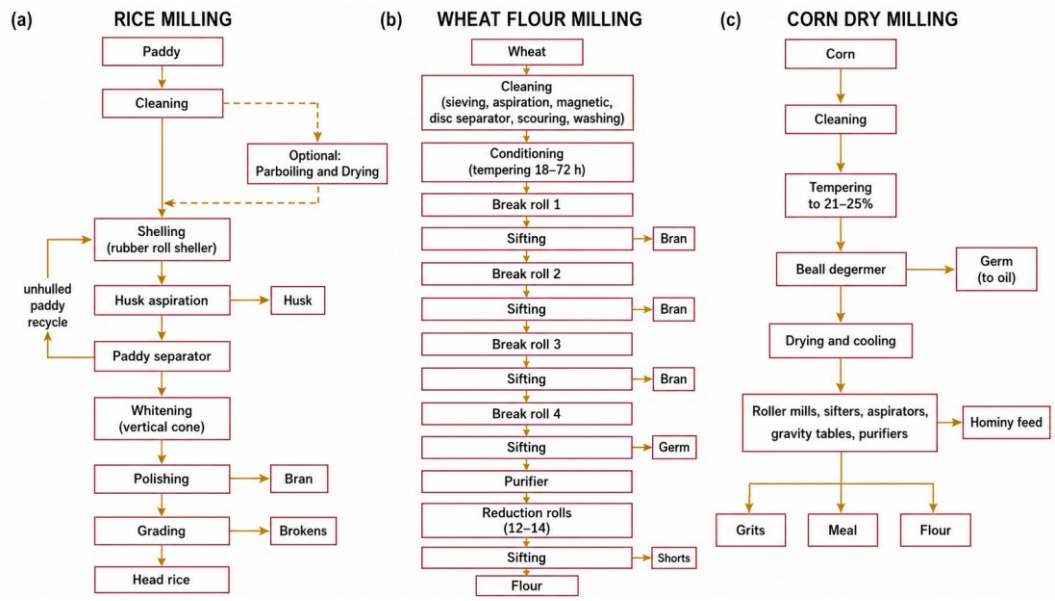


Fig. 2.6 Flow charts for (a) rice milling, (b) wheat flour milling, (c) corn tempering–degerming milling.

PREVIOUS YEAR QUESTIONS

- *Describe the various steps in modern wheat flour milling. · Explain the components of a wheat mill.*

  [IFoS 2025 · P2/8(b) · 15M · IFoS 2024 · P2/5(e) · 8M]

- *What are the objectives of the Tempering-Degerming (TD) method in corn dry milling? Describe the basic operations involved in the TD method.*

  [IFoS 2025 · P2/8(a) · 15M]

- *Outline the process involved in the milling of pulses using a flowchart. What are the equipments required in setting up of such a mill?*

  [OPSC-CSE 2024-25 · Paper-II, Q.10 · 15M]

13 OIL EXTRACTION, GINNING AND JUICE EXTRACTION

13.1 Mechanical Expression — the Oil Expeller

Oil is recovered from oilseeds by ***mechanical expression*** or by ***solvent extraction***, and often by both in sequence. Expression recovers 60–70 % of the oil in the meal by a screw press, leaving 4–5 % residual oil in the cake, whereas solvent extraction can bring the residue down to about 1 %.

Press	*Construction and action*	*Pressure attained*
Hydraulic press	Cooked flakes loaded and pressure raised gradually until oil flows, then drained 30–45 min; batch, capacity to about 7 t of cooked flakes/day	113–141 kg/cm²
Screw press / expeller	Horizontal shaft with an integral screw turning in a barrel of case-hardened bars or rings that let the oil drain. Volume displacement is far greater at the feed end than at discharge, so pressure rises along the barrel; a movable choke at the discharge sets the pressure by changing the annular gap	1550–1860 kg/cm²
Ram press	A pivoted lever drives a piston in a cage of spaced metal bars; the entry port opens at one end of the stroke to admit seed and closes as the piston advances	Manual, low pressure

▶ ***Sequence of operations in mechanical expression***

(1) ***Cleaning*** to remove stones, metal and dust. (2) ***Dehulling*** to reduce fibre and raise the oil and protein content of the kernel. (3) ***Flaking*** through roller mills to rupture the cells and increase oil recovery. (4) ***Cooking*** of the flakes — in cottonseed this precipitates the phosphatides, detoxifies the gossypol, coagulates the protein and lowers moisture from about 12 % to 5 %. (5) ***Pressing*** in the expeller and filtration of the crude oil. (6) Size reduction and bagging of the de-oiled cake. (7) ***Refining*** of the crude oil for edible grade.

13.2 Solvent Extraction

Solvent extraction applies the principle of ***differential solubility***: the oil dissolves in a non-polar solvent, usually food-grade hexane, while the meal does not, and the resulting solution — the ***miscella*** — is then separated from the solvent by distillation. Because the driving force is diffusion of solvent into the seed and of oil out of it, the seed is first flaked so that the diffusion path is short.

Taking soybean as the standard case: the beans are cleaned and milled; the meal is cooked under mild conditions; the heat-treated meal is converted to flakes on smooth flaking rolls; extraction is carried out batchwise or continuously, ***countercurrent solvent flow being preferred*** in continuous plants; the oil is separated from the

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miscella by distillation and stripping under vacuum; the extracted meal is desolventised by heating with live steam in a desolventiser; solvent from the distillation and stripping columns and from the desolventiser is condensed, recovered and returned to the solvent storage tank; and the oil goes to storage after cooling. The de-oiled cake retains about 1 % oil.

Basis	*Mechanical expression*	*Solvent extraction*
Principle	Applied pressure ruptures cells and squeezes oil out	Oil dissolves in a solvent and is recovered by distillation
Oil recovery	60–70 %; 4–5 % oil left in cake	Up to 99 %; about 1 % oil left in cake
Suitable feed	High-oil seeds — groundnut, mustard, coconut, sesame	Low-oil seeds — soybean, rice bran; also pre-pressed cake
Cake quality	Cake retains oil, better as cattle feed	De-oiled cake, higher protein per unit mass
Capital and safety	Simple, safe, small scale viable	High capital; hexane is flammable, needs solvent recovery and fire safeguards
Oil quality	Crude oil carries more fines and needs filtration	Cleaner miscella-derived oil, but solvent traces must be stripped

▶ ***Refining of crude oil***

(i) ***De-gumming*** — 2–3 % water mixed with the oil hydrates the phosphatides, which are then removed by settling, filtering or centrifuging. (ii) ***Neutralisation*** — free fatty acids neutralised with caustic soda or soda ash, forming soaps known as alkalifoots, removed by centrifuges and filters and washed out with water. (iii) ***Bleaching*** — decolourising with activated carbon or activated clay at high temperature. (iv) ***Deodorising*** — sparging superheated steam through the oil under vacuum to strip volatile odour compounds. (v) ***Winterization*** — holding the oil at low temperature so that higher-melting glycerides solidify and can be filtered out, giving a salad oil that stays clear when chilled.

Fig. 2.7 – Solvent extraction process flow chart

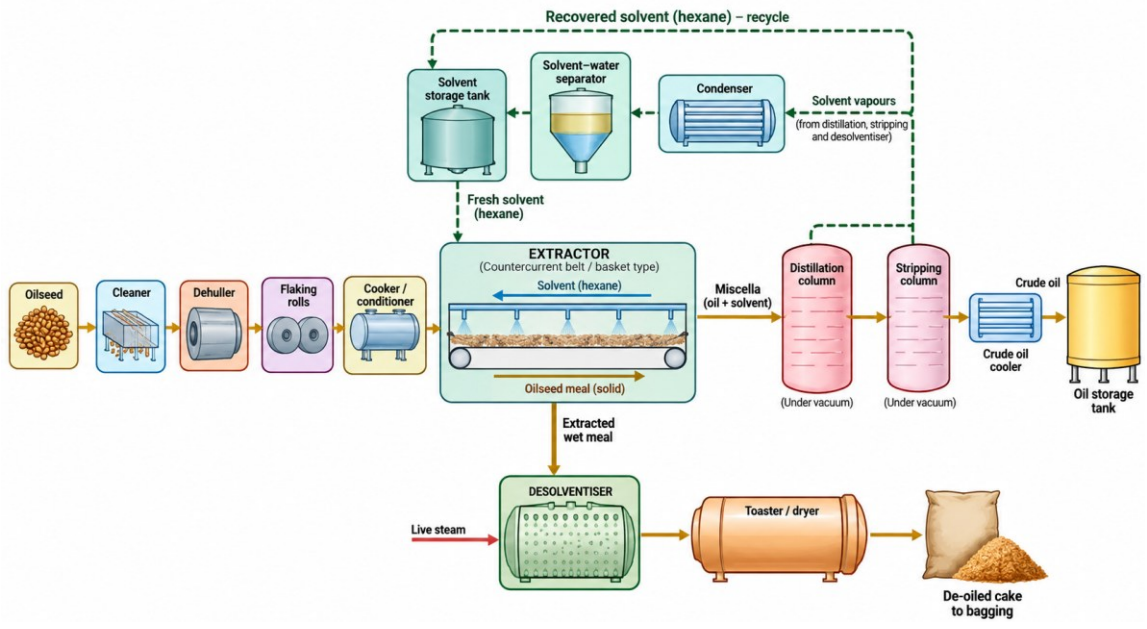


Fig. 2.7 Continuous countercurrent solvent extraction with solvent recovery.

13.3 *Ginning of Cotton, and Juice Extraction*

Ginning : *the process of separating cotton seed from the lint. The lint is pressed into bales; the seed may be crushed to yield oil, the residue being used as cattle fodder, while the linters are a source of highly pure cellulose for the synthetic textile industry.*

Gin	Components	Working
Roller gin	(a) roller, (b) fixed knife, (c) moving knife	The leather-covered roller revolves; lint adheres to its rough surface and is drawn under the fixed knife, set close enough that seed cannot pass. The moving knife oscillates against the roller, agitating the seed and beating it off the lint. Lint and seed discharge on opposite sides. Used widely in India
Saw gin	1 feeder, 2 picker roller, 3 steel ribs, 4 saw, 5 seed pan, 6 collecting brushes	Cotton falls from the feeder to the picker rollers, which rub it against a screen so that the seed is partially extracted and cleaned, and pass it to the saw teeth. The saw carries the material through a restricted opening between steel ribs; the ribs are spaced so that lint passes but seed cannot, so seed drops into the seed pan while the lint is carried on and stripped from the saw by rotating brushes on the far side

Juice extraction follows the same principles. ***Sugarcane*** juice is expressed by crushing rolls — a bullock-driven three-roller crusher has a feed roller and movable extracting rollers of 180–230 mm diameter, grooved for grip, extracting at least about 60 % of the juice. For ***fruits and vegetables*** a screw-type extractor or a fruit pulper with brushes and stainless-steel sieves is used, the juice then screened, deaerated, pasteurised and bottled or concentrated. [Editor: composed from scattered references — no supplied text treats juice extraction as a topic.]

PREVIOUS YEAR QUESTIONS

- *(i) Explain the processing and ginning of cotton. (ii) Briefly explain about mechanical oil expeller for production of edible oils.* [IFoS 2021 · P2/7(c) · 10M]
- *How are the principles of solvent extraction applied in the extraction of oils from oilseeds and what are the diverse applications of solvent-extracted oils in various industries? · What do you understand by solvent extraction? Explain its various components and processes. Sketch out the process flow chart. · Write brief notes on: Solvent extraction; Juice extraction*
  [OPSC·CSE 2023-24 · Q.16(a) · 20M · OPSC·CSE 2020-21 · Q.5(c)(ii) · 10M · OPSC·CSE 2016-17 · Q.8(c)]
- *Outline the process involved in the milling of pulses using a flowchart. What are the equipments required in setting up of such a mill?* [OPSC·CSE 2024-25 · Paper-II, Q.10 · 15M]

MODEL Q For the OPSC 20-marker, applications are half the question — refined edible oils and vanaspati, soap and detergents, paints, varnishes and plasticizers, lubricants and biodiesel, de-oiled cake as protein feed, lecithin from de-gumming, and rice bran wax. Do not stop at the flow chart.***

14 FILTRATION AND MEMBRANE SEPARATION

Filtration : *the separation of solid particles suspended in a liquid or gas by means of a porous medium which retains the solids and allows the fluid to pass. The suspension is the* ***slurry****, the porous medium the* ***filter medium****, the accumulated solids the* ***filter cake*** *and the clear liquid the* ***filtrate****. Where the solid proportion is small the operation is called clarification. A thin preliminary layer applied to the cloth to give sufficiently fine pores is a* ***pre-coat****.*

Type	Flow of feed and filtrate	Solids handled	Typical duty

Cake filter	Feed flows perpendicular to the medium; filtrate passes through and a cake builds on the upstream face until the press is dismantled	Relatively LARGE amounts, separated as a cake of crystals	Plate-and-frame press, rotary vacuum filter — slurries of high solid content
Clarifying filter	Feed flows through the medium; solids are trapped inside the medium or on its external surfaces. The pores are much LARGER in diameter than the particles removed, which distinguishes it from a screen	SMALL amounts, to give a sparkling clear liquid	Beverages, wine, edible oil polishing
Cross-flow filter	Feed flows under pressure at fairly high velocity ACROSS the medium; the high-speed liquid sweeps the surface so the deposited layer never builds up. Part of the liquid passes through as clear permeate, leaving a more concentrated retentate	Moderate; concentrates rather than de-waters	Ceramic, metal or polymer membranes — microfiltration, ultrafiltration, nanofiltration, reverse osmosis

MODEL Q The 2020 question ends by asking which filter suits a slurry of high solid content. Answer: the cake filter — cake filtration is by definition the case where the suspension carries a large proportion of solids, so a coherent cake forms and can be detached, whereas a clarifying filter would blind almost immediately and a cross-flow unit is designed to concentrate, not to de-water.***

▶ ***Rate of filtration***

$$dV/dt = A\,\Delta P \div \{ \mu\, r\, [\, w\,(V/A) + L\,] \}$$

V = volume of filtrate ; A = filter area ; ΔP = pressure drop ; μ = filtrate viscosity ; r = specific cake resistance ; w = solids per unit volume of liquid ; L = equivalent thickness of medium and pre-coat

Filtration rate rises with pressure drop and area and falls with viscosity, cake resistance and cake thickness. Two regimes follow. In ***constant-rate filtration*** the pressure must be raised as the cake grows. In ***constant-pressure filtration***, which describes most of a practical cycle once the initial cake is laid, integration gives

$$t \div (V/A) = [\, \mu\, r\, w / (2\,\Delta P)\,]\,(V/A) + \mu\, r\, L / \Delta P$$

A plot of t/(V/A) against V/A is a straight line; the slope gives r and the intercept gives L

▶ ***Membrane separation and nanofiltration***

Membrane processes remove water ***without a phase change***, which is their advantage over evaporation, where the latent heat of vaporisation dominates the operating cost. The driving force is hydrostatic pressure for microfiltration, ultrafiltration, nanofiltration and reverse osmosis, and a concentration difference for dialysis.

Process	*Retains*	*Operating pressure*
Microfiltration	Suspended particulates, bacteria	1–2 bar (15–30 psig)
Ultrafiltration	Macromolecules — proteins, polysaccharides	1–7 bar (15–100 psig)
Nanofiltration	Divalent ions, larger organic molecules	Well below RO — the chief attraction
Reverse osmosis	Salts and sugars; passes water only	20–50 bar (300–750 psig)

▶ ***Salient points of nanofiltration***

A ***cross-flow membrane process lying between ultrafiltration and reverse osmosis***, with nominal pore size ***below 1 nanometre*** — hence the name. Membranes are rated by ***molecular weight cut-off rather than pore size***. Transmembrane pressure is considerably lower than for RO, ***significantly reducing operating cost***. It rejects divalent ions while passing much of the monovalent salt, making it the process of

choice for ***softening*** and for removing disinfection by-product precursors from low-TDS water. Membranes remain subject to ***scaling and fouling***, so antiscalants are commonly required. Food uses: partial demineralisation of whey, concentration of sugar and juice streams, recovery of process water.

Fig. 2.8 — Types of filter and the membrane spectrum

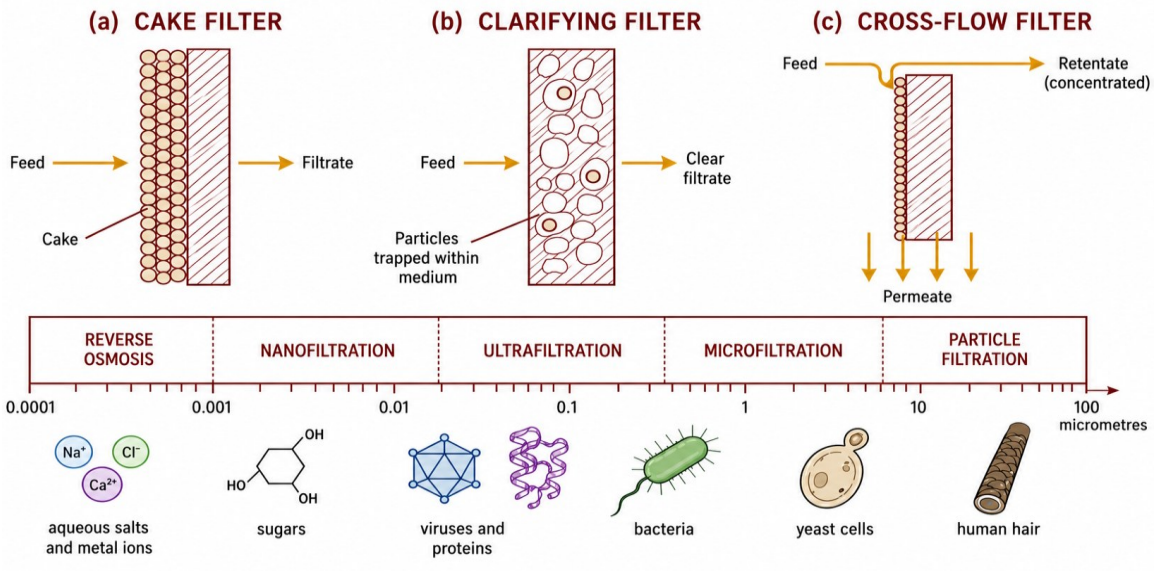


Fig. 2.8 (a) Cake, (b) clarifying and (c) cross-flow filters, and the membrane separation spectrum.

PREVIOUS YEAR QUESTIONS

- *Define filtration. Briefly discuss along with sketch (showing the flow of the feed and the permeate) the cake filter, clarifying filter and the cross-flow filter. If in a slurry there is high solid content, which type of filter will you recommend? Write with proper reasoning.*

  [IFoS 2020 · P2/7(b) · 15M (first part)]

- *Write the salient points of nano-filtration.* [UK·PSC ACF/RFO (Mains) 2025 · Q.7(i)(b) · 5M]

Source: Crop Process Engineering, Lessons 25–27, pp. 115, 134–147; Singh & Heldman, Ch. 11, pp. 623–625 and §13.1.

15 FORMULA SHEET

Quantity	*Formula*	*Notes and units*
General law of comminution	$dE/dx = -C/x^n$	n = 2 Rittinger, 1 Kick, 1.5 Bond
Rittinger's law	$E = C_R (1/x_p - 1/x_f)$	C_R in J·m/kg; fine grinding
Kick's law	$E = C_K \ln (x_f/x_p)$	C_K in J/kg; coarse crushing
Bond's law	$E = 0.3162\, W_i (1/\sqrt{D_p} - 1/\sqrt{D_f})$	D in mm, E in kWh/tonne, W_i = work index
Fineness modulus	FM = (Σ cumulative % retained)/100	IS multipliers 7,6,5,4,3,2,1,0
Average particle size	$D_p = 0.135\ (1.366)^{FM}$	mm
Screen overall balance	F = O + U	kg/h
Screen component balance	$F\cdot m_F = O\cdot m_O + U\cdot m_U \Rightarrow O/F = (m_F - m_U)/(m_O - m_U)$	m = mass fraction of oversize
Screen effectiveness	$E_O = O\cdot m_O/(F\cdot m_F)$; $E_U = U(1 - m_U)/[F(1 - m_F)]$; $E = E_O \times E_U$	dimensionless

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Effectiveness, fractions only	$E = (m_F - m_U)(m_O - m_F)(1 - m_U)m_O \div [(m_O - m_U)^2(1 - m_F)m_F]$	needs only a screen analysis
BIS cleaning efficiency	$\eta = E(F - G)(E - F)(1 - G) \div [F(E - G)^2(1 - F)]$	IS 5817:1980; E, F, G = clean-seed fractions at outlet, feed, foreign-matter outlets
Cyclone force / separation factor	$C = WV^2/(gR)$; $S = C/W = V^2/(gR)$	S independent of particle weight
Filtration rate	$dV/dt = A\Delta P \div \{\mu r[w(V/A) + L]\}$	fundamental filtration equation
Constant-pressure filtration	$t/(V/A) = [\mu rw/(2\Delta P)](V/A) + \mu rL/\Delta P$	straight line; slope gives r, intercept gives L
Break roll differential	≈ 2.5 : 1	fast roll to slow roll
Whitening cone brakes	$n = (D/100) - 2$	D = cone diameter, mm; peripheral speed ≈ 13 m/s

SUMMARY

- ***Size reduction*** : Five forces — compression, impact, attrition, cutting, shearing. Grinding is the least efficient unit operation: only ~1 % of input energy creates new surface. Breaking follows existing cracks, so small particles are disproportionately hard to break.
- ***Crushing laws*** : All three integrate $dE/dx = -C/x^n$. Rittinger (n = 2) suits fine grinding and overestimates; Kick (n = 1) suits coarse crushing and underestimates; Bond (n = 1.5) lies between and uses the work index. Every numerical is: find the constant from condition 1, apply it to condition 2.
- ***Machines*** : Jaw and gyratory crushers for coarse hard solids; crushing rolls for flaking and cane; hammer mill impact with fineness set by the screen; roller mill selective and uniform, the basis of flour milling; disc, ball and rod mills for fine grinding. Closed circuit beats open on energy and uniformity.
- ***Screening & separation*** : Fineness modulus indexes coarseness and converts to average size by $D_p = 0.135(1.366)^{FM}$, but must be quoted with the uniformity index. Screen effectiveness derives from two mass balances and reduces to the three mass fractions alone; capacity and effectiveness are opposing. Separation rests on eight bases — width/thickness, length, aerodynamic, surface form, specific gravity and friction, ferromagnetic, electrical, colour. The air-screen cleaner combines aspiration and screening in two air blasts and four screens; the cyclone separation factor $S = V^2/gR$ is independent of particle weight.
- ***Milling*** : Rice: the rubber roll sheller beats the Engelberg huller on breakage, head-rice yield and bran quality; the vertical cone whitener is abrasive at the top and frictional at the bottom. Wheat: seven steps, conditioning capped at 47 °C, corrugated break rolls at 2.5:1 and smooth reduction rolls. Corn TD: temper to 21–25 %, Beall degermer, 70:30 endosperm to hominy feed.
- ***Oil and filtration*** : Expression recovers 60–70 % with 4–5 % left in cake; solvent extraction leaves about 1 %. Refining is de-gum, neutralise, bleach, deodorise, winterize. Filters are cake, clarifying or cross-flow — high solid content calls for a cake filter. Nanofiltration sits between UF and RO, pore size below 1 nm, rated by molecular weight cut-off.

LAST-NIGHT REVISION

▶ ***Numbers that must be on your fingertips***

Item	Value	Item	Value
Energy creating new surface	≈ 1 % of input	Break roll differential / reduction rolls	2.5 : 1 / 12–14

Rittinger / Kick / Bond index n	2 / 1 / 1.5	Flour mill finished-flour sieve	120 mesh silk
Bond working constant	0.3162 (D in mm, E in kWh/t)	Wheat conditioning limit / tempering	47 °C / 18–72 h
Bond work index definition	80 % passing 100 µm from infinite size	Wheat composition / flour yield	85-12-3 % / 70 % flour
Jaw crusher — angle / strokes	20–30° / 250–400 per min	Beall degermer tempering moisture	21–25 %
Hammer mill tip speed	up to 100 m/s	Corn TD product split	70 % endosperm, 30 % hominy feed
IS sieve series / FM sample	100–15 mesh / 250 g, RoTap 5 min	Whitening cone gap / clearance / speed	10 mm / 2–3 mm / 13 m/s
Air-screen cleaner configuration	2 air blasts, 4 screens	Pulse seed composition	7–15 % hull, 85 % cotyledon
Cyclone effective turns / cone height	2 / H = 2–3 d	Residual oil — expression / solvent	4–5 % / ~1 %
Hydraulic / screw press pressure	113–141 / 1550–1860 kg/cm²	MF / UF / RO pressure	1–2 / 1–7 / 20–50 bar

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CHAPTER

3

DRYING, DEHYDRATION, EVAPORATION & FREEZING

Dryers & drying curves · Psychrometry · Evaporation & concentration · Freezing & refrigeration

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 3 (Agricultural Process Engineering). Chapter 3: drying and dehydration (dryers, drying curves); psychrometry; evaporation and concentration; freezing and refrigeration. Related unit operations bundled in past questions — size reduction, separation, filtration, packaging, decortication and dhal milling, blanching — are answered here and treated in depth in their own chapters.

Chapter Outline

1. **Scope & the Post-Harvest Processing Context**
2. **Psychrometry**
3. **Drying Theory**
4. **Dryers (Equipment)**
5. **Evaporation & Concentration**
6. **Freezing & Refrigeration**
7. **Related Unit Operations (bundled PYQ sub-parts)**
8. **Formula Sheet · Summary · Last-Night Revision**

1 SCOPE & THE POST-HARVEST PROCESSING CONTEXT

1.1 Post-harvest technology and its scope

Post-harvest technology (PHT) is the inter-disciplinary science and technique applied to agricultural produce ***after harvest*** for its protection, conservation, processing, packaging, distribution, marketing and utilization. It is the bridge between production and consumption: post-harvest losses of foodgrains are commonly cited at ~5–10% and are far higher for perishables.

Its scope spans a chain of ***unit operations*** — cleaning, grading, size reduction, densification, drying/dehydration, concentration/evaporation, filtration, freezing and packaging — plus storage, milling, material handling and by-product utilization.

Unit operation : *a single, discrete physical step common to many processes (drying, evaporation, size reduction) in which a specific change is brought about and which can be analysed by transport-phenomena (heat and mass transfer) laws.*

1.2 Engineering properties of agricultural produce

PREVIOUS YEAR QUESTIONS

- *Write the physical and thermal properties of food and their importance in food processing.* [IFoS 2017 · P2/7(b) · part · 10M]

Engineering properties are grouped as:

- ***Physical*** : size, shape, volume, surface area, ***bulk density, true density***, porosity, sphericity, 1000-grain weight, angle of repose, coefficient of friction — govern design of cleaners, graders, conveyors, storage bins and sizing/screening equipment.
- ***Thermal*** : specific heat, thermal conductivity, thermal diffusivity, enthalpy, surface heat-transfer coefficient : essential to design and analyse drying, heating, cooling, freezing and refrigeration systems and to compute heat loads and process times.
- ***Aero / hydrodynamic*** : terminal velocity, drag coefficient — pneumatic separation, fluidised-bed drying.
- ***Electrical & optical*** : dielectric constant (dielectric/microwave heating, moisture meters); colour/reflectance (grading).

Specific heat (c_p) — *heat required to raise unit mass by one degree, $Q = m \cdot c_p \cdot (T_2 - T_1)$. For high-moisture foods, $c_p \approx 0.837 + 3.349 \cdot X_w$ kJ/kg·°C (X_w = water mass fraction; Siebel's model).*

1.3 Water activity — the master preservation variable

PREVIOUS YEAR QUESTIONS

- *Define water activity.* [IFoS 2017 · P2/7(c) · part · 10M]

Water activity (a_w) : *the ratio of the partial vapour pressure of water in the food (p) to the saturation vapour pressure of pure water (p_o) at the same temperature: $a_w = p/p_o$ = ERH/100, where ERH is the equilibrium relative humidity (%). Pure water a_w = 1; foods lie between 0 and 1.*

Water activity — not total moisture — controls microbial growth and deterioration rate. Most ***bacteria need $a_w \approx 0.90$–1.00***, most ***yeasts and moulds down to ≈ 0.65***; below ~0.60 no microbial growth occurs. Drying lowers a_w below these thresholds and slows enzymatic and Maillard reactions. Lipid oxidation, however, shows a minimum near a_w ≈ 0.3 and rises again at very low a_w.

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1.4 *Importance of dehydration in food processing*

PREVIOUS YEAR QUESTIONS

- *What is the importance of dehydration in processing of food?* [IFoS 2019 · P2/5(b) · part · 8M]
- *Write brief notes on: Food dehydration.* [OPSC-CSE 2016-17 · P2/Q.8(c) · 20M]

Dehydration removes moisture to very low levels, arresting microbial deterioration and slowing spoilage reactions. Its importance: (i) long shelf-life and safe storage; (ii) major reduction in weight and volume → cheaper packaging, transport and storage; (iii) year-round and off-season availability; (iv) convenience / ready-to-use products (instant foods, milk and egg powder); (v) value addition and by-product utilisation; (vi) early harvest and better harvest-season planning, cutting field losses.

Drying vs dehydration : *both remove moisture, but* ***drying*** *is the general removal of water (often solar/heated air to a 'safe storage' moisture, e.g. grains to ~12–14%), whereas* ***dehydration*** *implies controlled artificial drying to very low final moisture (typically < 5%) under regulated temperature, humidity and airflow, usually for foods.*

1.5 *Moisture content — wet basis and dry basis*

$$M_{wb} = (\text{mass of water}) / (\text{total wet mass}) \times 100\ \%$$

$$M_{db} = (\text{mass of water}) / (\text{mass of bone-dry solids}) \times 100\ \%$$

$$M_{db} = M_{wb} / (100 - M_{wb}) \times 100 \qquad M_{wb} = M_{db} / (100 + M_{db}) \times 100$$

Dry-basis value always exceeds wet-basis. Wet basis is used commercially; dry basis in drying kinetics (dry-matter denominator stays constant).

1.6 *Overview of food preservation methods*

Preservation works by removing/immobilising water or arresting microbial and enzymatic action: drying/dehydration (lower a_w), concentration/evaporation (partial water removal), refrigeration & freezing (low temperature), thermal processing (blanching, pasteurisation, sterilisation), chemical (salt, sugar, acids, preservatives), irradiation, and modified/controlled-atmosphere storage and packaging. This chapter treats the four physical, engineering-heavy operations — drying, dehydration, evaporation and freezing.

2 PSYCHROMETRY

2.1 *Psychrometry and the properties of moist air*

Psychrometry : *the study of the thermodynamic properties of moist air (air–water-vapour mixtures) and of processes in which temperature and moisture content change. It underpins the analysis of every air-drying, humidification, cooling and air-conditioning operation.*

PREVIOUS YEAR QUESTIONS

- (i) Specific Humidity (ii) Dew Point (DP) Temperature (iii) Wet Bulb (WB) Temperature (iv) Decortication of Oilseeds. [Parts i–iii here; decortication in Section 7.]
  [IFoS 2025 · P2/5(a) · short notes · 8M]

- ***Dry-bulb temperature (DBT)*** : the true air temperature read by an ordinary thermometer shielded from moisture and radiation.
- ***Specific / absolute humidity (H)*** : mass of water vapour per unit mass of dry air (kg/kg dry air); $H = 0.622 \cdot p_w / (P - p_w)$.

- ***Relative humidity (RH, φ)*** : ratio of actual vapour pressure to saturation vapour pressure at the same DBT, as % ; RH = p_w /p_ws × 100.
- ***Percentage humidity*** : ratio of actual absolute humidity to absolute humidity at saturation at the same DBT.
- ***Dew-point temperature (DPT)*** : temperature to which moist air must be cooled at constant pressure and humidity to become just saturated; further cooling condenses water. At the dew point RH = 100%; it is a direct index of the air's actual moisture content.
- ***Wet-bulb temperature (WBT)*** : steady temperature of a wet-wicked thermometer over which air moves; evaporative cooling balances sensible heat gain. WBT ≤ DBT (equal only at saturation); the DBT − WBT depression measures how dry the air is.
- ***Humid heat (c_s)*** : c_s = 1.005 + 1.88·H kJ/kg·°C (≈ 0.24 + 0.45H kcal).
- ***Humid volume*** : volume of 1 kg dry air plus its vapour at the given T and P.
- ***Enthalpy (h)*** : h = 1.005·t + H(2501 + 1.88·t) kJ/kg dry air (datum 0 °C).

2.2 *The psychrometric chart*

📋 PREVIOUS YEAR QUESTIONS

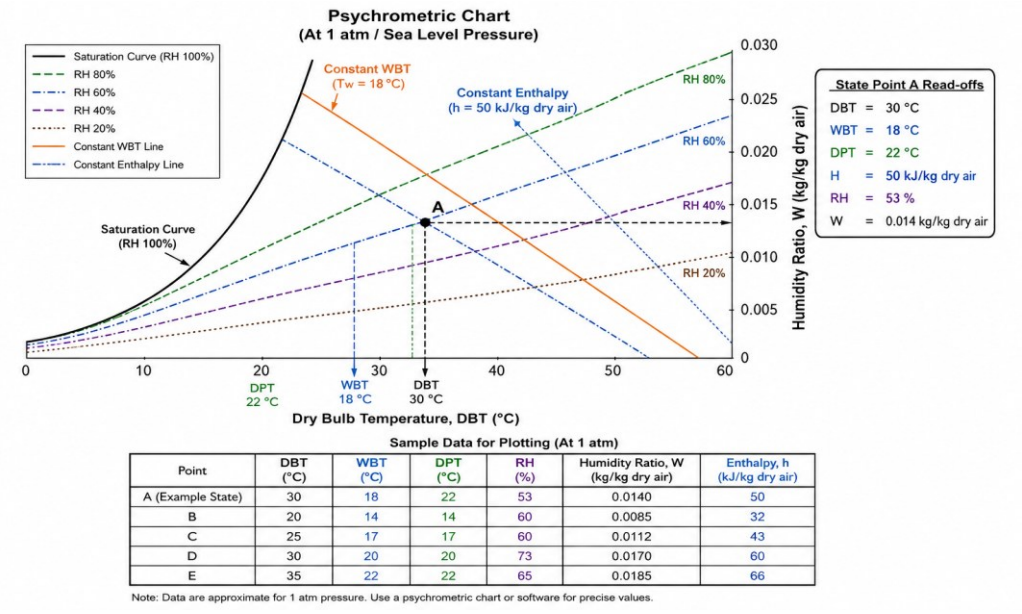
What are the different parameters which can be determined using psychrometric chart? Give four common uses of psychrometric chart in analysis of the drying process.

[IFoS 2023 · P2/5(b) · 8M]

The psychrometric chart plots the properties of moist air with ***DBT on the x-axis and humidity ratio on the y-axis***, with curved RH lines and families of WBT/enthalpy, humid-volume and dew-point lines.

MODEL Q Parameters readable from the chart (any two fix the state, the rest follow): (1) dry-bulb temperature, (2) wet-bulb temperature, (3) dew-point temperature, (4) relative humidity, (5) humidity ratio (specific humidity), (6) humid/specific volume, (7) enthalpy (and vapour pressure).***

Psychrometric chart (schematic)



Sample Data for Plotting (At 1 atm)

Point	DBT (°C)	WBT (°C)	DPT (°C)	RH (%)	Humidity Ratio, W (kg/kg dry air)	Enthalpy, h (kJ/kg dry air)
A (Example State)	30	18	22	53	0.0140	50
B	20	14	14	60	0.0085	32
C	25	17	17	60	0.0112	43
D	30	20	20	73	0.0170	60
E	35	22	22	65	0.0185	66

Note: Data are approximate for 1 atm pressure. Use a psychrometric chart or software for precise values.

Fig. 3.1 Schematic psychrometric chart with a state point

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2.3 Four uses of the psychrometric chart in drying analysis

- ***Sensible heating/cooling*** : heating drying air at constant humidity ratio: DBT, enthalpy and humid volume rise and RH falls (raising drying capacity); DPT and vapour pressure unchanged — a horizontal move.
- ***Heating with humidifying*** : direct fuel-fired dryers add heat and some combustion water vapour: enthalpy, humidity ratio, vapour pressure, DBT, WBT, DPT and humid volume all rise.
- ***Cooling with dehumidifying*** : air cooled below its dew point (cold storage): condensation removes moisture, so RH, DBT, WBT, enthalpy, humidity ratio and humid volume all fall.
- ***Adiabatic drying*** : columnar dryer: sensible heat of hot air converts to latent heat as it picks up grain moisture, at constant enthalpy (constant WBT). DBT falls, humidity ratio and RH rise along a constant-WBT line toward saturation.

Process	*H (humidity ratio)*	*RH*	*DBT*	*Enthalpy*	*Path on chart*
Sensible heating	constant	falls	rises	rises	horizontal → right
Heating + humidifying	rises	varies	rises	rises	up & right
Cooling + dehumidifying	falls	→ 100% then falls	falls	falls	down & left
Adiabatic drying	rises	rises	falls	≈ constant	along constant-WBT

2.4 Grain drying represented psychrometrically

PREVIOUS YEAR QUESTIONS

Illustrate the process of grain drying psychrometrically.

[OPSC·CSE 2022-23 · P2/Q.5(a) · 5M]

In a heated-air grain dryer the air undergoes two steps: (a) ambient air is sensibly heated (horizontal move right — RH drops sharply, giving a large moisture deficit), then (b) the hot air passes through the grain bed where adiabatic drying occurs — the air moves up a constant-WBT/enthalpy line, its DBT falling while humidity ratio and RH rise as it absorbs grain moisture, until it leaves near saturation. The horizontal distance represents sensible-heat input; the vertical climb represents moisture picked up per kg dry air.

Grain drying on the psychrometric chart

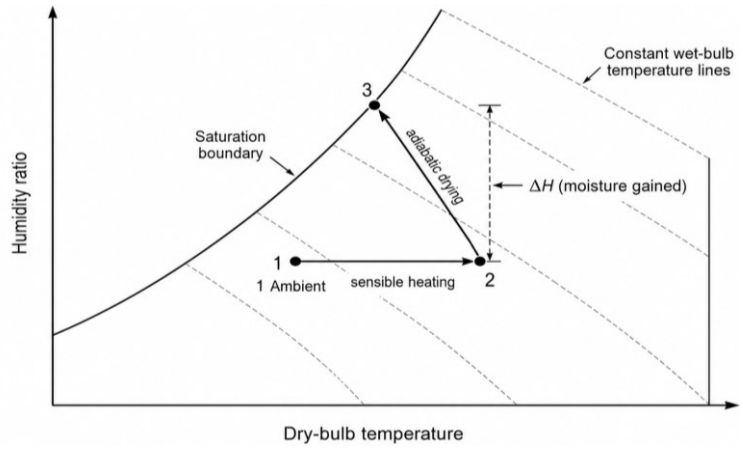


Fig. 3.2 Grain-drying path: sensible heating then adiabatic drying

3 DRYING THEORY

3.1 Principle and mechanism of drying

PREVIOUS YEAR QUESTIONS

Draw a typical drying curve and explain the mechanism of drying. How moisture content could be quickly removed – explain various measures.

[IFoS 2017 · P2/7(c) · part · 10M]

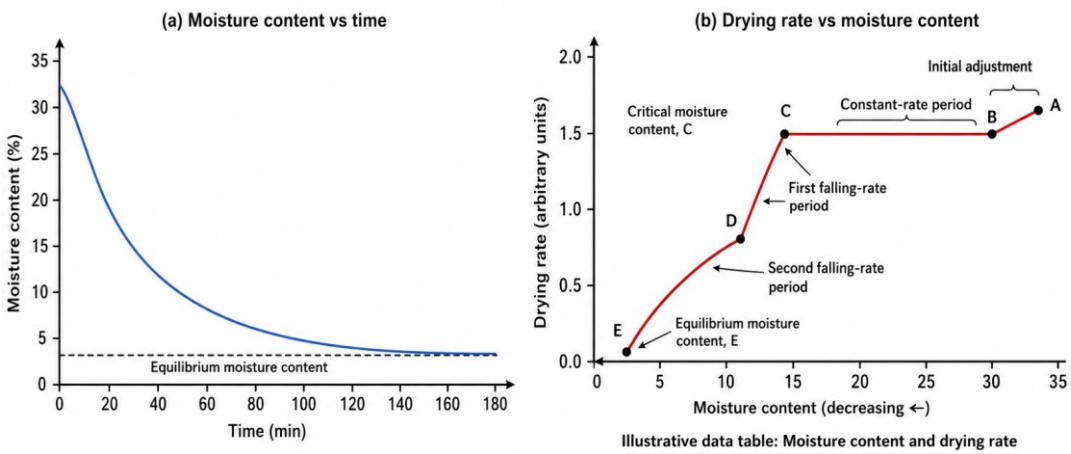
Drying is the simultaneous ***heat-and-mass-transfer*** removal of moisture from a solid by evaporation into a gas stream. Two conditions must coexist: heat to vaporise water, and a vapour-pressure gradient to carry vapour away. Water leaves in two linked steps — (a) internal movement of moisture to the surface (capillary flow, liquid/surface/vapour/thermal diffusion, hydrodynamic flow), and (b) surface evaporation into the air.

Bound vs unbound water : *unbound (free) water exerts full vapour pressure and is easily removed; bound water (held in capillaries, cell walls, or as solution) exerts a lowered vapour pressure and is progressively harder to remove.*

Measures to remove moisture faster — raise the vapour pressure of moisture in the product (sun/solar, conduction, infra-red) and/or lower the vapour pressure of the air (heated-air, desiccated-air, refrigerated-air drying). Practically: increase air temperature and velocity, reduce air RH, reduce layer thickness/bed depth, subdivide or agitate the product, and reduce particle size.

3.2 The drying curve and drying-rate periods

Drying curve of a particulate solid



Illustrative data table: Moisture content and drying rate

Point	MC (%)	Drying rate
A	32	0.2
B	28	1.5
C	18	1.5
D	10	0.8
E	3	0.0

Fig. 3.3 Drying curve: constant-rate and falling-rate periods

Constant-rate period : *surface stays saturated (behaves as a free water surface); internal supply equals surface evaporation, so the drying rate is constant and set by external conditions (air T, RH, velocity, exposed area, mass-transfer coefficient), not the product. Surface temperature ≈ air WBT. Very short for grains.*

Critical moisture content (CMC) : *the moisture content at which the constant-rate period ends and the falling-rate period begins — where the surface can no longer be kept fully wetted. Depends on product, thickness and drying conditions (CMC of wheat ≈ 69–85% db).*

Falling-rate period : *beyond CMC the rate falls as moisture falls; controlled by internal moisture diffusion, not the air. First falling-rate (wetted area shrinks) then second falling-rate (evaporation plane recedes into the solid) — down to equilibrium moisture. Most agricultural products dry almost entirely here.*

PREVIOUS YEAR QUESTIONS

- *Differentiate between: Constant-rate period drying and Falling-rate period drying.*

  [HP·PSC RFO 2021 · Q.7(c) · 10M]

- *Describe the relationship between drying rate and grain moisture content; the role of critical moisture content in drying kinetics.*

  [OPSC·CSE 2024-25 · P2/Q.7 · part · 15M]

Feature	Constant-rate	Falling-rate
Surface condition	fully wet	partly-to-fully dry
Rate controlled by	external air conditions	internal diffusion
Drying rate	constant	decreasing
Surface temperature	≈ wet-bulb temperature	rises toward air DBT
Water removed	mostly unbound	bound
Duration for grains	very short	dominant

3.3 Constant-rate equation

$$N_c = dw/d\theta = h \cdot A \cdot (t - t_w) / \lambda_w = k_y \cdot A \cdot (p_w - p_a)$$

h = air-film heat-transfer coeff.; $(t - t_w)$ = DBT − WBT; λ_w = latent heat; k_y = mass-transfer coeff.; $(p_w - p_a)$ = vapour-pressure driving force; A = area.

3.4 Equilibrium moisture content (EMC) and water activity

Equilibrium moisture content (EMC) : *the moisture a product finally attains in air of a given temperature and RH; at EMC the product's vapour pressure equals the air's and net drying stops. EMC vs RH at constant temperature gives the sigmoidal sorption isotherm, which shows hysteresis (adsorption and desorption differ). EMC sets the lower limit of any drying process and, with a_w, defines safe-storage moisture.*

3.5 Drying principles behind different methods

PREVIOUS YEAR QUESTIONS

- *Write about the basic drying principle(s) involved in the following: (i) Mechanical drying (ii) Chemical drying (iii) Vacuum drying (iv) Freeze drying.*

  [IFoS 2016 · P2/5(e) · 8M]

MODEL Q Mechanical — moisture removed by pressing/centrifuging/expression, no phase change (pre-dewatering). Chemical — a hygroscopic desiccant (silica gel, $CaCl_2$, conc. H_2SO_4, molecular sieves) adsorbs moisture by keeping surrounding vapour pressure low; no heat. Vacuum — reduced pressure lowers water's

boiling point, so moisture evaporates at low temperature (heat-sensitive foods); heat by conduction. Freeze drying — product frozen, then water removed by sublimation of ice under high vacuum below the triple point; highest quality.***

3.6 Thin-layer and deep-bed drying

PREVIOUS YEAR QUESTIONS

- *Differentiate between Thin-layer drying and Deep-bed drying.*

[IFoS 2023 · P2/6(a) · part · 10M]

- *What principles are involved in thin-layer and deep-bed drying of food grain? Discuss the factors which affect these methods of drying.*

[OPSC·CSE 2018-19 / Forest 2019-20 · P2 · 20M]

Thin-layer drying : *grain exposed as a layer thin enough that every kernel is in the same air condition; the whole layer dries uniformly and simultaneously — the basis of thin-layer equations (Lewis, Page, Henderson).*

Deep-bed drying : *bed deeper than ~15 cm; a drying zone / moisture front moves through the bed. Air dries lower layers first, gets humidified, and reaches upper layers cooler and moister, so top layers may re-absorb moisture. Analysed (Hukill) as a stack of thin layers.*

Feature	*Thin-layer*	*Deep-bed*
Bed depth	≤ 15–20 cm	> 15 cm
Air condition through bed	uniform	changes with depth
Drying uniformity	uniform, simultaneous	non-uniform, front moves
Moisture gradient	negligible	large top-to-bottom
Analysis basis	thin-layer equations	Hukill (sum of thin layers)
Use	research, shallow dryers	batch-in-bin, storage dryers

Factors affecting both: air temperature, air velocity/flow rate, air RH, bed depth, initial and desired final moisture, grain type/size, and (deep bed) airflow direction and drying-front development.

3.7 Efficiencies in drying

PREVIOUS YEAR QUESTIONS

- *Explain the following in relation to drying: (i) Fuel efficiency (ii) Thermal efficiency (iii) Drying efficiency.*

[IFoS 2022 · P2/8(c) · 10M]

- ***Fuel (combustion) efficiency*** : fraction of the fuel's calorific value transferred to the drying air = (heat delivered to air)/(calorific value of fuel).
- ***Thermal efficiency (overall)*** : (mass of water evaporated × latent heat)/(mass of fuel × net calorific value) × 100 — heat used to evaporate moisture ÷ heat available.
- ***Drying (effective heat) efficiency*** : $\eta = (t_2 - t_3)/(t_2 - t_wb)$; t_2 = heated-air DBT, t_3 = exhaust DBT, t_wb = WBT of drying air.

Heat utilisation factor (HUF) : *HUF = $(t_2 - t_3)/(t_2 - t_1)$ = drop in DBT of drying air ÷ rise in DBT given to ambient air (t_1 ambient, t_2 heated, t_3 exit). Related to coefficient of performance by HUF = 1 − COP, with COP = $(t_3 - t_1)/(t_2 - t_1)$. [Answers HP·PSC 2021 Q.7(d).]*

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3.8 Worked numerical — moisture content & water removed

◆ **WORKED NUMERICAL — Moisture content & water removed** [OPSC·CSE 2024-25 · P2/Q.7 · part · 15M]

Problem. *A bin holds 2000 kg wet grain containing 500 kg water, to be dried to 14% (w.b.). Find the initial and final moisture contents (w.b.) and the water removed.*

Given:

Initial mass of wet grain = 2000 kg

Initial mass of water = 500 kg

Therefore,

Dry matter = 2000 − 500 = 1500 kg

1. Initial Moisture Content on Wet Basis

Moisture content (w.b.) is given by:

MC (w.b.) = (Mass of water / Total mass of wet material) × 100

Initial MC = (500 / 2000) × 100

Initial MC = 25% (w.b.)

2. Final Moisture Content

The final moisture content is given as:

Final MC = 14% (w.b.)

At 14% moisture content, dry matter constitutes:

100 − 14 = 86% of the final mass.

Let the final mass of grain be M kg.

0.86 M = 1500

M = 1500 / 0.86

M = 1744.19 kg

Therefore, final water content:

Final water = 1744.19 − 1500

Final water = 244.19 kg

3. Water Removed

Water removed = Initial water − Final water

Water removed = 500 − 244.19

Water removed = 255.81 kg

Final Answer

Initial moisture content = 25% (w.b.)

Final moisture content = 14% (w.b.)

Water removed = 255.81 kg ≈ 256 kg

MODEL Q Standard 'solids-constant' mass balance: hold dry matter fixed and convert between wet mass and moisture using M_wb = water/total.***

3.9 Worked numerical — product yield with peeling loss

◆ **WORKED NUMERICAL — Potato drying product yield** [IFoS 2022 · P2/7(a) · 10M]

Problem. *Potatoes are dried from 14% total solids to 93% total solids. 8% by weight of the original potatoes is lost in peeling. Find the product yield from each 1000 kg of raw potatoes (with mass balance).*

Problem: Potatoes are dried from 14% total solids to 93% total solids. 8% by weight of the original potatoes is lost in peeling. Find the product yield from each 1000 kg of raw potatoes using a mass balance.

Solution:

Given:

Raw potatoes = 1000 kg

Initial total solids = 14%
Final total solids = 93%
Peeling loss = 8% of original potato mass

Assumption: Peeling loss has the same composition as the original potatoes.

1. **Peeling Loss**
   Peeling loss = 0.08 × 1000
   = **80 kg**
   Potatoes remaining after peeling:
   = 1000 − 80
   = **920 kg**
2. **Solids Entering the Dryer**
   Total solids in peeled potatoes:
   = 0.14 × 920
   = **128.8 kg solids**
   Since drying removes only water, the amount of total solids remains unchanged during drying.
   Therefore:
   Solids in final product = **128.8 kg**
3. **Final Product Yield**
   Final product contains 93% total solids.
   Let final product mass = M kg.
   0.93 M = 128.8
   M = 128.8 / 0.93
   M = **138.49 kg**
   Therefore,
   Final product yield = 138.49 kg per 1000 kg of raw potatoes
4. **Water Removed During Drying**
   Water initially present in peeled potatoes:
   = 920 − 128.8
   = **791.2 kg**
   Water present in final product:
   = 138.49 − 128.8
   = **9.69 kg**
   Therefore,
   Water removed:
   = 791.2 − 9.69
   = **781.51 kg**
   Mass Balance
   Input = Output
   1000 kg raw potatoes = Peeling loss + Water removed + Final dried product
   1000 = 80 + 781.51 + 138.49
   1000 = **1000 kg**
   Hence, the mass balance is satisfied.
   Final Answer
   Peeling loss = **80 kg**
   Potatoes entering dryer = **920 kg**
   Total solids entering dryer = **128.8 kg**
   Water removed during drying = **781.51 kg**
   Final dried product = **138.49 kg**

Product yield = 138.49 kg per 1000 kg raw potatoes
Percentage yield = 13.85%

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4 DRYERS (EQUIPMENT)

4.1 Classification of dryers

PREVIOUS YEAR QUESTIONS

- *Enlist the different types of dryers used for drying agricultural commodities.*
  [IFoS 2021 · P2/5(d) · part · 8M]
- *Give a brief account of the various methods of drying grains.*
  [OPSC·CSE 2020-21 · P2/Q.5(a)(i) · 8M]

MODEL Q By grain–air contact: (1) bin/bed type (deep-bed, flat-bed, batch-in-bin); (2) moving-bed / continuous-flow (mixing, non-mixing, LSU, recirculatory); (3) free-fall/gravity; (4) fluidised-bed; (5) contact/conduction (drum); (6) spray (liquids); (7) special — vacuum, freeze, foam-mat, infra-red, microwave. Also batch vs continuous; convective, conductive, radiative.***

Grain (solid) dryers: tray, deep-bed, flat-bed, continuous mixing/non-mixing, LSU, recirculatory, fluidised-bed, spouted-bed. Liquid/slurry dryers: drum (roller), spray, foam-mat, freeze.

4.2 Tray (cabinet) dryer

PREVIOUS YEAR QUESTIONS

- *State the principle of operation of a tray dryer.*
  [IFoS 2019 · P2/5(b) · part · 8M]

A batch, convective dryer: many shallow trays stacked with gaps in an insulated chamber; a fan blows heated air across or through the thin product layers. Moisture-laden air is partly exhausted and partly recirculated. Simple and versatile for fruits, vegetables and granular solids. Drawback: non-uniform drying between trays — improved by rotating/re-stacking trays or reversing airflow. A vacuum variant handles heat-sensitive products.

Tray (cabinet) dryer

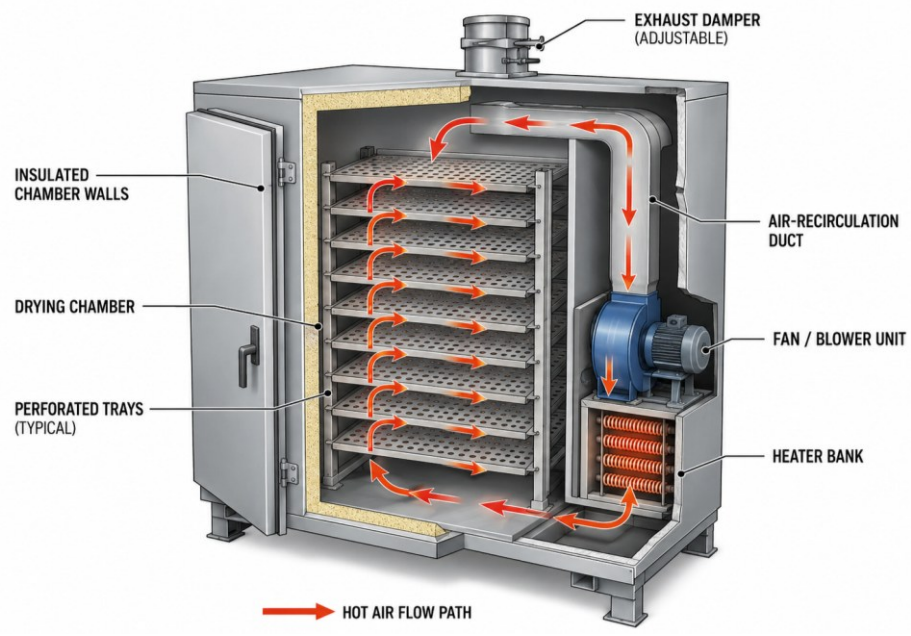


Fig. 3.4 Tray (cabinet) dryer

4.3 Deep-bed, flat-bed and continuous-flow dryers; multipass

PREVIOUS YEAR QUESTIONS

- *What do you mean by multipass drying?*

[IFoS 2020 · P2/6(c) · part · 15M]

Deep-bed ('batch-in-bin'): large static beds (grain 2.5–3 m; airflow ~2.94–3.92 m^3/min·tonne); a drying front moves up. Flat-bed: shallow (0.6–1.2 m) farm-level batch dryer, faster, less over-drying. Continuous-flow columnar: grain flows top-to-bottom between screens — mixing (baffles, low airflow, ≤65 °C) and non-mixing (parallel screens 15–25 cm apart, high airflow, ~54 °C).

Multipass drying : *grain is passed through the heating zone several times, removing only ~1–3% moisture per short pass (15–30 min) at 60–80 °C, with a tempering (rest) period of 4–24 h in a holding bin between passes to redistribute internal moisture. Avoids steep gradients and stress-cracks; faster, gentler, better-milling drying.*

4.4 LSU dryer

PREVIOUS YEAR QUESTIONS

- *Describe the constructional features and functioning of an LSU-type grain dryer.*

[IFoS 2020 · P2/6(c) · part · 15M]

- *Working principle / characteristic features of the LSU dryer.*

[OPSC·CSE 2015-16 & 2022-23 · P2 · (up to 20M)]

Developed at Louisiana State University (mid-1950s) for rice, for gentle treatment and good air–grain mixing. A mixing-type, continuous-flow dryer: a vertical column with staggered layers of inverted-V-shaped channels (ports); alternate rows are hot-air inlet ducts and exhaust outlet ducts, open at the bottom. Grain flows down by gravity, cascading over the inverted-Vs, repeatedly mixed and exposed to cross-flowing hot air. High capacity; standard in large commercial rice mills; often run multipass with tempering.

LSU dryer

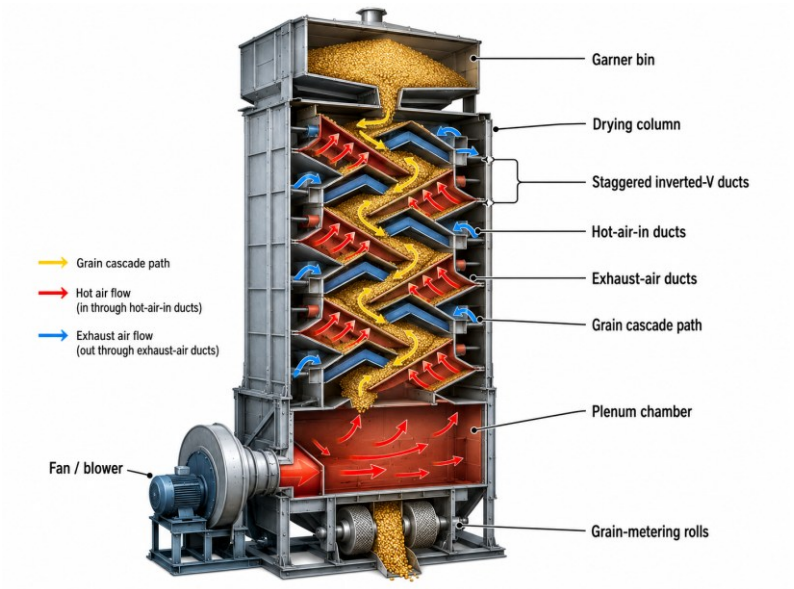


Fig. 3.5 LSU (inverted-V, mixing) continuous-flow dryer

4.5 Recirculatory batch (RPEC-type) dryer

PREVIOUS YEAR QUESTIONS

- *Describe the construction and operation of Recirculatory batch dryer (RPEC type) with neat sketch.*

[IFoS 2021 · P2/7(a)(i) · 10M]

Developed by the Rice Process Engineering Centre (RPEC), IIT Kharagpur. A batch, multipass dryer: a bucket elevator continuously lifts grain to a top garner/holding bin; grain flows down through a central heated drying column (hot air cross-flows through a louvered/inverted-V section) into a collecting boot and is re-elevated — recirculating repeatedly. Little moisture is removed per pass while most grain tempers in the holding column, so moisture equalises. Gives uniform, gentle drying (e.g. parboiled paddy) with good head-rice yield.

Recirculatory batch (RPEC) dryer

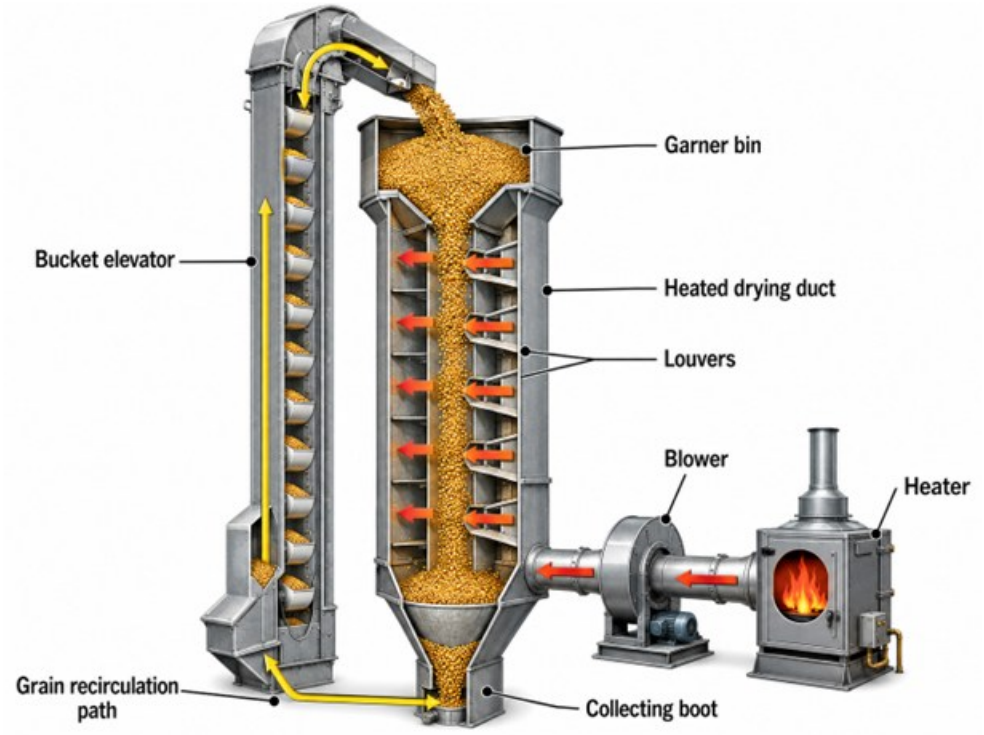


Fig. 3.6 RPEC recirculatory batch dryer

4.6 Fluidised-bed and spouted-bed dryers

Fluidised-bed dryer — hot air blown upward through a perforated distributor fluidises granular grain, giving intense grain–air contact, uniform temperature and very high drying rates; also dries pastes/solutions sprayed onto an inert fluidised bed. Spouted-bed — similar principle for larger particles with a central high-velocity air spout. Fast and uniform, but higher blower power.

4.7 Drum (roller) dryer

PREVIOUS YEAR QUESTIONS

- *Discuss the principle of working of (i) drum dryer and (ii) spray dryer.*

[OPSC·CSE / Forest 2018-19 & 2019-20 · P2 · 20M]

A contact/conduction dryer for liquids/slurries/pastes: one or more hollow metal drums rotating on horizontal axes, internally heated by steam. A thin film of feed is applied to the hot surface; as the drum rotates the film dries by conduction and the dried sheet is scraped off by a doctor knife, then milled. Types: single-drum, double-drum (feed in the nip) and twin-drum (rotate outward, feed at bottom). A vacuum drum dryer handles heat-sensitive foods. Used for milk, potato/tomato purée, starch, baby foods.

Drum (roller) dryer

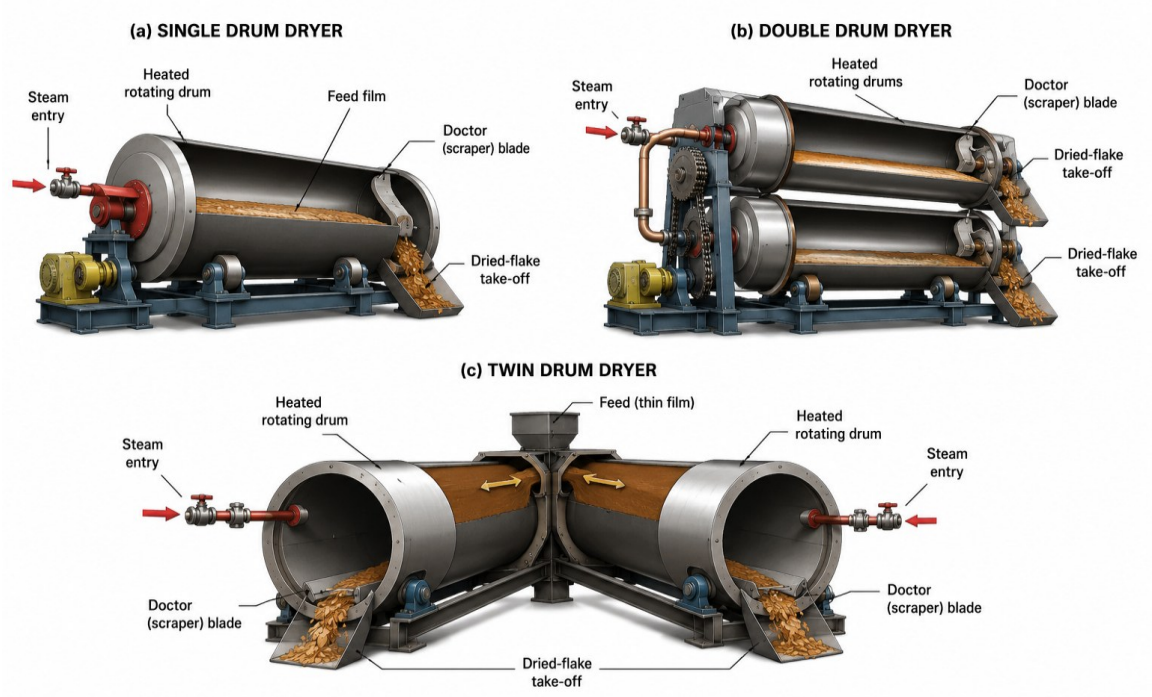


Fig. 3.7 Drum (roller) dryer — single, double, twin

4.7 *Spray dryer*

PREVIOUS YEAR QUESTIONS

- *What is spray drying and what are its main advantages in food processing industries? Explain spray dryer with the help of a schematic diagram.*

[IFoS 2023 · P2/7(b) · 15M]

Spray drying : *a continuous method of drying a liquid/slurry (pre-concentrated) by atomising it into fine droplets and contacting them with hot air in a large chamber, so each droplet dries almost instantly to a powder particle.*

Stages: (1) atomisation into a fine spray by a rotary (centrifugal-disc) or pressure/pneumatic nozzle; (2) spray–air contact and drying — droplets meet hot air (150–250 °C inlet) co- or counter-currently, evaporating in seconds while staying cool; (3) separation/recovery of powder from the exhaust by a cyclone separator / bag filter.

Advantages: very short drying time → minimal heat damage to heat-sensitive products (milk, egg, coffee, fruit juices); continuous, large-scale, automated; free-flowing, uniform, easily-reconstituted powder; moisture controlled by air temperature; low labour.

Spray dryer

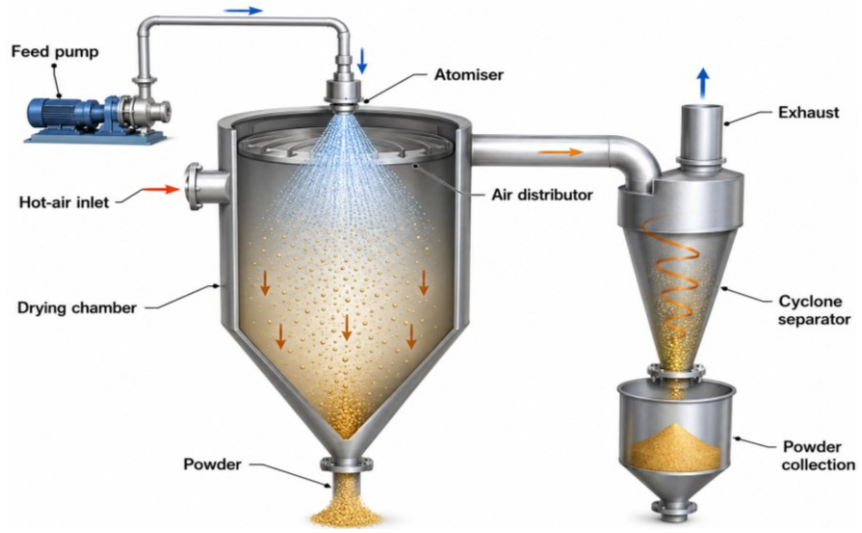


Fig. 3.8 Spray dryer with cyclone separator

4.9 Special dryers – freeze drying and foam-mat drying

PREVIOUS YEAR QUESTIONS

Explain freeze-drying system and its merits. [IFoS 2024 · P2/7(c) · 8M]

Freeze drying – phase diagram & system

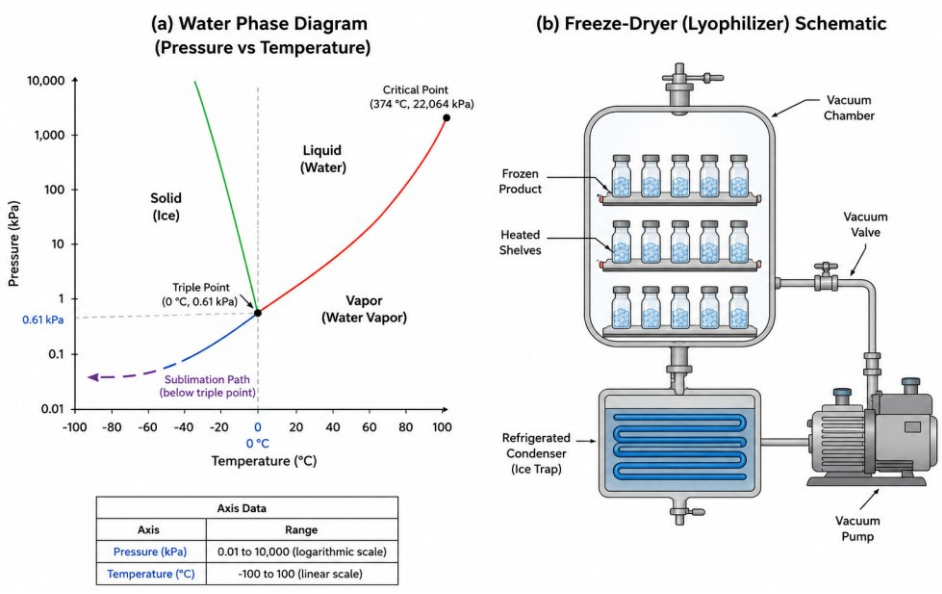


Fig. 3.9 Freeze drying: sublimation below the triple point

Freeze drying (**lyophilization**): water is removed from a frozen product by direct sublimation of ice to vapour, held below the triple point of water (0 °C, 4.58 mmHg / ~0.61 kPa) under high vacuum (~50 N/m²). Three stages: freezing (form ice crystals), primary drying (sublimation; heat by radiation/conduction; vapour condensed on a refrigerated coil), secondary drying (removal of residual bound water). Merits: original size/shape retained (negligible shrinkage), porous quickly-rehydrating product, excellent retention of flavour, aroma, colour and nutrients, minimal heat damage, long shelf-life. Demerits: high capital and energy cost, slow. Used for coffee, high-value fruits, biologicals.

Foam- drying : *a liquid food (fruit juice, pulp) is whipped into a stable foam with a small amount of edible foaming/stabilising agent (glyceryl monostearate, egg albumin), spread as a thin mat (~2–3 mm) on a perforated tray/belt, and dried rapidly with warm air. The foam's large surface area gives fast drying at lower temperature, protecting colour, flavour and vitamins; the dried mat is crushed to an instant powder. [Answers IFoS 2021 P2/5(d) foam-mat-for-juices part.]*

4.10 Worked numericals — drum-dryer capacity & air recycling

◆ WORKED NUMERICAL — Drum-drier evaporation rate [IFoS 2024 · P2/5(b) · 8M]

Problem. *Find the evaporation rate of a drum drier. Steam T = 160 °C; milk vaporisation T = 105 °C; U = 1200 kcal/h·m²·°C; drum D = 0.7 m; L = 1.05 m; latent heat λ = 540 kcal/kg; product scraped at 80% of the revolution.*

Problem : Find the evaporation rate of a drum drier.

Given:

Steam temperature, Ts = 160 °C
Milk vaporisation temperature, Tv = 105 °C
Overall heat-transfer coefficient, U = 1200 kcal/h·m²·°C
Drum diameter, D = 0.7 m
Drum length, L = 1.05 m
Latent heat of vaporisation, λ = 540 kcal/kg
Product is scraped after 80% of one revolution.

1. Temperature Difference

$$\Delta T = Ts - Tv$$
$$\Delta T = 160 - 105$$
$$\Delta T = \mathbf{55\ °C}$$

2. Effective Heat-Transfer Area

Total cylindrical surface area of the drum:

$$A = \pi DL$$
$$A = \pi \times 0.7 \times 1.05$$
$$A = \mathbf{2.309\ m^2}$$

Since the product remains on the drum for 80% of one revolution:

Effective area = 0.80 × 2.309

$$A_{effective} = \mathbf{1.847\ m^2}$$

3. Rate of Heat Transfer

$$Q = U \times A \times \Delta T$$
$$Q = 1200 \times 1.847 \times 55$$
$$Q = \mathbf{121{,}902\ kcal/h}$$

4. Evaporation Rate

$$\text{Evaporation rate} = Q / \lambda$$
$$\text{Evaporation rate} = 121{,}902 / 540$$
$$\text{Evaporation rate} = \mathbf{225.7\ kg/h}$$

Final Answer

Evaporation rate of the drum drier ≈ 226 kg of water per hour.

Mass-balance/energy relation used:

$$U\ A\ \Delta T = \dot{m}\ \lambda$$

Therefore,

$$\mathbf{\dot{m} \approx 225.7 \approx 226\ kg\ water/h}$$

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◆ **WORKED NUMERICAL — *Drum-dryer roller area*** **[OPSC·CSE 2020-21 · P2/Q.5(a)(ii) · 12M]**

Problem. *A drum dryer dries a product from initial TS 12% to final moisture 4%. ΔT (roller–product) = 65 °C; U = 1.74 kW/m²·K. Determine the roller surface area for a production rate of 50 kg product/h.*

Given:

Initial total solids = 12%

Final moisture content = 4%

Therefore, final total solids = 96%

Final product rate = 50 kg/h

ΔT = 65 °C

U = 1.74 kW/m²·K

Assume latent heat of vaporisation of water:

λ = 2257 kJ/kg

1. Dry Solids in Final Product

Dry solids are conserved during drying.

Dry solids in final product:

= 50 × 0.96

= **48 kg/h**

2. Calculate Feed Rate

The feed contains 12% total solids.

Feed rate = Dry solids / Initial solids fraction

Feed rate = 48 / 0.12

= **400 kg/h**

3. Water Evaporated

Water entering with feed:

= 400 − 48

= **352 kg/h**

Water remaining in final product:

= 50 − 48

= **2 kg/h**

Therefore,

Water evaporated = 352 − 2

= **350 kg/h**

4. Heat Required for Evaporation

Q = Water evaporated × Latent heat

Q = 350 × 2257

= **789,950 kJ/h**

Converting to kW:

Q = 789,950 / 3600

= **219.43 kW**

5. Roller Surface Area

Heat-transfer equation:

Q = U × A × ΔT

Therefore,

A = Q / (U × ΔT)

A = 219.43 / (1.74 × 65)

A = 219.43 / 113.1

A = **1.94 m²**

Final Answer

Feed rate = **400 kg/h**

Water evaporated = **350 kg/h**

Heat requirement = **219.43 kW**

Required roller surface area ≈ 1.94 m²

Note : The calculation assumes that the stated 50 kg product/h refers to the **final dried product** and uses λ = 2257 kJ/kg for water evaporation.

◆ **WORKED NUMERICAL — *Continuous dryer with air recycling*** **[OPSC·CSE 2017-18 · P2/Q.6(c) · 20M]**

Problem. *Wheat is dried 15% → 7% (w.b.) by mixing fresh warm air with recycled air. Absolute humidities: fresh 0.01, recycled 0.1, mixed (dryer inlet) 0.03 kg/kg. For a feed rate of 100 kg/h, find each air-stream flow (kg dry air/h), moisture removed and product flow rate.*

Fresh air = 0.01 kg water/kg dry air

Recycled air = 0.10 kg water/kg dry air

Mixed air entering dryer = 0.03 kg water/kg dry air

Feed rate = 100 kg/h

Find :

1. Moisture removed
2. Product flow rate
3. Fresh-air flow rate
4. Recycled-air flow rate

1. Dry Solids in Feed

Feed rate = 100 kg/h

Initial moisture = 15% (w.b.)

Dry solids = 100 × (1 − 0.15)

Dry solids = **85 kg/h**

Dry solids remain unchanged during drying.

2. Final Product Flow Rate

Final moisture content = 7% (w.b.)

Therefore, final dry-solids fraction:

= 1 − 0.07

= 0.93

Let final product flow rate = P kg/h.

0.93 P = 85

P = 85 / 0.93

P = **91.40 kg/h**

3. Moisture Removed from Wheat

Initial water in feed:

= 100 × 0.15

= **15 kg/h**

Water in final product:

= 91.40 × 0.07

= **6.40 kg/h**

Therefore,

Moisture removed:

= 15 − 6.40

= **8.60 kg/h**

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4. Total Dry-Air Flow Through Dryer

Humidity of air entering dryer:

$H_1 = 0.03$ kg water/kg dry air

Humidity of air leaving dryer (recycled air):

$H_2 = 0.10$ kg water/kg dry air

Increase in humidity:

$\Delta H = 0.10 - 0.03$

$\Delta H =$ **0.07 kg water/kg dry air**

Moisture balance over dryer:

Moisture removed = Dry-air flow × ΔH

$8.60 = G \times 0.07$

$G = 8.60 / 0.07$

G = **122.89 kg dry air/h**

Thus,

Fresh air + Recycled air = 122.89 kg dry air/h

5. Fresh and Recycled Air Flow Rates

Let:

F = Fresh-air flow rate, kg dry air/h

R = Recycled-air flow rate, kg dry air/h

Total air balance:

$F + R = 122.89$

Humidity balance at mixing point:

$0.01F + 0.10R = 0.03(F + R)$

Expanding:

$0.01F + 0.10R = 0.03F + 0.03R$

$0.07R = 0.02F$

Therefore,

$F = 3.5R$

Since:

$F + R = 122.89$

$3.5R + R = 122.89$

$4.5R = 122.89$

R = **27.31 kg dry air/h**

Therefore,

$F = 122.89 - 27.31$

F = **95.58 kg dry air/h**

Final Answer

Initial wheat feed = **100 kg/h**

Final product flow rate = **91.40 kg/h**

Moisture removed = **8.60 kg water/h**

Total mixed air entering dryer = **122.89 kg dry air/h**

Fresh-air flow rate = **95.58 kg dry air/h**

Recycled-air flow rate = **27.31 kg dry air/h**

Check:

Fresh air + Recycled air

= 95.58 + 27.31

= **122.89 kg dry air/h ✓**

5 EVAPORATION & CONCENTRATION

5.1 Principle and purpose

Evaporation : *partial removal of water from a dilute liquid food by boiling off the solvent (water) as vapour, leaving a more concentrated liquid product (not a dry solid). Reduces weight/volume and water activity, aids preservation, and is often a pre-step to drying/crystallisation (e.g. milk concentrated before spray drying).*

An evaporator is a steam-heated heat exchanger + vapour–liquid separator: saturated steam condenses, giving latent heat to boil the feed; vapour is removed (usually to a condenser under vacuum) and thick liquor drawn off. Vacuum operation lowers the boiling temperature, protecting heat-sensitive foods and increasing the steam–product ΔT.

5.2 Boiling-point elevation

PREVIOUS YEAR QUESTIONS

- *What is boiling point elevation?*

[IFoS 2019 · P2/6(b) · part · 15M]

Boiling-point elevation (BPE) : *the increase in the boiling temperature of a solution above that of pure water at the same pressure, caused by dissolved solids lowering the solvent's vapour pressure. BPE rises as the product concentrates. Estimated by Dühring's rule — a linear relation between the boiling point of the solution and that of pure water at the same pressure. BPE reduces the effective ΔT for heat transfer.*

5.3 Capacity and economy

PREVIOUS YEAR QUESTIONS

- *Define capacity and economy of an evaporator.*

[IFoS 2020 · P2/5(c) · part · 8M]

Capacity & economy : *Capacity — the rate of water evaporation (kg water/h; $q = U \cdot A \cdot \Delta T \div \lambda$). Economy (steam economy) — kg water evaporated per kg steam = $\dot{m}_vapour/\dot{m}_steam$. Single-effect economy ≈ 1; raised by multiple effects (an N-effect system approaches ~N) or vapour recompression.*

5.4 Single-effect evaporator — mass and energy balances

PREVIOUS YEAR QUESTIONS

- *Write the basic mass and energy balance equations for a single-effect evaporator, clearly defining each term.*

[IFoS 2018 · P2/7(a) · 10M]

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Single-effect evaporator (schematic)

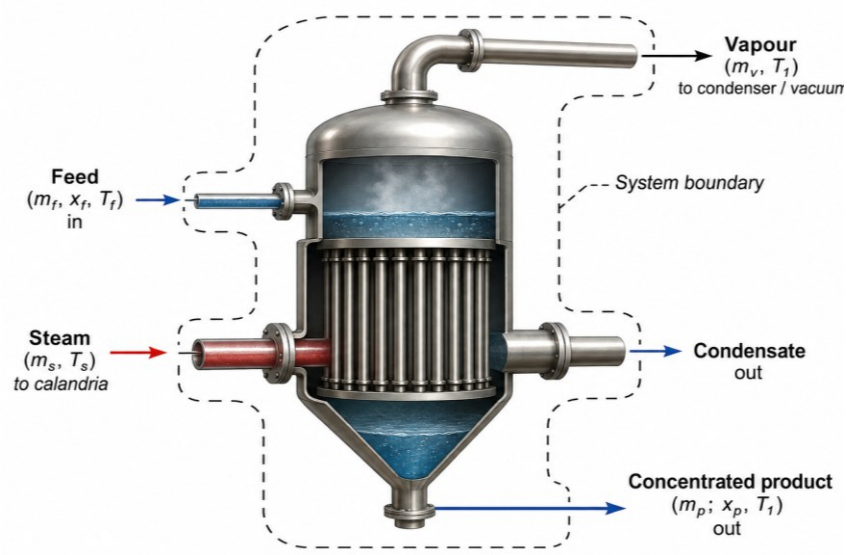


Fig. 3.10 Single-effect evaporator

Overall mass balance: $\dot{m}_f = \dot{m}_v + \dot{m}_p$

Solids balance: $\dot{m}_f \cdot x_f = \dot{m}_p \cdot x_p$

Enthalpy balance: $\dot{m}_f \cdot H_f + \dot{m}_s \cdot H_{vs} = \dot{m}_v \cdot H_{v1} + \dot{m}_p \cdot H_{p1} + \dot{m}_s \cdot H_{cs}$

Heat transfer: $q = U \cdot A \cdot (T_s - T_1) = \dot{m}_s \cdot \lambda_s$

$\dot{m}_f$, $\dot{m}_v$, $\dot{m}_p$, $\dot{m}_s$ = mass flow rates of feed, vapour, product, steam; x_f, x_p = solid fractions of feed and product; H_f, H_{p1} = enthalpies of feed and concentrate ($H = c_p(T - 0\ °C)$); H_{vs}, H_{v1} = enthalpies of saturated vapour at T_s and T_1; H_{cs} = enthalpy of condensate; U = overall heat-transfer coefficient; A = area; λ_s = latent heat of steam.

5.5 Multiple-effect evaporators and feeding arrangements

PREVIOUS YEAR QUESTIONS

- *Explain the operation of a triple-effect evaporator. What is a vacuum evaporator?* [OPSC·CSE 2015-16 · P2/Q.5(b) · 20M]
- *With the help of a simplified diagram explain the working of a forward-feed double-effect evaporator.* [OPSC·Forest 2019-20 · P2/Q.6(a) · 20M]

In a multiple-effect evaporator the vapour from one effect is the heating steam for the next, which operates at lower pressure/temperature — reusing latent heat and multiplying steam economy; a triple-effect uses three such stages in series.

- ***Forward feed*** : feed and steam flow in the same direction (effect 1 → 2 → 3); feed enters the hottest effect first and flows to progressively lower pressures, so no inter-effect pumps are needed, but viscosity rises as the cooling liquor concentrates in later effects.
- ***Backward feed*** : feed enters the last (coldest) effect and is pumped counter-current to the steam; good for viscous products but needs pumps.
- ***Vacuum evaporator*** : operates under vacuum so the product boils at a low temperature, protecting quality and increasing ΔT.

Forward-feed multiple-effect evaporator

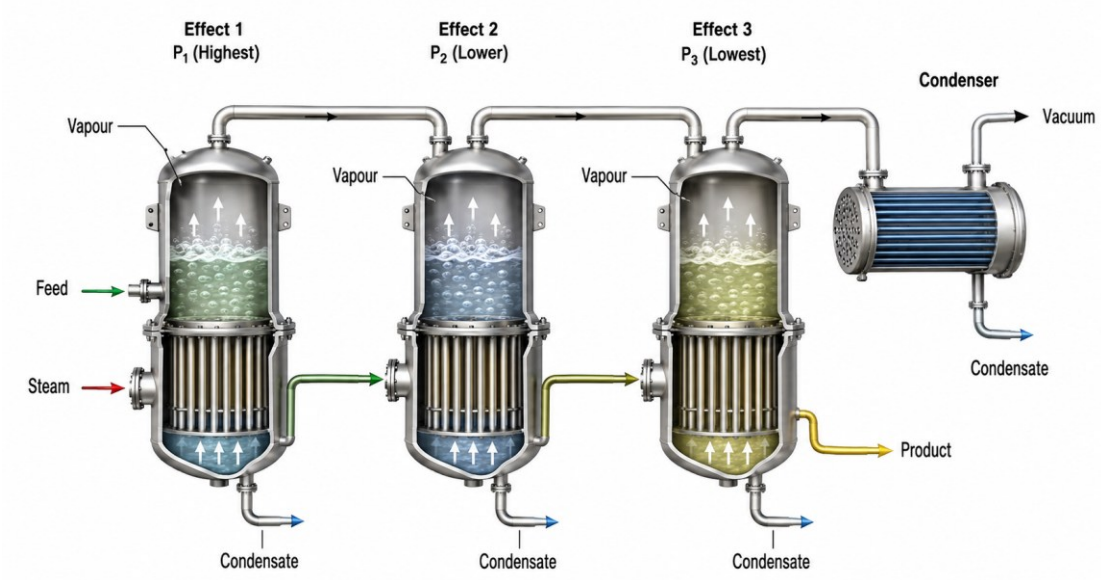


Fig. 3.11 Forward-feed multiple-effect evaporator

5.6 Types of evaporator by heat-exchange method

PREVIOUS YEAR QUESTIONS

- *State the principle of operation of a falling-film evaporator. Why is it preferred for concentrating heat-sensitive materials like fruit juice and milk?*

  [IFoS 2019 · P2/6(b) · part · 15M]

- *Describe the constructional features and operational principle of rising-film long-tube evaporator.*

  [OPSC-CSE 2022-23 · P2/Q.16(a) · 10M]

- **Batch pan** : simple jacketed/coil pan; long residence, low economy; small batches (jams).
- **Natural-circulation (short-tube/calandria)** : liquor circulates by density difference through a tube bundle.
- **Rising-film (climbing-film) long-tube** : feed enters the bottom of long vertical tubes; steam outside boils it and the vapour drags the liquid up as a thin climbing film; high heat-transfer; residence ~3–4 min.
- **Falling-film** : feed distributed to the top of vertical tubes flows down as a thin film under gravity; very short residence (~20–30 s) and low temperature — preferred for heat-sensitive fruit juice and milk because brief, gentle, low-temperature contact minimises thermal/colour/flavour damage; handles viscous liquids and permits many more effects than rising-film.
- **Forced-circulation & agitated thin-film** : pumped high-velocity (scaling/viscous liquids) and wiped-film for very viscous foods.

Rising-film vs falling-film long-tube evaporators

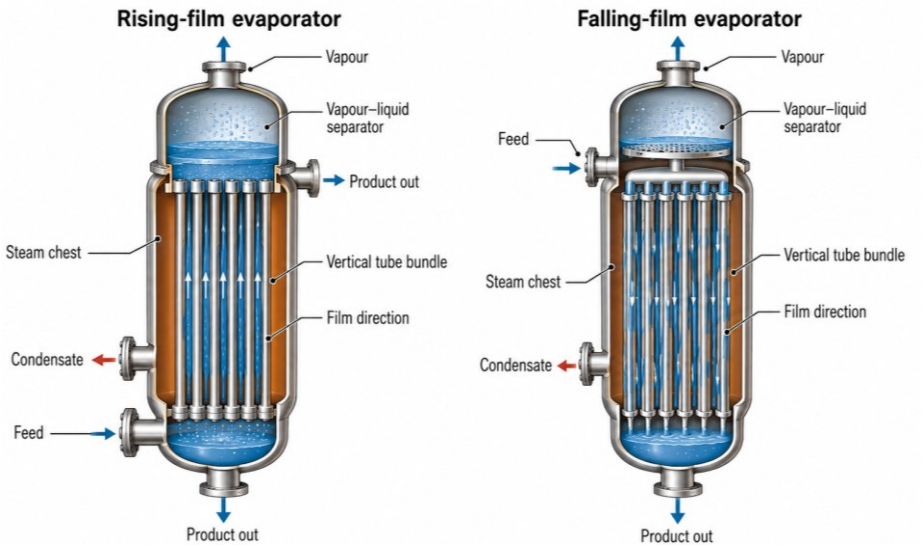


Fig. 3.11 Forward-feed multiple-effect evaporator

5.7 Worked numericals

◆ WORKED NUMERICAL — Single-effect, fruit juice concentration [IFoS 2020 · P2/5(c) · 8M]

Problem. *A single-effect evaporator concentrates fruit juice from 20% to 50% solids; feed 1000 kg/h. Find the concentrated product and the vapour evaporated.*

Given:

Feed, F = 1000 kg/h

Solids in feed = 20%

Solids in product = 50%

Since the solids are non-volatile, the amount of solids remains unchanged during evaporation.

1. **Solids present in the feed**

   Solids in feed = 1000 × 0.20 = 200 kg/h

2. **Amount of concentrated product**

Let the concentrated product be P kg/h.

Solids balance:

Solids in feed = Solids in product

200 = 0.50 × P

P = 200 / 0.50

P = 400 kg/h

Therefore,

Concentrated product = 400 kg/h

3. **Vapour evaporated**

Vapour evaporated = Feed − Concentrated product

= 1000 − 400

= 600 kg/h

Therefore,

Vapour evaporated = 600 kg/h

Final Answer:

Concentrated product = **400 kg/h**

Vapour evaporated = **600 kg/h**

◆ **WORKED NUMERICAL — *Orange juice — moisture removed*** **[IFoS 2019 · P2/6(c) · 10M]**

Problem. *Orange juice is concentrated from 80% moisture (w.b.) to 45% moisture (d.b.). Find the moisture removed from 100 kg.*

Given:

Initial mass of juice = 100 kg

Initial moisture content = 80% (wet basis)

Final moisture content = 45% (dry basis)

1. **Initial water and dry solids**
   Water in feed = 100 × 0.80 = 80 kg
   Dry solids = 100 – 80 = 20 kg
2. **Final amount of water**
   For 45% moisture on dry basis:
   Moisture content (d.b.) = Water / Dry solids
   0.45 = Final water / 20
   Final water = 0.45 × 20 = 9 kg
3. **Moisture removed**
   Moisture removed = Initial water − Final water
   = 80 – 9
   = 71 kg

Final Answer:

Moisture removed = **71 kg**

Moisture removed = 80 – 9 = 71 kg (product = 29 kg).

◆ **WORKED NUMERICAL — *Apple juice — moisture removed*** **[IFoS 2017 · P2/7(b) · 10M]**

Problem. *Apple juice is concentrated from 85% moisture (w.b.) to 50% moisture (d.b.). Find the moisture removed from 100 kg.*

Given:

Initial mass of juice = 100 kg

Initial moisture content = 85% (wet basis)

Final moisture content = 50% (dry basis)

1. **Initial water and dry solids**
   Water in feed = 100 × 0.85 = 85 kg
   Dry solids = 100 – 85 = 15 kg
2. **Final amount of water**
   For 50% moisture on dry basis:
   Moisture content (d.b.) = Water / Dry solids
   0.50 = Final water / 15
   Final water = 0.50 × 15 = 7.5 kg
3. **Moisture removed**
   Moisture removed = Initial water − Final water
   = 85 − 7.5
   = 77.5 kg

Final Answer:

Moisture removed = **77.5 kg**

◆ **WORKED NUMERICAL — *Cane-sugar evaporator*** **[OPSC·CSE 2018-19 · P2/Q.5(d) · 20M]**

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Problem. *Cane-sugar solution is concentrated at 10 000 kg/day from 38% to 74% sugar. Find the product and water removed.*

Given

Feed, F = 10,000 kg/day

Sugar in feed = 38%

Sugar in product = 74%

Since sugar is non-volatile, the amount of sugar remains unchanged during evaporation.

1. **Sugar present in the feed**

   Sugar in feed = 10,000 × 0.38 = 3,800 kg/day

2. **Amount of concentrated product**

   Let the amount of concentrated product be P kg/day.

   Sugar balance:

   Sugar in feed = Sugar in product

   3,800 = 0.74 × P

   P = 3,800 / 0.74

   P = 5,135.14 kg/day

   Therefore,

   Concentrated product = 5,135.14 kg/day

3. **Water removed**

   Water removed = Feed − Concentrated product

   = 10,000 − 5,135.14

   = 4,864.86 kg/day

   Therefore,

   Water removed = 4,864.86 kg/day

Final Answer:

Concentrated product = **5,135.14 kg/day**

Water removed = **4,864.86 kg/day**

Water removed = 10 000 − 5135 = 4865 kg/day.

◆ **WORKED NUMERICAL — *Initial steam rate — jacketed cream pan*** **[IFoS 2022 · P2/6(a) · 10M]**

Problem.

Given:

Initial cream temperature, $T_1 = 18°C$

Steam temperature, $T_s = 119.6°C$

Latent heat of steam, $\lambda = 526$ kcal/kg

Heating area, $A = 1\ m^2$

Overall heat-transfer coefficient, $U = 250$ kcal/m²·h·°C

1. **Initial temperature difference**

   $$\Delta T = T_s - T_1$$

   $$\Delta T = 119.6 - 18$$

   $$\Delta T = 101.6°C$$

2. **Initial rate of heat transfer**

   $$Q = U \times A \times \Delta T$$

   $$Q = 250 \times 1 \times 101.6$$

   $$Q = 25{,}400 \text{ kcal/h}$$

3. **Steam requirement**

Steam required = Q / λ

Steam required = 25,400 / 526

Steam required = 48.29 kg/h

Final Answer:

Initial steam requirement ≈ 48.3 kg/h

This is the initial steam consumption rate; it will decrease as the cream temperature rises and the temperature difference between steam and product becomes smaller.

Initial heat rate q = U·A·ΔT = 250 × 1 × (119.6 − 18) = 25 400 kcal/h.

Steam rate = q/λ = 25 400 / 526 ≈ 48.3 kg steam/h. (initial-stage rate; 120 L not needed for the rate).

6 FREEZING & REFRIGERATION

6.1 *Freezing as a method of preservation*

PREVIOUS YEAR QUESTIONS

- *State why freezing can be considered as a method of preservation of food.*

[IFoS 2019 · P2/7(c) · part · 10M]

Freezing : *preservation by lowering product temperature below its freezing point (typically to −18 °C or lower) so that most water turns to ice. It preserves by (i) removing sensible + latent heat to sub-zero temperatures that stop microbial growth and drastically slow enzymatic and chemical deterioration, and (ii) converting water to ice, lowering water activity. Freezing does not sterilise — microbes are dormant, not killed — so quality is retained only while the product stays frozen.*

6.2 *Slow vs quick freezing; ice-crystal size*

PREVIOUS YEAR QUESTIONS

- *Write a short note on different quick-freezing methods. What are the advantages of frozen foods?*

[IFoS 2022 · P2/5(b) · 8M]

- *What are the advantages and disadvantages of quick freezing?*

[IFoS 2019 · P2/7(c) · part · 10M]

Quick vs slow freezing — *quick (rapid) freezing passes the product through the zone of maximum ice-crystal formation (0 to −5 °C) very fast (minutes), forming many small ice crystals; slow freezing dwells for hours, forming large crystals that rupture cell walls, causing drip loss and texture damage on thawing.*

Feature	*Slow freezing*	*Quick freezing*
Time through 0 → −5 °C	hours	minutes
Ice crystals	large, extracellular	small, intracellular
Cell damage	high (rupture)	low
Drip loss on thawing	high	low
Quality	poorer	superior

Advantages of quick freezing: small crystals → minimal cell rupture, low drip loss, better texture/flavour/colour retention; faster passage limits microbial growth and solute-concentration damage; continuous, automated. Disadvantages: higher capital and energy cost; specialised equipment; some products crack from thermal

stress. Advantages of frozen foods: long shelf-life; near-fresh nutritional/sensory quality; year-round availability; convenience; wide product range (peas, fish, IQF fruits/vegetables).

6.3 Quick-freezing methods (equipment)

MODEL Q Air-blast freezer — cold air (−30 to −40 °C) at high velocity over product in a tunnel/room. Fluidised-bed / IQF (Individual Quick Freezing) — small pieces (peas, berries) fluidised on a perforated belt by an upward cold-air blast, freezing each piece separately and fast. Plate (contact) freezer — product pressed between hollow refrigerated plates; efficient for regular blocks/packages. Immersion / cryogenic — direct contact with cold brine or spraying liquid nitrogen (−196 °C) or CO_2; extremely rapid, best quality, higher cost.***

Quick-freezing systems

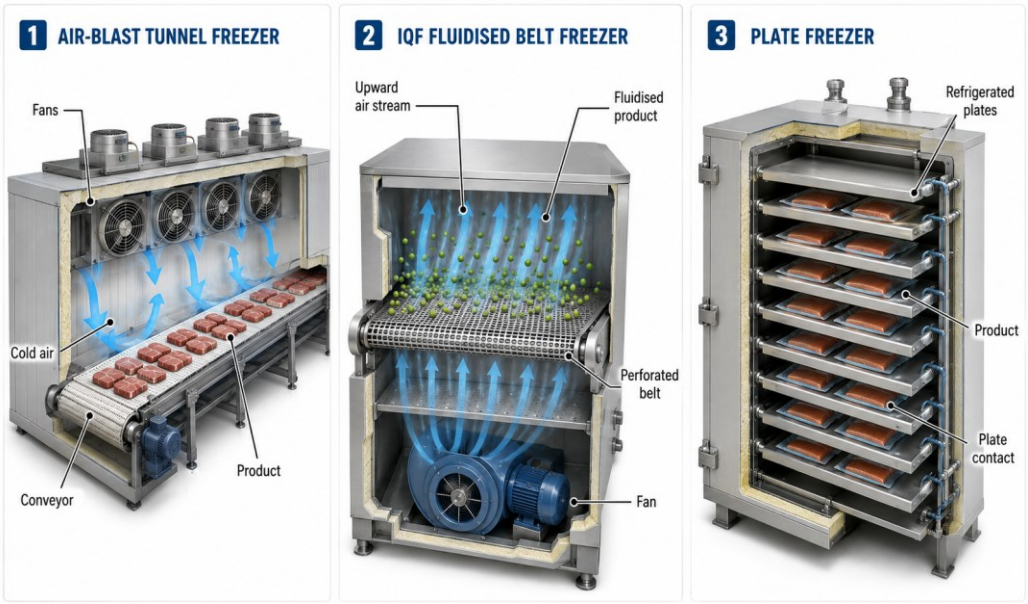


Fig. 3.13 Quick-freezing systems: air-blast, IQF, plate

6.4 Thawing

PREVIOUS YEAR QUESTIONS

Briefly explain: Thawing.

[HP·PSC RFO 2021 · Q.7(d) · 10M]

Thawing : *the reverse of freezing: supplying heat to melt the ice in a frozen product back to liquid water. Thawing is slower than freezing for the same temperature difference because thawed outer layers (water) conduct heat far more poorly than ice, slowing heat penetration to the core. Improper slow/warm thawing risks surface microbial growth, drip loss and quality loss; controlled (refrigerated) or rapid (microwave/vacuum-steam) thawing minimises this.*

6.5 Refrigeration — principle and the vapour-compression cycle

PREVIOUS YEAR QUESTIONS

Differentiate between refrigeration and freezing.

[UK·PSC ACF/RFO 2025 · Q.7(i)(a) · 5M]

> *Explain the functioning of compression refrigeration system with the help of a suitable sketch. What are the cares to be taken for proper maintenance?*
>
> [OPSC·CSE 2018-19 · P2/Q.8(c) · 20M]

Refrigeration vs freezing : *refrigeration is continuous removal of heat to keep a space/product below ambient (chilling, e.g. 0–5 °C cold storage); freezing takes the product below its freezing point to form ice (≤ −18 °C). Refrigeration is the general cooling process; freezing is a specific low-temperature application of it.*

The mechanical vapour-compression cycle has four components in a closed refrigerant loop: (1) evaporator — low-pressure refrigerant absorbs heat from the cold space and evaporates (refrigeration effect); (2) compressor — compresses vapour to high pressure/temperature (work input); (3) condenser — high-pressure vapour rejects heat and condenses; (4) expansion (throttling) valve — drops the liquid to low pressure/temperature, closing the loop.

Refrigeration effect & COP : *refrigeration effect = heat absorbed per kg refrigerant in the evaporator ($H_2 - H_1$); coefficient of performance COP = refrigeration effect ÷ compressor work; higher COP = more efficient.*

Maintenance cares: correct refrigerant charge and leak checks; clean condenser/evaporator coils; proper lubrication and compressor condition; clean air/oil filters; sound door seals and cold-room insulation; monitor operating pressures and temperatures; regular defrosting; verify controls, thermostats and safety cut-outs.

Vapour-compression refrigeration cycle

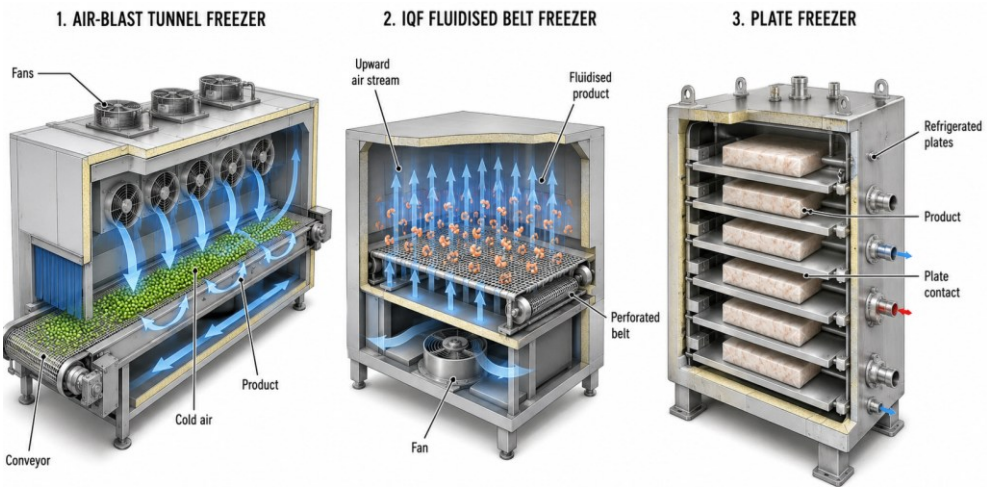


Fig. 3.14 Mechanical vapor-compression refrigeration cycle

6.6 Tonne of refrigeration

Tonne of refrigeration (TR) : *the rate of heat removal to freeze 1 tonne of water at 0 °C into ice at 0 °C in 24 hours (latent heat of fusion of one tonne of ice per day). 1 TR = 3.517 kW = 210 kJ/min = 12 000 BTU/h. (The 2025 PYQ uses 1 TR = 3.5 kW = 210 kJ/min.)*

6.7 Cold storage and the cold chain

PREVIOUS YEAR QUESTIONS

> *Discuss the advantages of cold storage in respect of food processing. What is cold food chain? How does it work?*
>
> [IFoS 2017 · P2/5(a) · 10M]

Cold storage holds perishables at controlled low temperature and humidity to slow respiration, ripening, microbial and enzymatic spoilage. Advantages: reduced post-harvest losses; year-round availability; price stabilisation and better returns; buffer stock; maintains quality/nutrition for processing.

Cold chain : *the unbroken sequence of refrigerated storage and transport from harvest/production through pre-cooling, cold storage, refrigerated transport, distribution and retail up to the consumer, keeping the product continuously within its required low-temperature range. It works by pre-cooling produce immediately after harvest, then maintaining temperature at every link (reefer vehicles, cold rooms, chilled cabinets); any break ('temperature abuse') accelerates spoilage, so continuous monitoring is essential.*

6.8 Worked numerical – refrigeration capacity (TR)

◆ **WORKED NUMERICAL – *Refrigeration capacity for cooling apples*** [IFoS 2025 · P2/6(b) · 10M]

Problem. *5000 kg apples are cooled 25 °C → 10 °C in 24 h. c_p = 3.25 kJ/kg·°C; heat of respiration 3400 kJ/tonne·24 h; infiltration 4100 kJ/tonne·24 h; lighting 150 W. 1 TR = 3.5 kW = 210 kJ/min. Find the refrigeration capacity (TR).*

Given:

Mass of apples, m = 5000 kg = 5 tonnes
Initial temperature, T_1 = 25°C
Final temperature, T_2 = 10°C
Specific heat, = 3.25 kJ/kg·°C
Cooling time = 24 h
1 TR = 210 kJ/min

1. Product Cooling Load

Temperature difference:

$\Delta T = 25 - 10 = 15°C$

Heat removed from apples:

$Q_1 = m \times c_p \times \Delta T$

$Q_1 = 5000 \times 3.25 \times 15$

$Q_1 =$ **243,750 kJ**

2. Heat of Respiration

$Q_2 = 3400 \times 5$

$Q_2 =$ **17,000 kJ/24 h**

3. Infiltration Load

$Q_3 = 4100 \times 5$

$Q_3 =$ **20,500 kJ/24 h**

4. Lighting Load

Lighting power = 150 W = 0.15 kW

$Q_4 = 0.15 \times 24 \times 3600$

$Q_4 =$ **12,960 kJ/24 h**

5. Total Refrigeration Load

Total load = $Q_1 + Q_2 + Q_3 + Q_4$

= 243,750 + 17,000 + 20,500 + 12,960

= **294,210 kJ/24 h**

6. Refrigeration Capacity

Total time = 24 × 60 = 1440 min

Refrigeration load per minute:

= 294,210 / 1440

= **204.31 kJ/min**

Since,

1 TR = 210 kJ/min

Refrigeration capacity:

TR = 204.31 / 210

= **0.973 TR**

Final Answer:

Required refrigeration capacity ≈ 0.97 TR

Therefore, a refrigeration system of approximately **1 TR capacity** would be required.

7 RELATED UNIT OPERATIONS (BUNDLED PYQ SUB-PARTS)

These topics appear only inside multi-part 'differentiate / short-note' PYQs mapped to this chapter; each is answered fully here and treated in depth in its own chapter.

7.1 *Size reduction — empirical laws (Rittinger vs Bond)*

PREVIOUS YEAR QUESTIONS

- *Differentiate between Rittinger's law and Bond's law of size reduction.*

[IFoS 2023 · P2/6(a) · part · 10M]

Rittinger (n = 2): $E = C_R (1/x_p - 1/x_f)$ — energy ∝ new surface area

Kick (n = 1): $E = C_K \cdot \ln(x_f / x_p)$ — energy ∝ size-reduction ratio

Bond (n = 3/2): $E = 0.3162 \cdot W_i (1/\sqrt{x_p} - 1/\sqrt{x_f})$ — W_i = Bond work index (kWh/tonne)

x = particle size; subscripts f, p = feed, product.

Feature	*Rittinger's law*	*Bond's law*
Exponent n	2	1.5
Energy proportional to	new surface area	√(surface-volume ratio), via work index
Best fit	fine grinding	coarse–medium–fine (general)
Key constant	Rittinger's constant C_R	Bond work index W_i
Basis	surface-energy theory	crack-propagation theory

7.2 *Bulk density vs true density*

PREVIOUS YEAR QUESTIONS

- *Differentiate between Bulk density and True density.*

[IFoS 2023 · P2/6(a) · part · 10M]

Bulk vs true density : *bulk density — mass per unit total (bulk) volume, including inter-particle voids (grain in a bin); true (particle) density — mass per unit volume of the solid only, excluding voids and open pores (pycnometer). Linked by porosity ε = 1 − (bulk density/true density).*

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Feature	Bulk density	True density
Volume basis	total incl. voids	solid only
Value	lower	higher
Depends on packing	yes	no
Measured by	known-volume container	pycnometer displacement
Use	bin/silo/transport sizing	porosity, characterisation

7.3 Pneumatic vs gravity separation

PREVIOUS YEAR QUESTIONS

- *Differentiate between Pneumatic separation and Gravity separation.*

[IFoS 2023 · P2/6(a) · part · 10M]

Pneumatic vs gravity separation : *pneumatic (aspiration) separation uses an air stream to separate particles by terminal velocity/aerodynamic drag (light chaff/dust carried away, heavy grain settles); gravity separation uses difference in specific gravity on an inclined oscillating porous deck with air (denser particles/stones stratify down, lighter up).*

Feature	Pneumatic separation	Gravity separation
Basis	terminal velocity / aerodynamic	density / specific gravity
Medium	air stream	vibrating deck + air
Separates	light chaff/dust from grain	stones/heavy from light of same size
Example	aspirator, air-screen cleaner	destoner, gravity separator

7.4 Decortication of oilseeds

PREVIOUS YEAR QUESTIONS

- *Decortication of Oilseeds.*

[IFoS 2025 · P2/5(a) · short note · 8M]

Decortication : *mechanical removal of the outer husk/hull/shell of oilseeds (groundnut, sunflower, castor, safflower) before oil extraction, in a decorticator (impact/attrition against a screen), followed by aspiration of kernels from hulls. It raises oil recovery and quality (less fibre, wax and colour in the oil), lowers expeller wear and yields a better cake; the hull is a by-product (fuel, fibre).*

7.5 Mini dal (dhal) mill

PREVIOUS YEAR QUESTIONS

- *Explain the mini dal/dhal mill for milling of pulses.*

[IFoS 2021 · P2/7(a)(ii) · 5M]

Dhal milling & mini dal mill : *dhal milling converts whole pulses into split, dehusked dhal: cleaning → conditioning (loosen husk by oil/water + drying) → de-husking (abrasive emery rollers) → splitting → separation → polishing. A mini dal mill is a compact single/twin-roller machine for farm/village scale that dehusks and splits pulses in one small unit, giving decentralised value-addition, lower losses and higher returns for small growers.*

Mini dal mill

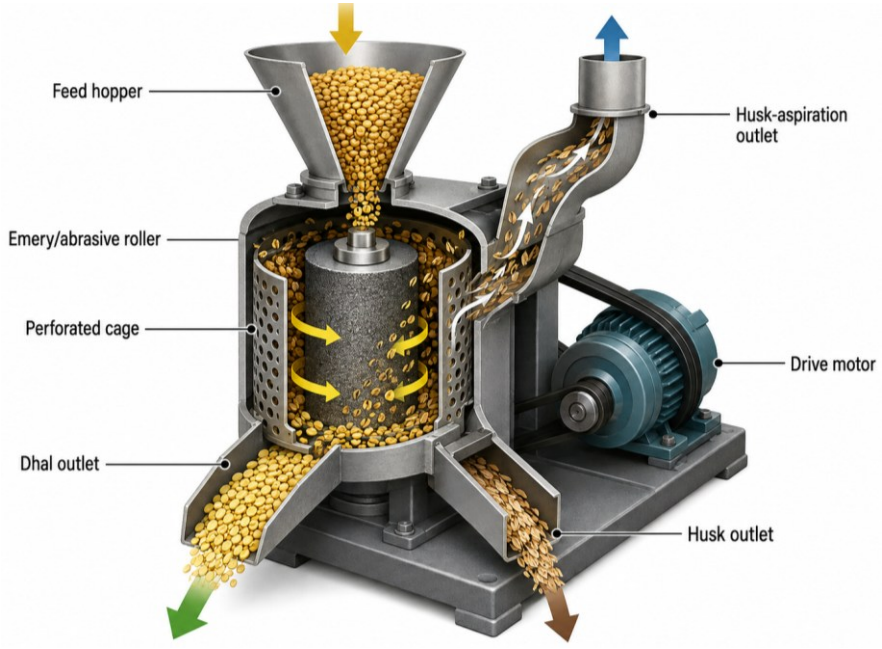


Fig. 3.15 Mini dal (dhal) mill

7.6 Filtration and filter aids

PREVIOUS YEAR QUESTIONS

- *What is a filter aid? Name any one material used as a filter aid. Describe the operation of any one batch filter used in agricultural processes.*

[IFoS 2018 · P2/7(c) · 15M]

Filter aid : *an inert, rigid, highly porous powder added to a slurry (or pre-coated on the medium) to keep the filter cake open and permeable, preventing fine/slimy solids from blinding the filter, raising filtration rate and clarity. Common material: diatomaceous earth (kieselguhr); also perlite, cellulose.*

Batch filter — plate-and-frame filter press: alternating plates and hollow frames clad with filter cloth are clamped in a stack. Slurry is pumped under pressure into the frames; filtrate passes through the cloth and drains via plate channels while solids build as cake inside the frames. When frames fill, the press is opened, cake removed, cloth cleaned and reassembled. Simple, flexible, high-pressure; labour-intensive and batch-wise. Used for clarifying juices, oils, syrups.

Plate-and-frame filter press

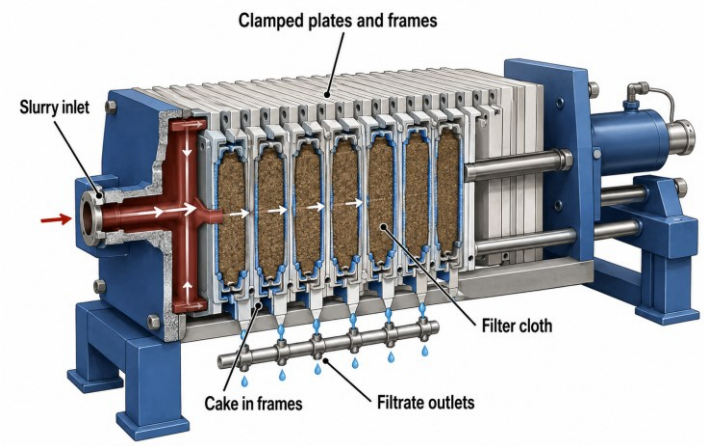


Fig. 3.16 Plate-and-frame (batch) filter press

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7.7 Blanching of fruits and vegetables

PREVIOUS YEAR QUESTIONS

- *Write the advantages of blanching of fruits and vegetables.*

[IFoS 2022 · P2/5(a) · 8M]

Blanching : *a mild heat pre-treatment (hot water ~70–100 °C or steam, short time) of fruits/vegetables before freezing, drying or canning, followed by prompt cooling.*

Advantages: inactivates spoilage enzymes (peroxidase, polyphenol oxidase, lipoxygenase) that cause off-colours, off-flavours and nutrient loss; expels intercellular/dissolved gases (especially O_2), reducing oxidation and can corrosion and improving colour; reduces surface microbial load and cleans the product; softens and shrinks tissue for easier filling/packing; sets/brightens colour (fixes chlorophyll); removes raw flavours. Essential before freezing/dehydration to prevent storage quality loss.

7.8 Modified vs Controlled Atmosphere Packaging

PREVIOUS YEAR QUESTIONS

- *Differentiate between Modified Atmosphere Packaging and Controlled Atmosphere Packaging.*

[IFoS 2023 · P2/6(a) · part · 10M]

MAP vs CAP : *Modified Atmosphere Packaging (MAP) — the gas composition around the product is altered at packing (lowered O_2, raised CO_2/N_2) but not actively regulated afterwards; it drifts with respiration and package permeability. Controlled Atmosphere (CA) storage — the gas composition is continuously monitored and actively maintained at set-points throughout storage (large refrigerated CA rooms, e.g. apples).*

Feature	MAP	CAP
Gas control	set once at packing, then passive	continuously monitored & maintained
Scale	retail packages	bulk storage rooms
Precision	approximate, drifts	tight, regulated
Equipment	gas-flush packaging machine	CA store + gas generators & sensors
Example	packed meat/produce trays	apple CA cold store

- *Source: Crop Process Engineering (AgriMoon), L13–16, L24, L25–28; Chakraverty & Singh (dhal milling, decortication); Food Packaging Technology (MAP/CAP).*

8 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

Formula Sheet

Moisture: $M_{wb} = \text{water/total} \times 100$; $M_{db} = \text{water/dry-solids} \times 100$

$M_{db} = M_{wb}/(100 - M_{wb}) \times 100$; $M_{wb} = M_{db}/(100 + M_{db}) \times 100$

Water activity: $a_w = p/p_0 = ERH/100$

Specific humidity: $H = 0.622\, p_w/(P - p_w)$; $RH = p_w/p_{ws} \times 100$

Humid heat: $c_s = 1.005 + 1.88H$; Enthalpy: $h = 1.005t + H(2501 + 1.88t)$

Constant-rate drying: $N_c = h \cdot A(t - t_w)/\lambda = k_y \cdot A(p_w - p_a)$

Dryer thermal efficiency: $\eta = (\text{water evaporated} \times \lambda)/(\text{fuel} \times \text{NCV}) \times 100$

$HUF = (t_2 - t_3)/(t_2 - t_1) = 1 - COP$; $COP = (t_3 - t_1)/(t_2 - t_1)$

Evaporator: $\dot{m}_f = \dot{m}_v + \dot{m}_p$; $\dot{m}_f x_f = \dot{m}_p x_p$; $q = U \cdot A \cdot \Delta T = \dot{m}_s \lambda_s$

Steam economy $= \dot{m}_v/\dot{m}_s$ (≈ 1 single-effect, $\approx N$ for N-effect)

Drum-dryer capacity: evaporation rate $= U \cdot A \cdot \Delta T/\lambda$ (A = effective drum area)

Size reduction: Rittinger $E = C_R(1/x_p - 1/x_f)$; Kick $E = C_K \ln(x_f/x_p)$; Bond $E = 0.3162\, W_i(1/\sqrt{x_p} - 1/\sqrt{x_f})$

Porosity: $\varepsilon = 1 - (\text{bulk density/true density})$

Refrigeration: COP = refrigeration effect/work ; 1 TR = 3.517 kW = 210 kJ/min = 12 000 BTU/h

SUMMARY

Chapter 3 covers four physical preservation operations of agricultural process engineering. Water activity ($a_w = p/p_o$), not total moisture, governs spoilage — bacteria need $a_w > 0.9$, moulds > 0.65 — and all four operations work by lowering it or the temperature. Psychrometry describes the drying air (DBT, WBT, dew point, humidity) via the chart (any two properties fix the state; four processes: sensible heating/cooling, heating-with-humidifying, cooling-with-dehumidifying, adiabatic drying at constant WBT). Drying proceeds through a constant-rate period (air-controlled, surface at WBT) and, past the critical moisture content, a falling-rate period (diffusion-controlled) to EMC; grains dry mostly in the falling-rate period. Thin-layer drying is uniform; deep-bed develops a moisture front (Hukill). Efficiencies: fuel, thermal, drying/effective, and HUF (= 1 − COP). Dryers span tray, deep/flat-bed, continuous (mixing/non-mixing), LSU (inverted-V mixing, rice), recirculatory RPEC (multipass with tempering), fluidised-bed, drum/roller (contact, doctor-blade), spray (atomise → hot air → cyclone), freeze (sublimation below the triple point) and foam-mat (whipped juice). Evaporation concentrates liquids: BPE (Dühring), capacity and economy, single- and multiple-effect (forward/backward feed), and film evaporators — falling-film (20–30 s) is preferred for heat-sensitive fruit juice/milk. Freezing preserves by ice formation and low a_w; quick freezing gives small crystals and less cell damage (air-blast, IQF, plate, cryogenic); thawing is slower than freezing. Refrigeration (evaporator–compressor–condenser–expansion valve, rated in TR) underpins cold storage and the unbroken cold chain.

LAST-NIGHT REVISION

- $a_w = p/p_o$ = ERH/100; bacteria >0.9, yeast/mould >0.65; no growth <0.6.
- Drying vs dehydration: dehydration = controlled artificial drying to very low (<5%) moisture.
- $M_{db} > M_{wb}$ always; hold dry solids constant in all mass balances.
- Chart: any two properties fix the state; adiabatic drying = constant-WBT line.
- Constant-rate = air controls, surface ≈ WBT; past CMC → falling-rate = internal diffusion; ends at EMC. Grains: mostly falling-rate.
- Thin-layer = uniform; deep-bed (>15 cm) = moving moisture front.
- $HUF = (t_2 - t_3)/(t_2 - t_1) = 1 - COP$.
- LSU = inverted-V mixing continuous dryer (rice); RPEC = recirculatory batch, multipass + tempering; 1–3%/pass, temper 4–24 h.
- Drum = contact, steam-heated, doctor blade; Spray = atomise → hot air (150–250 °C) → cyclone; both for liquids.

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- Freeze drying: sublimation below triple point (0 °C, 4.58 mmHg); best quality, costly.
- Falling-film evaporator (~20–30 s) → heat-sensitive juice/milk; economy ≈ N for N-effect; vacuum lowers boiling point.
- Evaporator numericals: solids balance $\dot{m}_f x_f = \dot{m}_p x_p$; vapour = feed − product.
- Quick freezing → small crystals, less drip; 1 TR = 3.517 kW = 210 kJ/min.
- Refrigeration = chilling above freezing; freezing = below freezing point (ice). Cold chain = unbroken refrigerated links, harvest → consumer.
- Rittinger (fine, ∝ new surface) vs Bond (∝ √S/V, work index); porosity ε = 1 − bulk/true.

CHAPTER

4

PACKAGING & MATERIAL HANDLING EQUIPMENT

Food packaging & MAP/CAP · Belt & screw conveyors · Bucket elevators · Grain handling & storage

SYLLABUS Chapter 4: packaging of agricultural produce; material-handling equipment — belt & screw conveyors and bucket elevators, their capacity and power requirement. Grain-handling selection and grain storage structures (bag storage, bins, silos) — recurring in past questions — are covered here.

Chapter Outline

1. **Scope & Grain-Handling Systems**
2. **Belt Conveyor**
3. **Screw Conveyor**
4. **Belt vs Screw Conveyor — Power Comparison**
5. **Bucket Elevator**
6. **Grain Storage Structures**
7. **Food Packaging & MAP/CAP**
8. **Formula Sheet · Summary · Last-Night Revision**

1 SCOPE & GRAIN-HANDLING SYSTEMS

1.1 Material handling in post-harvest operations

PREVIOUS YEAR QUESTIONS

- *What do you mean by value-added product with reference to food industries? Explain the operation of belt and screw conveyor and also bucket elevator.*

[OPSC·CSE 2015-16 · P2/Q.5(c) · 20M]

Material handling covers the operations that ***move, convey, elevate and transfer*** agricultural produce between processing steps, storage and transport. Mechanical handling devices lighten human labour, cut costs and enable large throughputs. In a processing plant, grain is handled many times — receiving, cleaning, drying, milling, storage and despatch — so efficient handling is central to plant layout and economics.

Value-added product : *a raw agricultural commodity that has been processed or transformed (cleaning, grading, milling, packaging, product-making) to* ***increase its economic value, shelf-life and usability*** *— e.g. paddy → polished/parboiled rice, wheat → flour/atta, milk → butter/cheese, fruit → juice/powder. Material-handling equipment links these value-adding steps.*

1.2 Common grain-handling equipment

PREVIOUS YEAR QUESTIONS

- *What are the common types of equipment used in grain handling? Discuss in brief the factors considered in their selection.*

[IFoS 2016 · P2/7(a) · 10M]

- *Name the different grain-handling equipments. Explain any one, stating its design consideration, components and operational characteristics.*

[OPSC·CSE 2016-17 · P2/Q.7(a) · 20M]

The most common mechanical devices for grain handling are: ***(1) belt conveyor, (2) bucket elevator, (3) screw conveyor, and (4) pneumatic conveyor***. Belt and screw conveyors move grain largely horizontally (or gently inclined); bucket elevators lift it vertically; pneumatic conveyors move it in an air stream through ducts.

1.3 Factors in selecting a conveying system

MODEL Q Selection factors: (1) characteristics of the product conveyed (size, density, flowability, fragility, moisture, abrasiveness); (2) required capacity and speed rating; (3) direction and distance of travel — horizontal vs vertical, lift and length; (4) available space and plant layout; (5) low dead-load of the conveyor relative to product weight; (6) use of gravity where possible; (7) power requirement and energy cost; (8) product damage and degradation; (9) dust/hygiene containment; (10) initial and operating cost, maintenance and reliability.***

1.4 Pneumatic conveyor

Pneumatic conveyor : *moves granular material in a closed duct by a high-velocity air stream (15–30 m/s). The product is carried in dispersed form either by suction (vacuum) or by a blowing (pressure) stream, and separated from the air at the outlet by a cyclone/receiving hopper.*

Three systems: ***pressure (blowing)***, ***suction (vacuum)*** and ***combined push–pull***. Components: an air mover (fan/blower/compressor), a product feeder, ducts, and a cyclone with a fabric filter for product–air separation.

Advantages: flexible routing (around obstacles, any direction), fully enclosed and dust-free, no moving parts in the conveying line, easy multi-point pick-up/delivery. Limitations: high power per tonne, product breakage / abrasion, wear of bends, and limited capacity/distance.

1.5 Comparison of grain-handling equipment

Equipment	Direction	Capacity	Power / tonne	Product damage	Typical use
Belt conveyor	horizontal / gentle incline	high	low	low	long horizontal runs
Screw conveyor	horizontal to vertical	moderate	high	moderate-high	short distances, metering
Bucket elevator	vertical	high	moderate	low-moderate	lifting to height
Pneumatic conveyor	any direction	low-moderate	very high	high (breakage)	flexible routing, dust-free

2 BELT CONVEYOR

2.1 Construction and working

PREVIOUS YEAR QUESTIONS

- *With a neat diagram describe the operation of a belt conveyor indicating the placement of valves and motors.*

  [IFoS 2018 · P2/6(a) · 15M]

- *With the help of a neat sketch, explain the functions of different components, working principle and power requirement of a belt conveyor.*

  [UK·PSC RFO 2012 · Q.6(iii) · 10M]

Belt conveyor : *an endless belt running over two end pulleys, its load supported on idlers, used to convey bagged or bulk material horizontally or on a gentle incline. Because the material rides on the belt with no relative motion, product damage is minimal and mechanical efficiency (anti-friction bearings) is high.*

Main components: the **belt** (reinforced rubber carcass — flat for bags, troughed for bulk grain); **drive (head) pulley and driven motor** with reducer; **tail/take-up pulley** for tension; **idlers** (carrying and return); **loading (feed) and discharge devices** (feed chute, scraper/plough, tripper); frame and drive. Grain is fed at the tail/start pulley and leaves over the head pulley in a parabolic path, or is discharged at intermediate points by a movable tripper or a scraper plough. For grains a belt speed of 2.5–2.8 m/s is recommended.

Belt conveyor — general arrangement

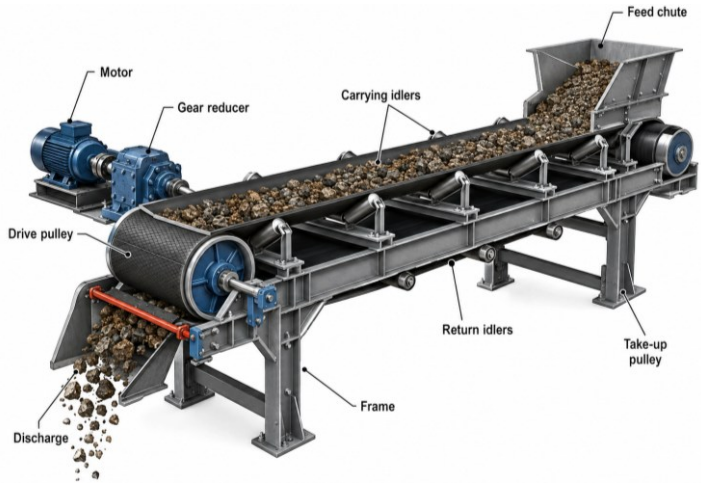


Fig. 4.1 Belt conveyor — components and drive

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2.2 Idlers and the uses of idler pulleys

PREVIOUS YEAR QUESTIONS

- *What are the different uses of idler pulley in a conveyor belt as well as in mechanical transmission?*

[OPSC·CSE 2018-19 / Forest 2019-20 · P2 · 20M]

Three kinds of carrying idlers are used: ***flat idlers*** (granular material, angle of repose ≥ 35°, low capacity); ***20° troughing idlers*** (general bulk material); and ***35°/45° troughing idlers*** (light small particles like grain, cotton seed). Idler spacing ≈ belt width (not exceeding 1.2 m); closer at loading points, with impact idlers to absorb shock.

▶ ***Uses of idler pulleys***

- ***In a conveyor belt*** : support the carrying and return runs; maintain the troughing shape; absorb impact at loading points (impact idlers); train/align the belt to run true (training idlers); increase the wrap/contact angle (snub idler); help maintain belt tension.
- ***In mechanical (belt/chain) transmission*** : act as a tensioner taking up slack and maintaining correct tension; increase the angle of wrap on the driving pulley to prevent slip; guide or change the direction of the belt; permit shorter centre distances; allow use of a fixed centre distance without adjustable mounts.

2.3 Feeding and discharge methods

PREVIOUS YEAR QUESTIONS

- *Explain the various methods for feeding and discharge in a belt conveyor.*

[OPSC·CSE 2018-19 · P2/Q.5(b) · 20M]

- ***Feeding*** : through a feed hopper/chute at the tail pulley; via a feed belt or vibratory feeder; through a controlled gate to regulate flow rate and centre the load on the belt to avoid spillage.
- ***Discharge*** : over the head pulley (parabolic throw) into a chute; at intermediate points by a movable tripper (raises the belt to discharge to either side); or by a scraper/plough (a fixed or adjustable blade that skims material off to the side).

2.4 Capacity and power

PREVIOUS YEAR QUESTIONS

- *Explain the working, capacity and power requirement of belt & screw conveyors and bucket elevators.*

[OPSC·CSE 2020-21 / 2017-18 · P2 · 20M]

Volumetric capacity $Q_v = A \times s \times 60 \quad (m^3/h)$

A = belt cross-section of load (m^2); s = belt speed (m/min).

Mass capacity $Q = (\rho \times Q_v)/1000 \quad (t/h)$

ρ = bulk density (kg/m^3).

$HP_1 = (s/0.3048) \times (A+B)(3.281\,L)/100$ (friction / empty belt)

$HP_2 = Q \times (0.48 + 0.01\,L)/100$ (horizontal conveying of load)

$HP_3 = (\text{lift}/0.3048) \times 1.015 \times (Q/1000)$ (lifting the load)

L = belt length (m); lift in m; Q in t/h; A, B = constants from belt width (Table 6.2); total HP = HP_1+HP_2+HP_3 (+ tripper).

The total power is the sum of the power to run the empty belt against friction (HP_1), to convey the load horizontally (HP_2) and to lift it (HP_3), plus an allowance for trippers. A troughing angle of 20° suits paddy (surcharge angle ≈ 20°).

◆ **WORKED NUMERICAL — *Belt-conveyor capacity (flow rate)*** **[IFoS 2018 · P2/6(b) · 10M]**

Problem. *The mass of material on a 20 m belt conveyor is 200 kg and the belt moves at 2 m/min. Calculate the capacity (flow rate) in kg/s.*

Given:

Mass of material, M = 200 kg

Belt length, L = 20 m

Belt speed, v = 2 m/min

1. Mass of material per metre of belt

Mass per metre = M / L

= 200 / 20

= 10 kg/m

2. Conveyor capacity

Capacity = Mass per metre × Belt speed

= 10 × 2

= 20 kg/min

3. Convert into kg/s

Capacity = 20 / 60

= 0.333 kg/s

Final Answer:

Conveyor capacity = 0.333 kg/s

2.5 *Belt tension, belt material and merits*

The belt must carry the load without excessive sag or slip. Adequate ***belt tension*** is maintained by a take-up (gravity or screw) at the tail pulley; the driving pulley needs enough angle of wrap and friction (lagging) to transmit power without slipping (governed by $T_1/T_2 = e^{\mu\theta}$). Belts are reinforced-rubber, built from a fabric/synthetic (polyester–polyamide) carcass of several plies for tensile strength, with a rubber cover for wear protection.

- ***Advantages*** : gentle handling (no relative motion, minimal damage); high capacity and long horizontal reach; high mechanical efficiency (anti-friction bearings) and low power; long life, low operating cost; can discharge at multiple points via tripper.
- ***Limitations*** : limited lift (steep inclines cause roll-back); higher initial cost for long runs; not dust-tight; needs alignment/training and take-up maintenance.

3 SCREW CONVEYOR

3.1 *Construction, working and trough shapes*

PREVIOUS YEAR QUESTIONS

Explain the working principle of screw conveyor with a neat drawing. List various shapes of

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screw conveyor trough.

[IFoS 2023 · P2/5(c) · 8M]

- *Explain the construction and working principle of screw conveyor. State the formulae to express the capacity and power requirement of screw conveyor with detail notations.*

[MH·PSC Forest 2024 · Q.7(a) · 15M]

Screw (auger) conveyor : *a rotating helical screw (flight) mounted on a shaft inside a U-shaped or tubular trough; rotation of the screw pushes the material along the trough. Used for short-distance horizontal (or inclined up to 90°) conveying in grain, feed and processing plants. Simple drive, low initial cost, but relatively high power and wear.*

Main parts: ***screw blade/flight*** (a continuous one-piece helix), ***shaft***, ***trough***, inlet and outlet gates, bearings (end and hanger) and drive. The standard screw ***pitch equals its diameter***. A small clearance between flight edge and trough means a horizontal trough cannot be fully emptied; direction of rotation does not affect capacity.

▶ ***Trough shapes***

- ***U-shaped trough*** : the most common; open top, for general free-flowing materials.
- ***Flared / enlarged trough*** : side walls widen at the top; for non-easy-flowing materials or those with lumps.
- ***Tubular (closed) trough*** : fully closed circular cross-section; used for conveying at inclination or for vertical lift.

▣ *Screw conveyor and trough shapes*

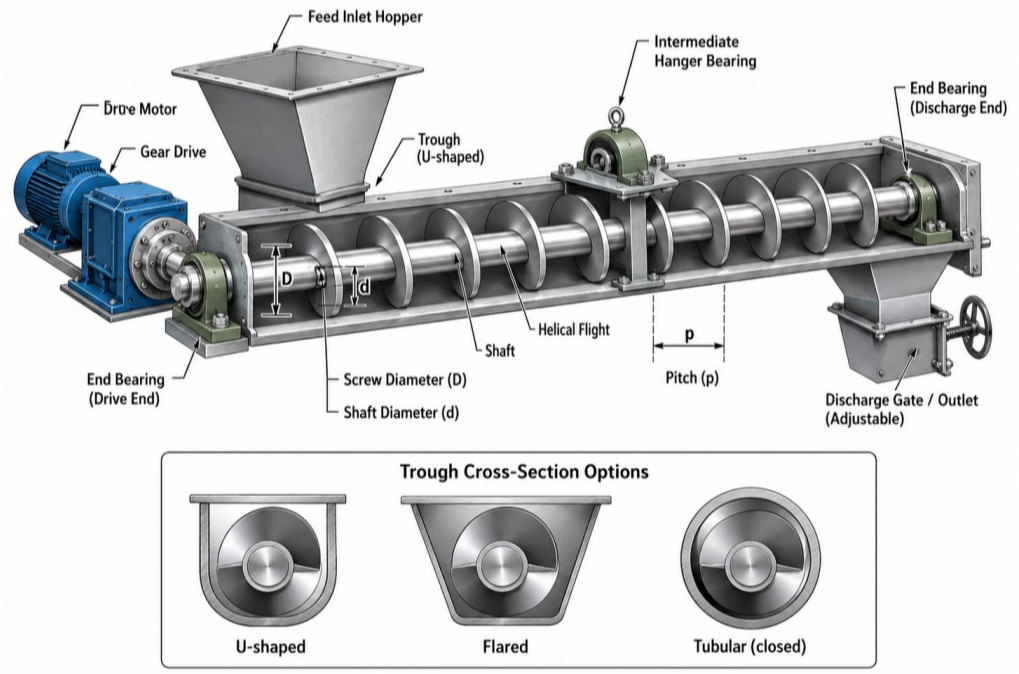


Fig. 3.1 Schematic psychrometric chart with a state point

3.2 *Capacity and power*

Capacity $Q = 47.2\ (D^2 - d^2) \cdot p \cdot n = (\pi/4)(D^2 - d^2) \cdot p \cdot n \cdot 60 \quad (m^3/h)$

D = screw diameter (m); d = shaft diameter (m); p = pitch (m); n = screw speed (rpm).

$$\text{Horse power} = (Q \cdot L \cdot W \cdot F)/4560$$

Q = capacity (m^3/min); L = conveyor length (m); W = bulk material weight (kg/m^3); F = material factor.

Mass capacity follows by multiplying the volumetric capacity by bulk density and a loading (fill) factor. In inclined operation the capacity falls with the angle of lift.

◆ **WORKED NUMERICAL — *Screw-conveyor capacity (illustrative)*** **[demonstrates the capacity formula]**

Problem. *A screw conveyor has screw diameter D = 0.30 m, shaft diameter d = 0.06 m, pitch p = 0.30 m and runs at n = 50 rpm. Grain bulk density 750 kg/m³, loading factor 0.4. Find the theoretical volumetric and mass capacity.*

Given :

Screw diameter, D = 0.30 m

Shaft diameter, d = 0.06 m

Pitch, p = 0.30 m

Speed, n = 50 rpm

Bulk density, ρ = 750 kg/m³

Loading factor, ϕ = 0.4

1. Cross-sectional area available for grain

$$A = (\pi/4)(D^2 - d^2)$$

$$A = (\pi/4)[(0.30)^2 - (0.06)^2]$$

$$A = (\pi/4)(0.09 - 0.0036)$$

$$A = \mathbf{0.06786\ m^2}$$

2. Volumetric capacity

Volume conveyed per revolution:

$$V = A \times p$$

$$V = 0.06786 \times 0.30$$

$$= 0.02036\ m^3/rev$$

Considering 50 rpm and loading factor 0.4:

$$Q_v = A \times p \times n \times \phi$$

$$Q_v = 0.06786 \times 0.30 \times 50 \times 0.4$$

$$= \mathbf{0.407\ m^3/min}$$

Therefore,

$$Q_v = 0.407 \times 60$$

$$= \mathbf{24.43\ m^3/h}$$

3. Mass capacity

Mass capacity = Volumetric capacity × Bulk density

$$Q_m = 0.407 \times 750$$

$$= \mathbf{305.4\ kg/min}$$

or,

$$Q_m = 305.4 \times 60$$

$$= \mathbf{18{,}324\ kg/h}$$

$$\approx \mathbf{18.3\ tonnes/h}$$

Final Answer:

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Volumetric capacity = 0.407 m³/min = 24.43 m³/h

Mass capacity = 305.4 kg/min = 18.3 tonnes/h

Note: At 100% filling, the geometric capacity would be about **1.018 m³/min**. The stated answer incorporates the given **0.4 loading factor**.

- ***Advantages*** : simple, compact and enclosed (dust-tight, minimal spillage); low initial cost; easy multi-point loading/discharge; can convey and gently mix or meter material; works at any inclination.
- ***Limitations*** : high power per tonne (sliding friction); more wear of flight and trough; product breakage from shear between flight and trough; limited to short distances and moderate capacity.

4 BELT VS SCREW CONVEYOR — POWER COMPARISON

PREVIOUS YEAR QUESTIONS

- *Among the two types of conveyors — belt and screw — which type consumes more power and why? With a diagram, explain the operation of a screw conveyor.*

  [IFoS 2019 · P2/6(a) · 15M]

- *Among belt and screw conveyors, which consumes more power and why?*

  [MH·PSC Forest 2024 · Q.7(a) · part · 15M]

The ***screw conveyor consumes more power*** than a belt conveyor of the same capacity and length. Reason: in a screw conveyor the material is ***dragged and tumbled along a stationary trough***, so it is in continuous sliding friction with the flight and the trough walls, and part of the material rotates with the screw — all of which dissipate energy and cause wear. In a belt conveyor the material ***rides on the moving belt with no relative motion***, the belt runs on anti-friction idler bearings, and only rolling friction is involved — giving high mechanical efficiency and low power per tonne. Hence, for the same duty, the screw conveyor's power demand and wear are markedly higher, which is why it is used mainly for short distances.

Feature	*Belt conveyor*	*Screw conveyor*
Material motion	rides on belt, no relative motion	dragged/tumbled in fixed trough
Friction type	rolling (idler bearings)	sliding (flight & trough)
Power per tonne	low	high
Wear & product damage	low	higher
Distance	long horizontal	short
Capacity	high	moderate

5 BUCKET ELEVATOR

5.1 *Construction, types and working*

PREVIOUS YEAR QUESTIONS

- *Describe the characteristic features of a bucket elevator.*

  [OPSC·CSE 2022-23 · P2/Q.8(a) · 10M]

- *Describe the working principle of centrifugal-type bucket elevator used for handling grains. Describe the formula for determining the power requirement of a bucket elevator.*

  [UK·PSC 2021 / ACF 2019 · Q.7(iv) · 10M]

Bucket elevator : *buckets attached to an endless belt or chain running over a head (drive) pulley and a boot (tail) pulley, for efficient vertical conveyance of bulk grain — from a few metres to over 50 m, at 2 to 1000 t/h. Enclosed in dust-tight legs; compact horizontal footprint.*

Classification : ***spaced-bucket*** (centrifugal-discharge, positive-discharge, marine-leg, high-speed) and ***continuous-bucket*** (super-capacity, internal-discharge). The spaced-bucket centrifugal-discharge type is most common for grain. Main parts: ***head section, boot section, elevator legs, belt/chain and buckets***. Buckets are filled by digging in the boot (front, back or combined feed) and discharge at the head by gravity (low speed) or centrifugal force (high speed) — in grain elevators the discharge is a combination of both. Belt speeds are 2.5–4 m/s. A cut-off plate near the bucket lip prevents ***back-logging*** (material falling back into the down-leg, which reduces capacity).

Bucket elevator — centrifugal-discharge type

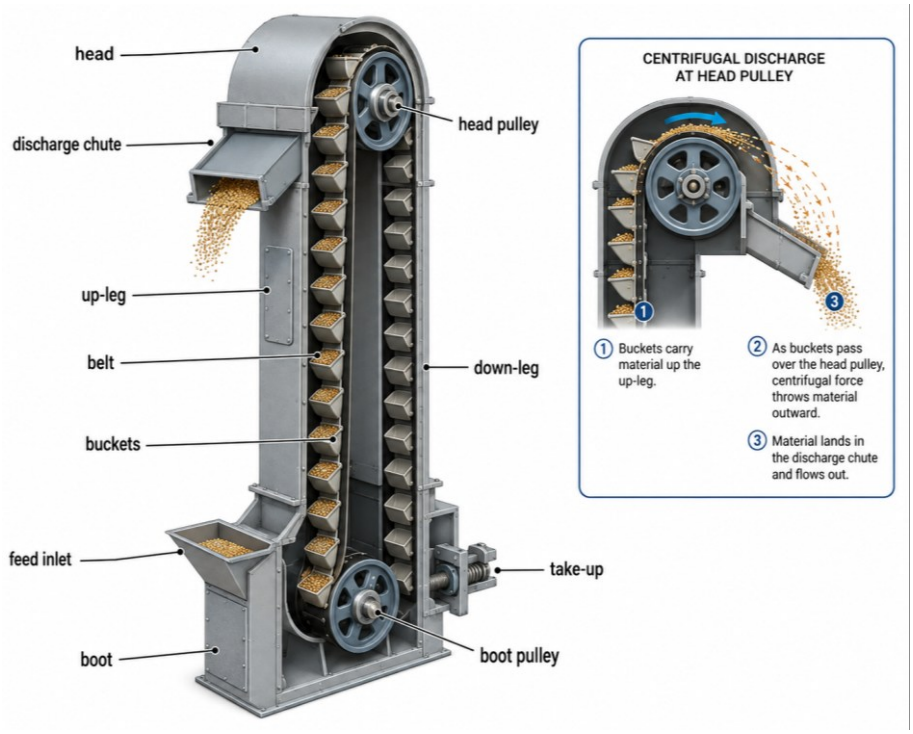


Fig. 3.1 Schematic psychrometric chart with a state point

5.2 *Centrifugal discharge, speed and capacity*

At the head pulley a bucket's load is acted on by gravity (downward) and centrifugal force (outward). For clean centrifugal discharge the resultant should point toward the bucket lip; the head-pulley speed is found by equating centrifugal force to gravity.

Centrifugal force $c_f = W \cdot V^2/(g \cdot r)$

W = weight of grain; V = velocity; g = 9.81 m/s²; r = pulley radius + ½ bucket projection.

For optimum discharge $c_f = W \Rightarrow V = \sqrt{(g \cdot r)}$, and with $V = 2\pi nr/60$: $n = 29.9/\sqrt{r}$ (rpm)

Capacity Q_v = (bucket volume) × (buckets per m of belt) × (belt speed, m/min) × 60 (m^3/h)

Capacity $Q = (\rho \times Q_v)/1000$ (t/h)

ρ = bulk density (kg/m³); apply a fill (degree-of-lifting) factor to bucket volume.

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◆ **WORKED NUMERICAL — *Bucket-elevator capacity (illustrative)*** [demonstrates the capacity formula]

Problem. *Buckets of 2 L capacity are spaced 0.30 m apart on a belt moving at 90 m/min; fill factor 0.75; grain bulk density 750 kg/m³. Find the volumetric and mass capacity.*

Given :

Bucket capacity = 2 L = 0.002 m³

Bucket spacing = 0.30 m

Belt speed = 90 m/min

Fill factor = 0.75

Bulk density of grain = 750 kg/m³

1. Number of Buckets Passing per Minute

Number of buckets/min = Belt speed / Bucket spacing

= 90 / 0.30

= **300 buckets/min**

2. Effective Volume per Bucket

Effective bucket volume = Bucket capacity × Fill factor

= 0.002 × 0.75

= **0.0015 m³**

3. Volumetric Capacity

Volumetric capacity = Number of buckets/min × Effective volume per bucket

= 300 × 0.0015

= **0.45 m³/min**

Converting into m³/h:

= 0.45 × 60

= **27 m³/h**

Therefore,

Volumetric capacity = 27 m³/h

4. Mass Capacity

Mass capacity = Volumetric capacity × Bulk density

= 27 × 750

= **20,250 kg/h**

= **20.25 tonnes/h**

Final Answer

Volumetric capacity = 27 m³/h

Mass capacity = 20,250 kg/h = 20.25 tonnes/h

5.3 *Design parameters and power*

PREVIOUS YEAR QUESTIONS

What parameters are to be considered while designing a bucket elevator? Describe briefly.

[IFoS 2017 · P2/5(b) · 10M]

MODEL Q Design parameters: required capacity (t/h) and lift height; bucket size, shape and spacing; belt/chain speed and head-pulley diameter (set by centrifugal-discharge condition); fill factor; bulk density and flowability of grain; belt tension and strength (loads from height, product, bucket weight, digging resistance); running clearances (belt vs bucket width, casing, lip); power requirement; and back-logging prevention. Power = power to lift the grain (ṁ·g·H) + power to overcome friction (belt/bucket dead load and axle friction), with an allowance for transmission losses.***

Lifting power $P = \dot{m} \cdot g \cdot H$ (÷ efficiency, or × loss allowance)
$\dot{m}$ = grain mass flow (kg/s); H = lift height (m). Equivalently P(kW) = Q·H/367 for Q in t/h.

5.4 *Worked numericals*

◆ **WORKED NUMERICAL — *Bucket-elevator power (paddy)*** **[OPSC·CSE 2022-23 · P2/Q.8(b) · 5M / 2024-25 · Q.8]**

Problem. *Calculate the power required for a bucket elevator to convey 0.5 tonnes of paddy per minute to a height of 11 m. Allow 20% for frictional and transmission losses.*

Given :

Capacity = 0.5 tonne/min = 500 kg/min
Height, H = 11 m
Acceleration due to gravity, g = 9.81 m/s²
Losses = 20%

1. Convert Mass Flow Rate into kg/s

Mass flow rate:
= 500 / 60
= **8.33 kg/s**

2. Theoretical Power Required

Power required for lifting:
$P = \dot{m} \times g \times H$
$P = 8.33 \times 9.81 \times 11$
P = **899 W**
= **0.899 kW**

3. Allow for 20% Losses

Actual power required:
= 0.899 × 1.20
= **1.079 kW**
Therefore,
Power required ≈ 1.08 kW

Final Answer

Theoretical power = **0.899 kW**
Power including 20% frictional and transmission losses = **1.08 kW**
Required bucket-elevator power ≈ 1.1 kW

◆ **WORKED NUMERICAL — *Bucket-elevator speed & power*** **[IFoS 2025 · P2/7(b) · 10M]**

Problem. *A bucket elevator lifts foodgrains (750 kg/m³) to 25 m. Bucket volume 3500 cc, spacing 40 cm on the belt; head–foot centre distance 25.30 m; head pulley 30 cm dia on a 5 cm shaft; belt + empty buckets 5 kg/m; degree of lifting 80%; axle coefficient of friction 0.4. Find the speed and power to lift 4 t/h.*

Given :

Capacity, Q = 4 t/h = 4000 kg/h
Bulk density, ρ = 750 kg/m³
Bucket volume = 3500 cc
= 3500×10^{-6} m³
= 0.0035 m³
Bucket spacing, S = 0.40 m

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Degree of filling = 80% = 0.80

Lift height, H = 25 m

Head–foot centre distance = 25.30 m

Head pulley diameter, D = 0.30 m

Shaft diameter, d = 0.05 m

Mass of belt + empty buckets = 5 kg/m

Coefficient of axle friction, μ = 0.4

1. Grain Carried by Each Bucket

Actual volume of grain per bucket:

$V = 0.0035 \times 0.80$

$V = 0.0028\ m^3$

Mass carried per bucket:

$m = V \times \rho$

$m = 0.0028 \times 750$

$m =$ **2.10 kg/bucket**

2. Belt Speed

Required capacity:

$Q = 4000/60$

$Q = 66.67$ kg/min

Number of buckets required per minute:

Number of buckets/min = 66.67/2.10

= 31.75 buckets/min

Since buckets are spaced 0.40 m apart:

Belt speed = 31.75 × 0.40

= **12.70 m/min**

or

Belt speed = 12.70/60

= **0.212 m/s**

Therefore,

Required belt speed = 12.7 m/min ≈ 0.212 m/s

3. Head Pulley Speed

Circumference of head pulley: $= \pi D$

$= \pi \times 0.30$

= 0.9425 m

Pulley speed:

N = Belt speed / Pulley circumference

N = 12.70/0.9425

= **13.47 rpm**

4. Power Required to Lift Grain

Mass flow rate:

$\dot{m} = 4000/3600$

= 1.111 kg/s

Theoretical lifting power:

$P_1 = \dot{m}gH$

$P_1 = 1.111 \times 9.81 \times 25$

$P_1 = 272.5$ W

$P_1 =$ **0.273 kW**

5. Power Required to Overcome Axle Friction

Length of the two vertical belt runs:

$$L = 2 \times 25.30$$
$$= 50.60 \text{ m}$$

Mass of belt + empty buckets:

$$W_1 = 50.60 \times 5$$
$$= \mathbf{253 \text{ kg}}$$

Number of loaded buckets on ascending side:

$$= 25.30/0.40$$
$$= 63.25 \text{ buckets}$$

Mass of grain carried on ascending side:

$$W_2 = 63.25 \times 2.10$$
$$= \mathbf{132.83 \text{ kg}}$$

Total mass supported:

$$W = 253 + 132.83$$
$$= \mathbf{385.83 \text{ kg}}$$

Total weight:

$$= 385.83 \times 9.81$$
$$= 3785 \text{ N}$$

Frictional torque at shaft: $T = \mu W(d/2)$

$$T = 0.4 \times 3785 \times 0.025$$
$$= \mathbf{37.85 \text{ N·m}}$$

Angular velocity of head pulley: $\omega = v/(D/2)$

$$\omega = 0.212/0.15$$
$$= 1.411 \text{ rad/s}$$

Frictional power: $P_2 = T\omega$

$$P_2 = 37.85 \times 1.411$$
$$= 53.4 \text{ W}$$
$$P_2 = \mathbf{0.053 \text{ kW}}$$

6. Total Power Required

Total power: $P = P_1 + P_2$

$$P = 0.273 + 0.053$$
$$P = \mathbf{0.326 \text{ kW}}$$

Therefore,

Total power required ≈ 0.33 kW

In horsepower:

Power ≈ **0.44 hp**

Final Answer

Belt speed = 12.7 m/min = 0.212 m/s

Head pulley speed ≈ 13.5 rpm

Theoretical lifting power = 0.273 kW

Power required to overcome axle friction ≈ 0.053 kW

Total power required ≈ 0.326 kW ≈ 0.33 kW (≈ 0.44 hp)

MODEL Q For such elevator problems: speed follows from the capacity equation (buckets per minute ×

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effective bucket volume = required volume rate); power = grain-lifting power plus axle/belt friction. State the fill factor and friction model used.***

5.5 Main parts, merits and limitations

- ***Head section*** : houses the drive pulley (lagged for grip) and the curved hood/discharge chute, shaped so material clears the buckets into the chute (a cut-off plate prevents back-logging).
- ***Boot section*** : bolted assembly at the base with the tail pulley, belt take-up (gravity/screw) and the feed inlet located so buckets dig above the return-pulley centre line.
- ***Legs & belt*** : dust-tight up- and down-legs (single or double); the belt carries the entire load (height, product, bucket and digging resistance) and needs high tensile strength and low stretch (≤1–2%).
- ***Advantages*** : high-capacity vertical lift; compact horizontal footprint; enclosed, dust-free, reasonably quiet; cheap means of elevation.
- ***Limitations*** : purely vertical; sensitive to correct speed for clean discharge; back-logging and belt/bucket wear; needs careful feeding and take-up.

6 GRAIN STORAGE STRUCTURES

6.1 Storage need and types of structures

PREVIOUS YEAR QUESTIONS

What are various types of food-grain storage structures?

[OPSC·CSE 2020-21 · P2/Q.6(a) · part · 20M]

Grain must be stored safely between harvest and use; good storage (moisture and insect control) keeps losses below ~0.5%. Storage structures are grouped as:

- ***Traditional structures*** : indigenous bins of mud, bamboo, brick or wood — kothar, morai, muda, bukhari, kanaj — of 1–50 t capacity; low cost but poor moisture/pest protection.
- ***Improved farm structures*** : Pusa bin (mud-cum-polythene, moisture-proof), PAU bin, metal/aluminium bins — better sealed for safe farm storage.
- ***Bag storage in godowns*** : grain in gunny/HDPE bags stacked on dunnage in covered warehouses.
- ***CAP (cover-and-plinth) storage*** : open transit storage of bag stacks on a raised plinth under polythene covers.
- ***Modern bulk storage*** : mild-steel/RCC/aluminium bins and silos for mechanised bulk handling.

▶ ***Bag vs bulk storage***

Aspect	Bag storage	Bulk storage
Handling	manual, labour-intensive	mechanised, automated
Space	more (stacks + gangways)	less per tonne
Bag cost	recurring	none
Inspection/segregation	easy, lot-wise	difficult
Losses (rodents/spillage)	higher	lower (sealed)
Capital cost	lower	higher

6.2 Bag storage and its design

PREVIOUS YEAR QUESTIONS

Discuss design considerations in bag storage structures for grains. Design a bag storage structure for storing 200 tonnes of paddy. Make rational assumptions.

[MH·PSC Forest 2024 · Q.3(b) · 15M]

In bag storage, grain in gunny/HDPE bags is stacked in a covered godown. ***Design considerations***: bag size and weight; stack size and height (stability, safe manual handling); dunnage (wooden crates/bamboo mats/polythene beneath the stack to prevent ground-moisture ingress); gangways/alleys for movement, inspection and fumigation; clearance from walls and roof; ventilation and moisture control; loading/unloading access; rat- and bird-proofing; and fire safety. In CAP storage, stacks (up to ~18 bags high, ≈150 t) are built on dunnage over a raised plinth and covered with 1000-gauge polythene.

◆ **WORKED NUMERICAL — *Bag storage design — 500 t wheat*** **[IFoS 2021 · P2/7(b) · 15M]**

Problem. *Design a bag storage structure for 500 t wheat. Bag 70 × 50 × 30 cm holding 50 kg; keep 15 bags in length and 15 in width per stack, 15 layers high. Assume reasonable data.*

Given Data

Total wheat to be stored = 500 t = 500,000 kg
Weight of wheat per bag = 50 kg
Bag dimensions = 0.70 m × 0.50 m × 0.30 m
Bags in length per stack = 15
Bags in width per stack = 15
Number of layers = 15
Assume:
Clearance between adjacent stacks = 1.0 m
Clearance between stack and wall = 1.0 m
Clear internal height of storage building = 6.0 m

1. Total Number of Bags Required

Number of bags = Total quantity / Capacity of one bag
Number of bags = 500,000 / 50
= **10,000 bags**

2. Number of Bags in One Stack

Bags per stack = 15 × 15 × 15
= **3375 bags**
Storage capacity of one stack:
= 3375 × 50
= 168,750 kg
= **168.75 t**

3. Number of Stacks Required

Number of stacks = 500 / 168.75
= 2.96

Therefore, provide:

Number of stacks = 3
Capacity provided by 3 full stacks:
= 3 × 168.75
= **506.25 t**

Thus, three stacks are sufficient for storing 500 t of wheat.

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4. Dimensions of One Stack

Stack length:

= 15 × 0.70

= **10.50 m**

Stack width:

= 15 × 0.50

= **7.50 m**

Stack height:

= 15 × 0.30

= **4.50 m**

Therefore, size of each stack:

10.5 m × 7.5 m × 4.5 m

Floor area occupied by one stack:

= 10.5 × 7.5

= **78.75 m²**

For three stacks:

= 3 × 78.75

= **236.25 m²**

5. Design of Storage Building

Assume that the three stacks are arranged longitudinally in one row.

Required building length: = (3 × stack length) + (2 × inter-stack clearance) + (2 × wall clearance)

= (3 × 10.5) + (2 × 1.0) + (2 × 1.0)

= 31.5 + 2 + 2

= **35.5 m**

Required building width:

= Stack width + clearance on both sides

= 7.5 + 1 + 1

= **9.5 m**

Since stack height is 4.5 m, provide sufficient clearance for ventilation, handling and roof structure.

Adopt clear building height:

= **6.0 m**

6. Required Floor Area

Floor area of storage structure:

= 35.5 × 9.5

= **337.25 m²**

Therefore, provide approximately:

340 m² of floor area

Final Design

Total wheat storage capacity = **500 t**

Number of bags = **10,000**

Bags per stack = **3375**

Number of stacks required = **3**

Size of each stack = **10.5 m × 7.5 m × 4.5 m**

Recommended internal godown dimensions = **35.5 m × 9.5 m × 6.0 m**

Required floor area = **≈ 337 m²**, say **340 m²**

Capacity provided by three full stacks = **506.25 t**

Recommended Practical Provisions

Provide a raised, damp-proof floor and dunnage below the bags; maintain adequate wall and stack clearances for inspection and ventilation; provide rodent-proof construction, ventilation openings, fire-safety arrangements and suitable loading/unloading access.

Hence, a bag storage structure of approximately 35.5 m × 9.5 m floor dimensions with about 6 m clear height is adequate for storing 500 tonnes of wheat under the stated stacking arrangement.

◆ **WORKED NUMERICAL — *Bag storage design — 200 t paddy*** **[MH·PSC Forest 2024 · Q.3(b) · 15M]**

Problem. *Design a bag storage structure for 200 t paddy. Rational assumptions: 50 kg bags, bag 70 × 50 × 30 cm.*

Total bags = 200 000/50 = 4000 bags.

Stack (15 L × 15 W footprint) = 225 bags/layer; keep height ~9 layers (≈2.7 m) for stability.

Stacks bags/stack = 225×9 = 2025; number of stacks = 4000/2025 ≈ 2 stacks.

Footprint each 10.5 m × 7.5 m = 78.75 m²; two stacks = 157.5 m².

Floor area = bags 157.5 m²; with ~40% gangways/clearance ≈ 220 m² godown floor.

6.3 *Bulk storage — bins and silos*

PREVIOUS YEAR QUESTIONS

What are various types of food-grain storage structures? Explain aluminium bin and R.C.C. bin with schematic diagram. List out the factors affecting the design of silo.

[OPSC·CSE 2020-21 · P2/Q.6(a) · 20M]

Modern bulk storage uses ***bins and silos*** of mild steel, RCC, galvanised/aluminium sheet, ferro-cement, brick or fibreglass; in India mild-steel and RCC bins are common. Advantages over bags: cheaper handling and quality control, less space, no bag cost, easy mechanisation/automation, and protection from rodents and birds. An ***aluminium bin*** is a light, corrosion-resistant sheet-metal bin (often domestic/farm scale, e.g. Pusa bin variants) with a filling hole on top and an outlet at the bottom; an ***RCC bin/silo*** is a reinforced-concrete cylindrical structure with a conical bottom and bottom outlet, durable and of large capacity (1.5–60 t and above).

▶ *Deep vs shallow bins*

Bins are classed by the ***plane of rupture***: in a ***shallow bin*** the plane of rupture from the base meets the free grain surface (grain pressure largely on the floor); in a ***deep bin*** it meets the opposite wall (much of the weight carried by wall friction). This distinction governs the pressure analysis.

▶ *Factors affecting silo/bin design*

- apparent (compacted) density of grain — ~20% above loose bulk density, used for load design; bottom layers densest.
- lateral and vertical pressure of grain on walls and floor (deep-bin theory — Janssen/Airy — wall friction reduces the vertical pressure increase with depth).
- angle of repose and flowability; angle of internal friction and wall (external) friction (depends on wall material — steel, concrete, stainless).
- grain moisture content and its effect on flow and spoilage; provision against moisture migration (temperature-driven) and aeration.

- capacity, height-to-diameter ratio, bottom (conical) shape and outlet for free flow; structural loads (wind, seismic), foundation, and material of construction.

▶ ***Lateral pressure in a deep bin (Janssen)***

$$p_v = (\gamma R/\mu' K)(1 - e^{(-\mu' K \cdot h/R)}) \; ; \quad p_h = K \cdot p_v$$

p_v, p_h = vertical & lateral pressure at depth h; γ = bulk unit weight; R = hydraulic radius (area/perimeter); μ' = coefficient of wall friction; K = ratio of lateral to vertical pressure. Wall friction makes pressure approach a limiting value with depth (unlike a fluid) — the basis of deep-bin design.

▣ ***Deep vs shallow bin; RCC & aluminium bin***

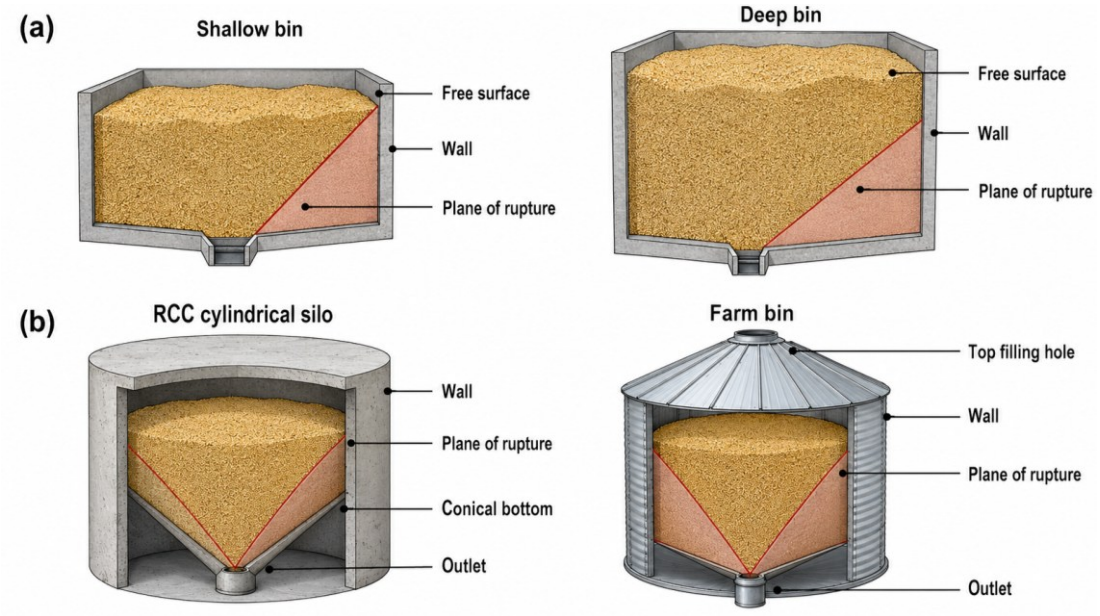


Fig. 4.4 Deep vs shallow bins; RCC silo and aluminium bin

6.4 Requirements of good storage and causes of loss

A good storage structure should be ***moisture-proof, air-tight (or well-aerated), and rodent-, bird- and insect-proof***, with adequate strength for grain pressure, easy loading/unloading, provision for inspection, fumigation and aeration, and economy of construction.

▶ ***Causes of storage loss***

Losses arise from ***moisture migration*** (temperature differences set up convection currents inside the bin, carrying moisture to a cold spot where it condenses and spoils grain), high grain moisture and warm climate promoting mould and insect growth, respiration heating, and attack by insects, rodents and birds. Control: dry grain to safe moisture before storage, aerate to remove respiration heat, and seal/fumigate against pests.

7 FOOD PACKAGING & MAP/CAP

7.1 Functions and requirements of food packaging

PREVIOUS YEAR QUESTIONS

Write the functions of a food packaging material.

[IFoS 2020 · P2/8(c) · part · 10M]

> *Why is packaging essential? Describe the requirements, advantages and classify the materials used for packaging.*
>
> [OPSC-CSE 2020-21 · P2/Q.6(c) · 20M]

Packaging is the essential link between food producer and consumer, preserving quality achieved by processing. Its ***functions***: ***containment*** (hold the product through filling, handling, transport); ***protection*** (barrier against microbes, insects, rodents, moisture gain/loss, oxygen, light, aroma loss and physical damage); ***preservation*** (extend shelf-life); ***communication*** (labelling, branding, bar codes, dating); ***convenience*** (easy handling, opening, dispensing, resealing); and ***unitization*** (group items for efficient distribution).

▶ ***Requirements of a good food package***

Non-toxic and food-compatible; barrier to moisture, gases, odour and UV light; resistant to physical damage; tamper-evident; easy to open, dispense and reseal; meets size/shape/weight needs; good printability and appearance; economical; and easy to dispose of or recycle.

7.2 Packaging materials and their characteristics

PREVIOUS YEAR QUESTIONS

> *Explain different types of food packaging materials with their characteristics.*
>
> [IFoS 2025 · P2/5(b) · 8M]

- ***Glass*** : inert, transparent, impermeable, rigid, reusable; but heavy and fragile — jars/bottles for jams, beverages, pickles.
- ***Metal (tinplate, aluminium)*** : excellent barrier (light, gas, moisture), strong, heat-processable (cans); tinplate for cans, aluminium for foil, cans and laminates; risk of corrosion — needs lacquering.
- ***Paper & paperboard*** : light, cheap, printable, biodegradable; poor moisture/gas barrier unless waxed/laminated/coated — cartons, bags, corrugated boxes (secondary packaging).
- ***Plastics (flexible & rigid)*** : versatile, light, heat-sealable, mouldable; LDPE/HDPE (moisture barrier, bags/bottles), PP (clarity, heat resistance), PET (strong, clear bottles), PVC, PS; varying gas/moisture barrier.
- ***Laminates & co-extrusions*** : multilayer combinations (e.g. paper/foil/PE) giving tailored barrier, strength and heat-sealability — pouches, aseptic cartons, retort pouches.

▶ ***Classification of packaging***

By function/level: ***primary*** (in direct contact with food), ***secondary*** (groups primary packs), ***tertiary*** (for bulk transport/distribution). By rigidity: rigid (glass, metal cans), semi-rigid (trays, tubs) and flexible (films, foils, pouches). By use: consumer vs bulk packaging.

▶ ***Barrier properties and shelf-life***

A material's ***permeability*** to water vapour (WVTR) and gases (O_2, CO_2) largely decides the shelf-life of the packed food: a low-permeability (high-barrier) package slows moisture change and oxidation. Glass and metal are near-perfect barriers; plastics and papers vary widely, so laminates and coatings build the required barrier while keeping the package light, printable and heat-sealable. Selection matches barrier, mechanical and cost needs to the product's sensitivity and target shelf-life.

7.3 Modern packaging techniques

- ***Aseptic packaging*** : product and package are sterilised separately and filled/sealed in a sterile environment — gives long ambient shelf-life without refrigeration (e.g. UHT milk, juices in Tetra Pak laminate cartons).
- ***Vacuum packaging*** : air is evacuated before sealing, removing O_2 to slow oxidation and aerobic spoilage (e.g. meats, cheese).
- ***Active packaging*** : the package interacts with the food — O_2 scavengers, moisture absorbers, CO_2 emitters, antimicrobial films — to extend shelf-life beyond an inert barrier.
- ***Intelligent / smart packaging*** : indicators and sensors (time–temperature, freshness, gas indicators) that communicate the product's condition.

Advantages of modern packaging: longer shelf-life, better retention of quality and nutrition, reduced spoilage and losses, consumer convenience and safety, and improved marketability.

7.4 *Modified & controlled atmosphere packaging*

PREVIOUS YEAR QUESTIONS

What is modified atmosphere packaging? Briefly describe how a MAP works. Differentiate between modified atmosphere storage and controlled atmosphere storage.

[IFoS 2020 · P2/8(c) · part · 10M]

Modified Atmosphere Packaging (MAP) : *the atmosphere around the food is altered at the time of packing — typically by lowering O_2 and raising CO_2 (and/or N_2) — to slow respiration, microbial growth and oxidation, then the pack is sealed. It is* ***not actively regulated*** *thereafter: the gas mix drifts with product respiration and the film's permeability. MAP works by gas-flushing or vacuum-then-backflush at sealing, choosing a film of suitable gas permeability so a beneficial equilibrium atmosphere is maintained around the product, extending shelf-life.*

Feature	*Modified Atmosphere (MAP)*	*Controlled Atmosphere (CAP)*
Gas control	set once at packing, then passive	continuously monitored & maintained
Scale	retail packages	bulk cold-storage rooms
Precision	approximate, drifts	tight, regulated set-points
Equipment	gas-flush packaging machine	CA store + gas generators & sensors
Example	packed meat/produce trays	apple/kiwi CA cold store

◆ *Source: Food Packaging Technology, L3 (functions) & materials chapters; Singh & Heldman, Ch. 15.*

8 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

Formula Sheet

Belt capacity: $Q_v = A \cdot s \cdot 60\ (m^3/h)$; $Q = \rho \cdot Q_v/1000\ (t/h)$

Belt power: $HP = HP_1 + HP_2 + HP_3$; $HP_1=(s/0.3048)(A+B)(3.281L)/100$; $HP_2=Q(0.48+0.01L)/100$; $HP_3=(lift/0.3048)(1.015)(Q/1000)$

Belt flow rate (simple): $Q =$ (load per m) × belt speed

Screw capacity: $Q = 47.2(D^2-d^2)\cdot p \cdot n\ (m^3/h)$; pitch p = diameter D (standard)

Screw power: $HP = Q \cdot L \cdot W \cdot F / 4560$

Bucket elevator discharge: $c_f = W \cdot V^2/(g \cdot r)$; $V = \sqrt{(g \cdot r)}$; $n = 29.9/\sqrt{r}$ (rpm)

Bucket elevator capacity: $Q_v = V_{bucket} \times (buckets/m) \times belt\ speed(m/min) \times 60$; $Q = \rho \cdot Q_v/1000$

Lifting power: $P = \dot{m} \cdot g \cdot H$ ($\div \eta$ or $\times$ loss allowance) ; $P(kW) = Q(t/h) \cdot H/367$

SUMMARY

Chapter 4 covers packaging and the mechanical handling of agricultural produce. The four grain-handling devices are the belt conveyor, screw conveyor, bucket elevator and pneumatic conveyor; selection depends on product characteristics, capacity, direction/distance, space, dead-load, gravity, power and cost. The belt conveyor moves material on an endless belt over idlers (flat, 20°, 35/45° troughing) with feed at the tail and discharge over the head or by tripper/plough; capacity $Q_v = A \cdot s \cdot 60$ and power = $HP_1+HP_2+HP_3$. Idler pulleys support and train the belt and, in transmission, act as tensioners and increase wrap angle. The screw conveyor pushes grain with a rotating helix in a U-shaped, flared or tubular trough; capacity = $47.2(D^2-d^2)pn$ and power = QLWF/4560; it consumes more power than a belt because the grain is dragged in sliding friction against the trough. The bucket elevator lifts grain vertically with spaced or continuous buckets, discharging by gravity or centrifugal force ($n = 29.9/\sqrt{r}$); power = grain-lifting power + friction. Storage structures span bag storage (dunnage, stacking, CAP), and bulk bins/silos (mild-steel, RCC, aluminium; deep vs shallow by plane of rupture), designed for apparent density, lateral pressure, friction angles, moisture and capacity. Food packaging provides containment, protection, preservation, communication, convenience and unitization using glass, metal, paper/board, plastics and laminates; MAP alters the pack atmosphere once at sealing, while CA storage actively maintains it.

LAST-NIGHT REVISION

- Grain-handling: belt, screw, bucket elevator, pneumatic; select by product, capacity, direction, space, power, cost.
- Belt conveyor: material rides on belt (no relative motion) → low power, low damage; feed at tail, discharge over head or by tripper/plough.
- Idlers: flat (≥35° repose), 20° trough (general), 35/45° trough (grain); spacing ≈ belt width, ≤1.2 m.
- Idler pulley uses: support/train belt, impact absorption, wrap-angle (snub); transmission → tensioner, increase wrap, guide belt.
- Belt capacity $Q_v = A \cdot s \cdot 60$; power = HP_1(friction)+HP_2(horizontal)+HP_3(lift).
- Screw conveyor: pitch = diameter; troughs U-shaped / flared / tubular; $Q = 47.2(D^2-d^2)pn$; HP = QLWF/4560.
- Screw consumes MORE power than belt — grain dragged in sliding friction against trough (vs rolling on belt).
- Bucket elevator: spaced (centrifugal/positive) & continuous; discharge gravity (low speed) or centrifugal (high speed); $n = 29.9/\sqrt{r}$; speed 2.5–4 m/s.
- Elevator capacity = bucket vol × buckets/m × speed(m/min) × 60; power = $\dot{m}gH$ (+ friction, +20% losses); $P(kW)=Q \cdot H/367$.
- Belt flow-rate numerical: Q = (load/length) × speed. Bucket power: 0.5 t/min to 11 m, +20% ≈ 1.08 kW.
- Bag storage: dunnage below, gangways for movement/fumigation, stack height for stability; CAP = cover & plinth (~18 bags, 150 t).

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- Bins/silos: MS, RCC, aluminium; deep vs shallow by plane of rupture; design for apparent density (~+20%), lateral pressure (Janssen), friction angles, moisture.
- Packaging functions: containment, protection, preservation, communication, convenience, unitization. Materials: glass, metal/tinplate/Al, paper/board, plastics (LDPE/HDPE/PP/PET), laminates.
- MAP = atmosphere set once at packing (passive); CA storage = continuously monitored & maintained.

CHAPTER

5

DAIRY & MILK PROCESSING

Cream separation & homogenization · Pasteurization & sterilization · Butter · ice-cream · cheese · shrikhand · Milk powder

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 3 (Agricultural Process Engineering). Chapter 5: processing of milk and dairy products — homogenization, cream separation, pasteurization, sterilization, spray & roller drying, butter making, ice cream, cheese and shrikhand manufacture. Heat exchangers, milk chilling, standardization and thermal-death kinetics — recurring in past questions — are covered here.

Chapter Outline

1. **Scope & Milk-Processing Context**
2. **Cream Separation & Standardization**
3. **Homogenization**
4. **Pasteurization & Sterilization**
5. **Heat Exchangers in Dairy**
6. **Dairy Products: Butter, Ice Cream, Cheese, Shrikhand**
7. **Milk Powder: Spray & Roller Drying**
8. **Formula Sheet · Summary · Last-Night Revision**

1 SCOPE & MILK-PROCESSING CONTEXT

1.1 Milk and its composition

Milk : *the whole, clean, lacteal secretion obtained by the complete milking of one or more healthy milch animals, excluding that obtained 15 days before and 5 days after calving (colostrum). It is a near-complete single food.*

Physico-chemically milk is a triple system — an ***emulsion*** of fat globules, a ***colloidal dispersion*** of casein micelles and whey proteins, and a ***true solution*** of lactose, soluble salts and vitamins in water.

Constituent (%)	Cow	Buffalo
Water	87.0	84.0
Fat	3.6–4.4	6.5–7.4
Protein	3.3	3.8
Lactose	4.6	5.2
Ash (minerals)	0.7	0.8
Total solids	≈ 12.7	≈ 16.3

Total solids (TS) & SNF : *TS = everything except water = fat + SNF. SNF (solids-not-fat) = protein + lactose + ash (+ minor constituents) ≈ 8.5–9 %. These drive standardization and product yield.*

1.2 Importance and scope of milk processing

Milk is highly perishable — a nutrient-rich, near-neutral-pH, high-moisture medium in which bacteria multiply fast. Processing converts it into safe, stable, value-added products. The dairy chain is: reception → chilling → clarification → cream separation → standardization → homogenization → pasteurization/sterilization → (concentration/drying or product manufacture) → packaging → cold storage. It ensures safety, shelf-life, uniform quality, value addition and year-round availability.

1.3 Considerations in processing milk and dairy products

PREVIOUS YEAR QUESTIONS

- *What are the important considerations in processing of milk and dairy products? Explain in detail.*

  [OPSC·Forest 2015-16 | P2/Q.6(a) | 20M]

- *List out the general design considerations for a milk processing plant.*

  [HP·PSC RFO 2021 | Q.7(b) | 10M]

Processing considerations: use of clean, fresh, low-count raw milk; prompt chilling and an unbroken cold chain; strict hygiene and sanitation (Cleaning-In-Place, CIP); gentle handling to avoid fat damage and foaming; correct time–temperature combinations; prevention of contamination; standardization of fat/SNF; product-specific processing; and effluent/waste management.

Milk-plant design considerations: site selection (assured milk-shed, water, power, drainage, transport); planned capacity and product mix; hygienic layout with unidirectional flow and separation of raw and processed areas; stainless-steel, CIP-friendly equipment; adequate refrigeration, steam and water utilities; effluent treatment; cold storage; quality-control laboratory; and provision for expansion.

1.4 *Reception and chilling of milk*

PREVIOUS YEAR QUESTIONS

- *Why is chilling of milk essential? Write the different types of milk chilling systems.*

[IFoS 2022 | P2/8(b)(i) | 15M]

At reception, milk in cans or tankers is weighed/measured, sampled and tested (fat, SNF or **solids-not-fat**, acidity, adulteration), graded, then filtered/clarified and chilled.

Chilling : *rapidly cooling raw milk to ≤ 4–5 °C soon after milking. Fresh milk leaves the udder at ~37 °C — the optimum for bacterial growth — so unless cooled quickly, bacteria multiply, acidity rises and milk sours. Chilling is bacteriostatic (not bactericidal): it arrests microbial multiplication until processing, but does not kill organisms, so chilled milk must still be pasteurized.*

Milk-chilling systems: (1) surface/cascade (over-plate) cooler with chilled water/brine; (2) plate chiller (PHE) with chilled water/glycol; (3) internal tubular cooler; (4) bulk milk cooler (BMC) — an insulated direct-expansion refrigerated tank with agitator, at collection centres; (5) can-immersion / ice-bank chillers.

1.5 *Physico-chemical properties and platform tests*

A few physical properties govern processing and adulteration detection:

- ***Acidity & pH*** : fresh milk pH ≈ 6.6; natural (apparent) titratable acidity ≈ 0.14–0.16 % lactic acid (cow) — a rise indicates bacterial souring.
- ***Specific gravity*** : ≈ 1.028–1.034 (cow); measured by lactometer; falls on watering, rises on skimming — the basis of the lactometer/CLR test for adulteration.
- ***Freezing point*** : ≈ −0.512 to −0.55 °C — very constant; a rise toward 0 °C reveals added water (the most reliable adulteration test).
- ***Boiling point & viscosity*** : boiling point ≈ 100.5 °C; viscosity ≈ 1.5–2.0 cP, rising with fat and on homogenization.

Platform (reception) tests screen incoming milk quickly: organoleptic; ***Clot-on-Boiling (COB)*** and ***alcohol test*** (detect developed acidity/heat instability); titratable acidity; ***lactometer*** reading (CLR) for added water/skimming; fat by Gerber; and the ***Methylene Blue Reduction Test (MBRT)*** for bacterial load.

2 CREAM SEPARATION & STANDARDIZATION

2.1 *Principle of cream separation*

Cream separation : *separating milk into a fat-rich fraction (cream) and a fat-depleted fraction (skim milk), exploiting the density difference between fat (sp. gr. ≈ 0.93) and skim milk (≈ 1.036).*

Gravity creaming (**Stokes' law: rise velocity ∝ globule diameter² × density difference ÷ viscosity**) is slow and obsolete. In centrifugal separation the milk in the rapidly revolving bowl is subjected to a centrifugal force 3000–6000 times gravity; the denser skim milk is flung to the periphery while the lighter cream moves toward the axis, and the two leave by separate outlets (cream outlet nearer the axis, higher than the skim outlet).

Centrifugal force $F = K \cdot W \cdot R \cdot N^2$

W = mass of revolving body; R = radius of rotation; N = rpm; K = constant. This is Newtonian rotation, $F = m\omega^2 R$, rewritten with $\omega = 2\pi N$: the constant K absorbs $4\pi^2$ and the unit conversion, which is why N can be entered directly in rpm.

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Separation is faster with larger fat globules, higher temperature (warm milk ≈ 40 °C, lower viscosity), higher bowl speed and closer disc spacing.

2.2 Centrifugal cream separator — construction and working

PREVIOUS YEAR QUESTIONS

- *With the help of a neat diagram, describe the operation of a cream separator.* [IFoS 2019 | P2/7(a) | 15M]
- *Explain the working of centrifugal cream separator.* [IFoS 2020 | P2/7(a) | 15M]

The commercial machine is a disc-bowl separator: a bowl holding a stack of closely-spaced conical discs rotates at high speed. Milk fed through the hollow central spindle is distributed into the thin spaces between the discs; the short radial distance across each film lets fat separate quickly — skim milk (heavier) travels outward to the periphery and out of the skim spout, while cream (lighter) is displaced inward to the axis and out of the cream spout. A cream screw (regulating screw) adjusts the fat percentage of the cream.

Main parts: supply can, float/regulating chamber, milk distributor, disc stack, bowl shell, cream screw, cream spout, skim-milk spout, spindle, gear drive. Types: warm-milk vs cold-milk; power-driven (factory) vs hand-driven (farm); open-bowl, semi-enclosed, hermetically-sealed (airtight, foamless).

Centrifugal (disc-bowl) cream separator

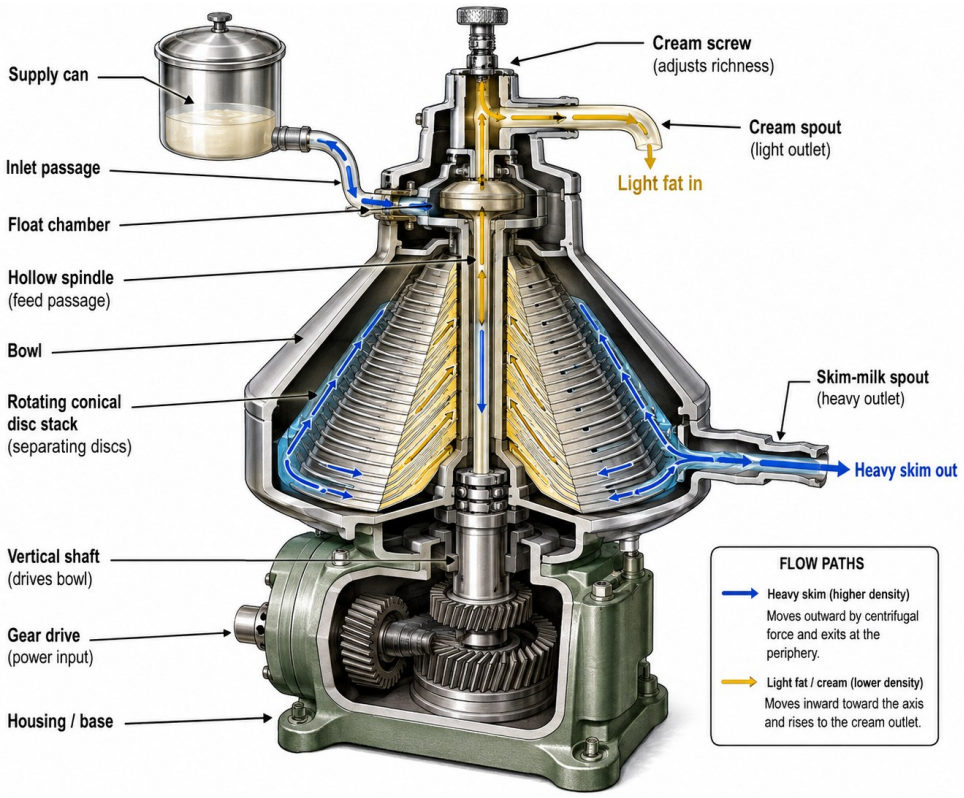


Fig. 5.1 Centrifugal disc-bowl cream separator

2.3 Worked numerical — separator start-up power

WORKED NUMERICAL — Centrifugal separator start-up power [IFoS 2020 | P2/7(a) | 15M]

Problem. *Calculate the power to start up a centrifugal cream separator: bowl density 7850 kg/m³, 100*

rev/s, outer and inner disc radii 0.25 m and 0.225 m, length over which mass is concentrated 0.35 m, time to reach running speed 300 s.

Given. $\rho = 7850$ kg/m³; $N = 100$ rev/s; $r_o = 0.25$ m; $r_i = 0.225$ m; $L = 0.35$ m; $t = 300$ s.

Find. start-up power P.

Assumptions. bowl = hollow cylinder between r_i and r_o; P = kinetic energy ÷ time; friction neglected.

Formula. $m = \rho\cdot\pi(r_o^2-r_i^2)\cdot L$; $I = \tfrac{1}{2}m(r_o^2+r_i^2)$; $\omega = 2\pi N$; $KE = \tfrac{1}{2}I\omega^2$; $P = KE/t$.

Where these come from. The bowl is treated as a hollow cylinder, so its volume is

$$\pi(r_o^2-r_i^2)L \text{ and } m = \rho\cdot\pi(r_o^2-r_i^2)L.$$

For a hollow cylinder spinning about its own axis the standard mass-moment-of-inertia result is

$$I = \tfrac{1}{2}m(r_o^2+r_i^2),$$

which reduces to $\tfrac{1}{2}mr^2$ for a solid cylinder ($r_i = 0$).

One revolution = 2π rad, so N rev/s gives $\omega = 2\pi N$ rad/s.

Rotational kinetic energy $KE = \tfrac{1}{2}I\omega^2$ is the rotational analogue of $\tfrac{1}{2}mv^2$.

Start-up power is the energy that must be supplied divided by the time taken to reach speed, $P = KE/t$; nothing here is dairy-specific — it is rigid-body rotation applied to the separator bowl.

Substitution.

$$m = 7850\cdot\pi(0.25^2-0.225^2)\cdot 0.35$$

$$= 102.5 \text{ kg};$$

$$I = \tfrac{1}{2}\cdot 102.5\cdot(0.0625+0.050625) = 5.80 \text{ kg}\cdot\text{m}^2;$$

$$\omega = 2\pi\cdot 100 = 628.3 \text{ rad/s};$$

$$KE = \tfrac{1}{2}\cdot 5.80\cdot 628.3^2 = 1.144\times 10^6 \text{ J}.$$

Answer = $P = 1.144\times10^6/300 \approx 3.81$ kW (≈ 5.1 hp).

Check. units J/s = W ✓; this is the average power to reach running speed in 300 s — steady running power is far lower (only friction/windage).

2.4 *Skimming efficiency*

PREVIOUS YEAR QUESTIONS

- *Define the terms 'standardization' and 'skimming efficiency'.*

[AP·PSC RFO 2012 | Q.2(F) | 5M]

Skimming efficiency : *a measure of how completely fat is removed from milk by the separator = fraction of the milk's fat recovered in the cream, commonly (1 − % fat in skim milk / % fat in whole milk) × 100. A well-run separator leaves only 0.05–0.1 % fat in the skim; it improves with warm milk, correct speed and throughput, and clean, well-adjusted discs.*

2.5 *Standardization of milk*

PREVIOUS YEAR QUESTIONS

- *Discuss the techniques involved in standardization of milk.*

[IFoS 2024 | P2/8(d) | 10M]

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Standardization : *adjusting the fat and/or SNF content of milk (or cream) to a definite value fixed by legal standards or product requirements.*

Techniques : (i) removing fat — partially separating cream from whole milk; (ii) adding skim milk to lower fat; (iii) adding cream to raise fat; (iv) blending a high-fat and a low-fat milk; (v) removing water (rare). Two-component blends are computed by Pearson's square or by fat mass balance. The SNF of the resulting cream comes from the same balance: separation only concentrates the fat, leaving the non-fat phase unchanged in composition, so the milk's SNF is shared in proportion to the non-fat fractions —

SNF in cream = (100 − %fat_cream)/(100 − %fat_milk) × %SNF_milk.

Pearson's square : *place the higher-fat component top-left and lower-fat bottom-left, the desired fat in the centre; diagonal differences give the parts: parts of high-fat = |low-fat% − target%| ; parts of low-fat = |high-fat% − target%|.*

Classes of market milk (standardized to legal fat/SNF)

Standardization produces the legal market-milk classes: ***full-cream*** (6.0 % fat, 9.0 % SNF), ***standardized*** (4.5 % fat, 8.5 % SNF), ***toned*** (3.0 % fat, 8.5 % SNF — made by adding SMP/skim to buffalo milk), ***double-toned*** (1.5 % fat, 9.0 % SNF) and ***skimmed*** (≤ 0.5 % fat). Toning stretches high-fat buffalo milk to serve more consumers at lower cost. (Exact figures per FSSAI/state standards)

2.6 Worked numericals — standardization

◆ WORKED NUMERICAL — Standardization — 28% cream + 3% milk → 500 kg @ 4% [IFoS 2021 · P2/6(b) · 15M]

Problem. *How many kg each of 28% cream and 3% milk are required to make 500 kg of mixture testing 4% fat? Show proof.*

Given:

Fat content in cream = 28%
Fat content in milk = 3%
Required mixture = 500 kg
Required fat content in mixture = 4%
Let the quantity of 28% cream be = x kg

$$\text{Therefore, quantity of 3\% milk} = (500 - x)\ \text{kg}$$

$$\text{Total fat in the final mixture} = 4\%\ \text{of}\ 500\ \text{kg}$$

$$= (4/100) \times 500$$
$$= 20\ \text{kg}$$

Now, fat contributed by cream + fat contributed by milk = total fat in mixture

$$(28/100)x + (3/100)(500 - x) = 20$$
$$0.28x + 0.03(500 - x) = 20$$
$$0.28x + 15 - 0.03x = 20$$
$$0.25x = 5$$
$$x = 5/0.25$$
$$x = 20\ \text{kg}$$

Therefore,

$$\text{Quantity of 28\% cream} = 20\ \text{kg}$$
$$\text{Quantity of 3\% milk} = 500 - 20$$

$$= 480 \text{ kg}$$

ANSWER:

$$28\% \text{ Cream required} = 20 \text{ kg}$$
$$3\% \text{ Milk required} = 480 \text{ kg}$$

PROOF:

Fat present in 20 kg of 28% cream:

$$= (28/100) \times 20$$
$$= 5.6 \text{ kg}$$

Fat present in 480 kg of 3% milk:

$$= (3/100) \times 480$$
$$= 14.4 \text{ kg}$$

Total fat in the mixture:

$$= 5.6 + 14.4$$
$$= 20 \text{ kg}$$

Total weight of mixture:

$$= 20 + 480$$
$$= 500 \text{ kg}$$

Percentage of fat in the final mixture:

$$= (20/500) \times 100$$
$$= 4\%$$

Hence, 20 kg of 28% cream and 480 kg of 3% milk are required to prepare 500 kg of mixture containing 4% fat.

Hence proved.

◆ **WORKED NUMERICAL — *Standardization — 30% cream + 5% milk → 1000 kg @ 10%*** **[IFoS 2020 · P2/7(c) · 10M ; MH·PSC 2024 · Q.6(c) · 10M]**

Problem. *How many kg each of 30% cream and 5% milk are required to make 1000 kg of mixture at 10% fat?*

Given:

Fat content in cream = 30%
Fat content in milk = 5%
Required mixture = 1000 kg
Required fat content in mixture = 10%
Let the quantity of 30% cream = x kg
Therefore, quantity of 5% milk = (1000 − x) kg
Total fat in the final mixture:

$$= 10\% \text{ of } 1000 \text{ kg}$$
$$= (10/100) \times 1000$$
$$= 100 \text{ kg}$$

Now,

Fat from cream + Fat from milk = Total fat in mixture

$$(30/100)x + (5/100)(1000 - x) = 100$$
$$0.30x + 0.05(1000 - x) = 100$$
$$0.30x + 50 - 0.05x = 100$$
$$0.25x = 50$$
$$x = 50/0.25$$

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$$x = 200 \text{ kg}$$

Therefore,

Quantity of 30% cream = 200 kg

Quantity of 5% milk = 1000 − 200

= 800 kg

ANSWER:

30% Cream required = 200 kg

5% Milk required = 800 kg

PROOF:

Fat present in 200 kg of 30% cream:

$$= (30/100) \times 200$$
$$= 60 \text{ kg}$$

Fat present in 800 kg of 5% milk:

$$= (5/100) \times 800$$
$$= 40 \text{ kg}$$

Total fat in the mixture:

$$= 60 + 40$$
$$= 100 \text{ kg}$$

Total weight of mixture:

$$= 200 + 800$$
$$= 1000 \text{ kg}$$

Percentage of fat in the final mixture:

$$= (100/1000) \times 100$$
$$= 10\%$$

Hence, 200 kg of 30% cream and 800 kg of 5% milk are required to prepare 1000 kg of mixture containing 10% fat.

Hence proved.

2.7 *Cream – types, grades and neutralization*

Cream is graded by fat content: ***table/light cream*** (20–25 % fat), ***whipping cream*** (30–40 %), ***heavy cream*** and ***plastic cream*** (65–85 %, for butter/recombining). Cream for buttermaking is often ***neutralized*** when its developed acidity is high: alkali (lime or sodium carbonate/bicarbonate) is added to bring acidity down to ~0.06–0.10 % lactic acid, preventing casein coagulation on pasteurization and off-flavours in the butter.

3 HOMOGENIZATION

3.1 *Definition and importance*

PREVIOUS YEAR QUESTIONS

- *Why is homogenisation of milk important in the dairy industry?*

  [IFoS 2019 | P2/7(a) | 10M]

- *What do you mean by 'homogenization' of milk?*

  [AP · PSC RFO20212 | P2/7(a) | 10M]

- *What is Homogenization and Sterilization? Describe the purpose and methods of homogenization in brief.*

  [OPSC · Forest 2015-16 | P2/6(b) | 20M]

Homogenization : *a mechanical treatment in which milk is forced under high pressure through a*

narrow homogenizing valve, breaking the fat globules into small, uniform ones (mean diameter from ~3–4 µm to < 1–2 µm) so the fat stays permanently dispersed and does not rise as a cream layer.

Importance: gives a stable emulsion (no creaming), uniform fat distribution, a whiter and creamier appearance with richer mouthfeel/body, improved digestibility, and consistent products. Its stabilising effect rests on three factors — a smaller mean fat-globule diameter (Stokes' law → slower rise), a narrower size distribution, and a large increase in surface area (freshly created surface adsorbs casein, preventing re-coalescence).

3.2 Principle and mechanism

A homogenizer is a high-pressure, multi-cylinder positive piston pump fitted with a homogenizing valve. Milk (usually 60–70 °C) is forced through the narrow gap between valve and seat: velocity rises from ~4–6 m/s to ~120 m/s in ~0.2 ms. Fat globules are torn apart by intense turbulence (eddies the size of the globules) and cavitation, completing emulsification in under 50 µs. Variables: pressure, valve type, single- or two-stage, fat content, temperature and viscosity. Power follows from the work the pump does against the valve: forcing a volume V through against a pressure drop p costs work p·V, so per unit time the theoretical power is P = p × Q (pressure × volumetric flow rate) — the formula used in the §3.5 numerical.

Two-stage homogenizer

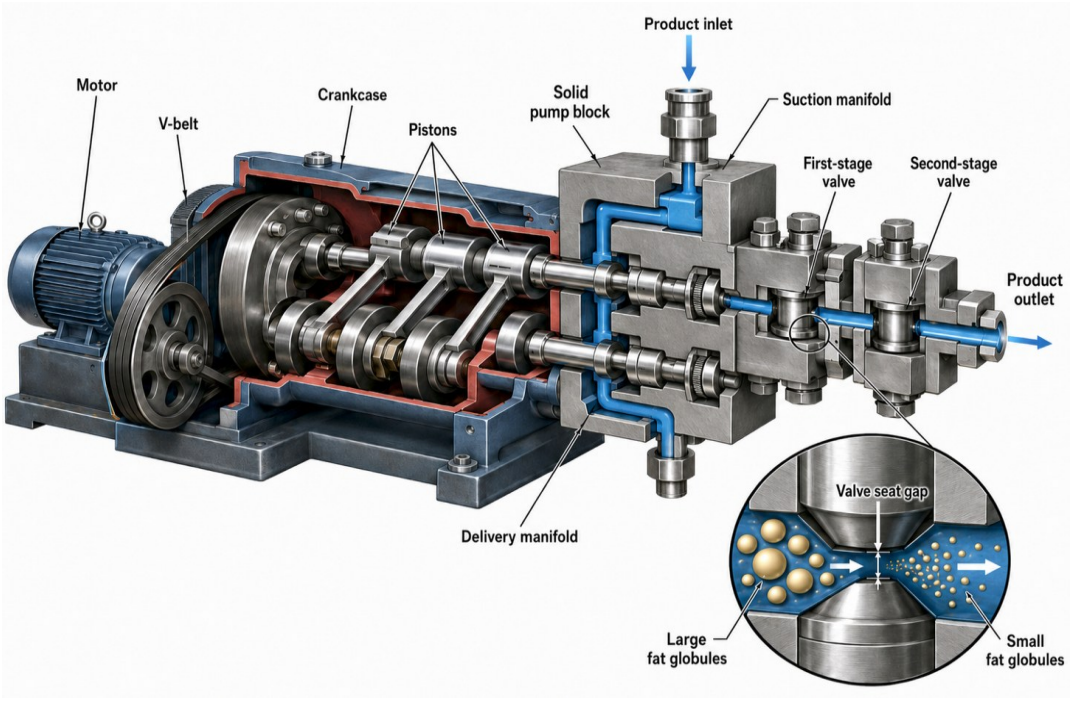


Fig. 5.2 Two-stage homogenizer with valve detail

3.3 First- and second-stage homogenization

PREVIOUS YEAR QUESTIONS

Explain about first and second stage of homogenization.

[OPSC · Forest 2023-24 | P2/8(b) | 20M]

- ***First stage*** : High pressure (~14–21 MPa / 2000–3000 psi); accomplishes most of the fat-globule size reduction, but the fresh small globules tend to clump/cluster (fat–casein clusters).

- ***Second stage*** : A lower pressure (~3.5 MPa / ~500 psi) applied immediately after; it breaks up these clusters into individual globules, giving a fully stable, non-clumping emulsion. Two-stage is preferred for high-fat products (cream, evaporated milk).

3.4 *Homogenization efficiency*

PREVIOUS YEAR QUESTIONS

Briefly explain: Homogenization efficiency.

[HP · PSC RFO 2021 | Q.7(d) | 10M]

Homogenization efficiency : *a measure of how effectively fat globules have been reduced and stabilised against creaming. Judged by the USPHS homogenization test (fat in the top 100 mL of a stored quart differs from the remainder by ≤ 10 % of the mean after 48 h) or by fat-globule size measurement. Higher efficiency = smaller, uniform globules and no cream line; it increases with pressure and two-stage operation.*

3.5 *Worked numerical — homogenizer power*

◆ **WORKED NUMERICAL — *Homogenizer power*** **[IFoS 2024 · P2/6(b) · 10M ; IFoS 2023 · P2/7(a)(i) · 10M]**

Problem. *If the milk flow in a homogenizer is 1000 L/h at 250 kg/cm², calculate the horsepower required for homogenization.*

Given:

Milk flow rate = 1000 L/h

Pressure = 250 kg/cm^2

Step 1: Convert flow rate into m^3/s

$$1000 \text{ L} = 1 \text{ m}^3$$

Therefore,

$$\text{Flow rate} = 1 \text{ m}^3/\text{h}$$
$$= 1/3600 \text{ m}^3/\text{s}$$
$$= 0.0002778 \text{ m}^3/\text{s}$$

Step 2: Convert pressure into N/m^2

$$1 \text{ kg/cm}^2 = 98{,}066.5 \text{ N/m}^2$$

Therefore,

$$250 \text{ kg/cm}^2 = 250 \times 98{,}066.5$$
$$= 24{,}516{,}625 \text{ N/m}^2$$

Step 3: Calculate power

$$\text{Power} = \text{Pressure} \times \text{Flow rate}$$
$$= 24{,}516{,}625 \times 0.0002778$$
$$= 6{,}810 \text{ W approximately}$$
$$= 6.81 \text{ kW}$$

Step 4: Convert kW into horsepower

$$1 \text{ HP} = 746 \text{ W}$$

Therefore,

$$\textbf{Horsepower required} = 6810/746$$
$$= 9.13 \text{ HP}$$

ANSWER:

Horsepower required for homogenization = approximately 9.1 HP

Hence, a homogenizer handling 1000 L/h of milk at 250 kg/cm^2 theoretically requires about 9.1 HP.

Note : This is the theoretical power requirement. In actual operation, the motor horsepower would be higher because of mechanical and hydraulic efficiency losses.

3.6 *Advantages and limitations of homogenization*

- ***Advantages*** : no cream-line (stable emulsion); softer curd (more digestible); whiter, richer, more uniform appearance and mouthfeel; better distribution of fat in products; improved keeping quality of the emulsion; needed for recombined/toned milk, cream, ice-cream mix and evaporated milk.
- ***Limitations*** : increased sensitivity to light (sunlight/oxidized flavour) and to lipolysis if raw; reduced heat stability; milk cannot be cream-separated afterwards; slightly higher viscosity; added equipment and energy cost; must be combined with pasteurization (homogenization is not a preservation step).

4 PASTEURIZATION & STERILIZATION

4.1 *Pasteurization — definition and purpose*

PREVIOUS YEAR QUESTIONS

- *What is pasteurisation of milk? Enlist the methods of pasteurization. Write the advantages of high temperature short time (HTST) pasteurization of milk.*
  [IFoS 2020 · P2/5(d) · 8M]
- *What do you understand by pasteurization, homogenization and sterilization of milk? What are its purpose and advantages? Explain how it is carried out?*
  [OPSC·CSE 2020-21 · P2/Q.5(c)(i) · 10M]
- *Explain the working principles of equipments for pasteurization, sterilization and homogenization.*
  [OPSC·Forest 2019-20 · P2/Q.6(b) · 20M]
- *Explain the working principles of equipments for receiving, pasteurization, sterilization and homogenization. (Receiving §1.4; homogenization §3; pasteurization/sterilization below.)*
  [OPSC·CSE 2017-18 · P2/Q.8(a) · 20M]
- *Explain the working principles of equipments for sterilization and homogenization of milk.*
  [OPSC·CSE 2016-17 · P2/Q.6(a) · 20M]

Purposes : (1) public-health — destroy all pathogenic micro-organisms; (2) keeping-quality — destroy most spoilage organisms and inactivate enzymes. It is not sterilisation — some thermoduric/spore organisms survive, so pasteurised milk must be refrigerated.

4.2 *Methods of pasteurization*

Method	Temperature–time	Use
LTLT / Batch / Holder	63 °C for 30 min	small scale
HTST (High-Temp Short-Time)	72 °C for 15 s	continuous, large scale
UHT (Ultra-High-Temperature)	135–150 °C for 2–5 s + aseptic pack	long ambient shelf-life

4.3 *Batch (holder) pasteurizer*

PREVIOUS YEAR QUESTIONS

- *Define pasteurization and sterilization of milk. Describe the working of a batch type pasteurizer.*
  [UK·PSC RFO 2021 · Q.7(iii) · 10M ; UK·PSC ACF 2019 · Q.7(iii) · 10M]
- *With a schematic, explain the features of a batch pasteurizer.*

[OPSC·CSE 2024-25 · P2/Q.16 · part · 20M]

Milk is heated and held in a jacketed vessel: an insulated outer casing, a stainless-steel inner vessel forming a jacket through which hot water/steam circulates, an agitator for uniform heating, a hinged cover and an outlet cock. Milk is heated to 63 °C, held 30 min, then rapidly cooled (jacket refrigerant or a separate surface/plate cooler). Agitation and a bottom inlet valve prevent foam (which can shelter surviving microbes); a cover prevents skin formation. Simple, low capacity (< 3000–5000 L).

Batch (holder) pasteurizer

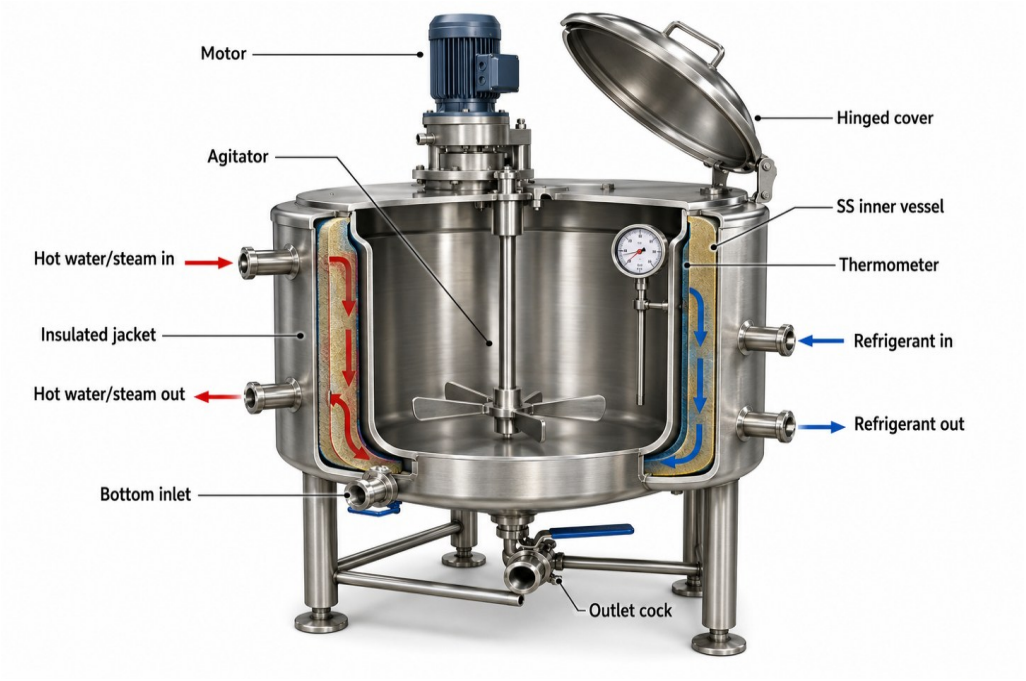


Fig. 5.3 Batch (holder) pasteurizer

4.4 *HTST pasteurizer*

PREVIOUS YEAR QUESTIONS

- *What do you understand by pasteurization? Describe the working of HTST pasteurizer with a neat diagram. How does it differ from batch type?*

  [OPSC·CSE 2018-19 · P2/Q.8(a) · 20M]

- *What is pasteurization? What are its various types, methods and purpose? Give operational details of the HTST plant with a neat sketch showing all components.*

  [OPSC·CSE 2016-17 · P2/Q.6(b) · 20M ; OPSC·CSE 2015-16 · P2/Q.6(a) · 20M]

- *Describe the method of HTST pasteurization with the help of a neat sketch. Why should milk be pasteurized?*

  [UK·PSC RFO 2012 · Q.6(ii) · 10M ; AP·PSC RFO 2012 · Q.4(D) · 10M]

The HTST pasteurizer is a continuous system built around a plate heat exchanger with regeneration, heating and cooling sections. Flow: cold raw milk (4 °C) from a constant-level tank → regeneration section (warmed to ~57–68 °C by the hot outgoing pasteurised milk across the plates — energy saving) → timing (positive-displacement) pump → heating section (hot water raises it to ≥ 72 °C) → holding tube (held ≥ 15–16 s) →

temperature sensor + recorder-controller → flow-diversion valve (FDV). If ≥ 72 °C the FDV allows forward flow; if under-heated it diverts milk back to the raw tank. Correctly heated milk returns through the regeneration section (giving up heat) and the cooling section (chilled water/brine) to ~4 °C, then to packaging.

Advantages of HTST: continuous and high-capacity; energy-efficient (regeneration recovers 85–90 % of heat); rapid, uniform treatment with less flavour/nutrient damage; compact; automatic time–temperature control and safety (FDV).

HTST pasteurizer flow diagram

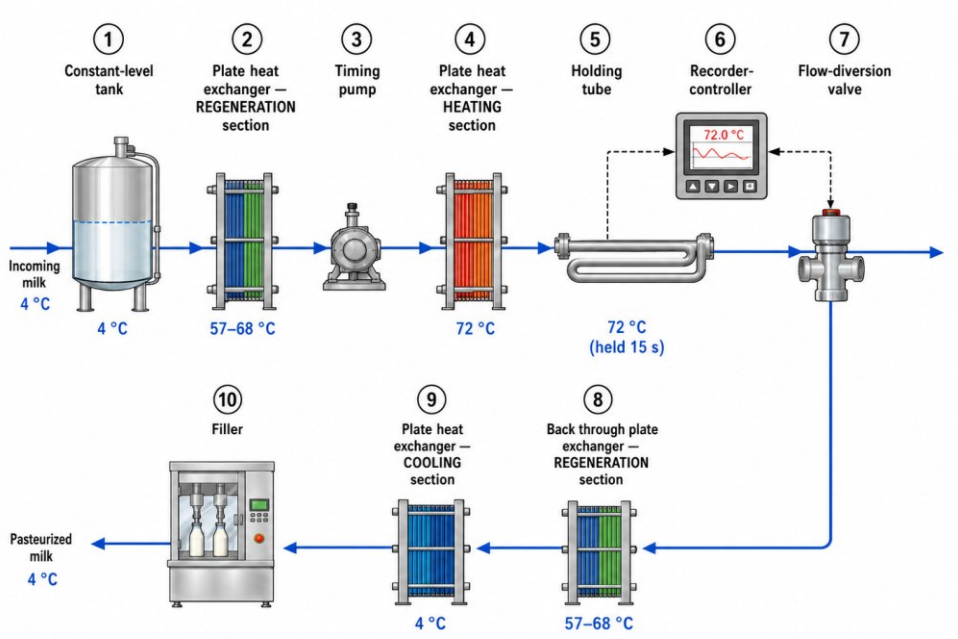


Fig. 5.4 HTST pasteurizer flow diagram

PREVIOUS YEAR QUESTIONS

- *Differentiate between HTST pasteurizer and Batch type Pasteurizer.*

[UK·PSC RFO 2015 · Q.8(i) · 10M]

Feature	*HTST*	*Batch (holder)*
Temperature–time	72 °C / 15 s	63 °C / 30 min
Operation	continuous	batch
Capacity	high	low
Equipment	plate heat exchanger	jacketed vat
Regeneration	yes (85–90 %)	no
Energy & labour	low per L	high
Control	automatic (FDV)	manual

4.5 Sterilization; UHT and in-bottle sterilization

PREVIOUS YEAR QUESTIONS

- *What is the difference between sterilisation and pasteurisation?*

[IFoS 2018 · P2/8(b) · part · 15M]

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- *Describe In-bottle sterilization of milk.*

  [IFoS 2023 · P2/7(a)(ii) · 5M]

- *How do UHT treatment and steam sterilization ensure the safety and longevity of dairy products, extending shelf life and facilitating global distribution?*

  [OPSC·CSE 2023-24 · P2/Q.17(b) · 20M]

Sterilization : *heating milk above 100 °C long enough to destroy all micro-organisms including spores, giving a commercially sterile, long-life product stable at room temperature.*

- ***In-bottle (conventional) sterilization*** : milk is pre-heated, homogenized, filled into clean bottles, sealed, and heated in a batch retort or continuous hydrostatic steriliser to ~108–120 °C for 20–30 min (steam under pressure), then cooled. Long shelf-life but a cooked flavour and some browning.
- ***UHT*** : milk heated to 135–150 °C for 2–5 s (direct steam injection/infusion or indirect PHE), then aseptically packaged in sterile laminate cartons. Near-sterile with minimal flavour/nutrient damage; months of ambient shelf-life, enabling global distribution without refrigeration.

UHT heating is of two kinds: ***direct*** (steam injection into milk, or milk infusion into steam — very fast heating/cooling, best flavour, but needs a flash-cooling/de-aeration step to remove the added water) and ***indirect*** (through a plate or tubular heat exchanger — no dilution, allows regeneration, but slightly more heat load). Both are always followed by aseptic packaging into pre-sterilized laminate cartons.

Feature	Pasteurization	Sterilization
Temperature	63–72 °C	> 100 °C
Organisms killed	pathogens + most spoilage	all, including spores
Spores	survive	destroyed
Shelf-life	short, refrigerated	long, ambient
Flavour change	slight	marked (UHT minimal)

4.6 Thermal-death kinetics — D-value and z-value

PREVIOUS YEAR QUESTIONS

- *Differentiate 'D' value from 'z' value in thermal processing of foods.*

  [OPSC·CSE 2022-23 · P2/Q.7(b) · 5M]

- *Explain the thermal destruction kinetics in terms of D-value and Z-value.*

  [OPSC·CSE 2024-25 · P2/Q.16 · part · 20M]

Microbial thermal death is logarithmic (first-order): at a constant lethal temperature the survivors fall by a fixed fraction per unit time. Because the death rate constant obeys the **Arrhenius law**, the z-value converts directly into an activation energy: $E_a = 2.303 \cdot R \cdot T_1 \cdot T_2 / z$ (T in K, R = 8.314 J mol^{-1} K^{-1}). A small z means death is steeply temperature-sensitive, i.e. a large E_a.

D-value & z-value : *D-value (decimal reduction time) — the time at a given temperature to destroy 90 % (one log cycle) of the organisms. z-value — the temperature rise (°C) needed to reduce the D-value ten-fold (slope of the thermal-death-time curve). D measures resistance at one temperature; z measures how that resistance changes with temperature.*

$D = t/(\log N_0 - \log N)$; $z = (T_2 - T_1)/(\log D_1 - \log D_2)$; $F = D \times (\log \text{reductions})$; $E_a = 2.303 \cdot R \cdot T_1 \cdot T_2 / z$

4.7 Worked numerical — D, z and activation energy

◆ **WORKED NUMERICAL — *D-value, z-value and activation energy*** [OPSC·CSE 2016-17 · P2/Q.7(b) · 20M]

Problem. *Milk pasteurization is carried out at 85 °C for 4 s or 71 °C for 40 s; in both the sterilizing value is 8. Find the decimal reduction times, the z-value for reference temperatures 71 °C and 85 °C, and the activation energy.*

Given / Find. 85 °C/4 s and 71 °C/40 s; S = 8 for both; find D at each, z, and E_a.

Given:

At 85°C:

Heating time, $t_{85} = 4$ s

Sterilizing value = 8 decimal reductions

At 71°C:

Heating time, $t_{71} = 40$ s

Sterilizing value = 8 decimal reductions

1. CALCULATION OF DECIMAL REDUCTION TIME (D-VALUE)

The sterilizing value or number of decimal reductions is:

$n = t/D$

Therefore,

$$D = t/n$$

At 85°C:

$$D_{85} = 4/8$$

$$D_{85} = 0.5 \text{ s}$$

At 71°C:

$$D_{71} = 40/8$$

$$D_{71} = 5 \text{ s}$$

Therefore:

$$D_{71} = 5 \text{ s}$$

$$D_{85} = 0.5 \text{ s}$$

2. CALCULATION OF z-VALUE

The relationship between D-value and temperature is:

$$\log(D_{71}/D_{85}) = (85 - 71)/z$$

Substituting the values:

$$\log(5/0.5) = 14/z$$

$$\log(10) = 14/z$$

$$1 = 14/z$$

Therefore,

$$z = 14°C$$

ANSWER:

z-value = 14°C

Thus, an increase of 14°C causes a tenfold decrease in the decimal reduction time.

The same z-value applies whether 71°C or 85°C is taken as the reference temperature.

3. CALCULATION OF ACTIVATION ENERGY

The relationship between D-values and activation energy is:

$$\log(D_{71}/D_{85}) = [Ea/(2.303R)] \times [(1/T_{71}) - (1/T_{85})]$$

Where:

Ea = Activation energy

$R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$

Convert temperatures into Kelvin:

$$T_{71} = 71 + 273.15$$

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$$= 344.15 \text{ K}$$
$$T_{85} = 85 + 273.15$$
$$= 358.15 \text{ K}$$

Now,

$$\log(5/0.5) = [Ea/(2.303 \times 8.314)] \times [(1/344.15) - (1/358.15)]$$

Since,

$$\log(10) = 1$$

Therefore,

$$Ea = (2.303 \times 8.314) / [(1/344.15) - (1/358.15)]$$
$$Ea \approx 168{,}550 \text{ J/mol}$$
$$Ea \approx 168.6 \text{ kJ/mol}$$

FINAL ANSWER:

Decimal reduction time at 71°C:

$$\mathbf{D_{71} = 5 \text{ s}}$$

Decimal reduction time at 85°C:

$$\mathbf{D_{85} = 0.5 \text{ s}}$$

z-value:

$$\mathbf{z = 14°C}$$

Activation energy:

$$\mathbf{Ea \approx 168.6 \text{ kJ/mol}}$$

4.8 *Testing pasteurization efficiency — the phosphatase test*

Phosphatase test : *the standard check for correct pasteurization. The enzyme alkaline phosphatase is naturally present in raw milk and is inactivated by proper pasteurization (its thermal resistance is slightly greater than that of the target pathogens). A negative phosphatase test therefore confirms adequate heat treatment; a positive test indicates under-pasteurization or contamination with raw milk. The peroxidase (Storch) test conversely confirms milk was not over-heated above ~80 °C.*

5 HEAT EXCHANGERS IN DAIRY

5.1 *Heat exchangers used in the food industry*

PREVIOUS YEAR QUESTIONS

What are common types of heat exchangers used in the food industry? How are heat exchangers classified based on relative direction of motions of fluid flow?

[IFoS 2023 · P2/6(c) · 15M]

Heat exchanger : *a device that transfers heat between a hot and a cold fluid separated by a solid wall (indirect) or by direct mixing, without the two mixing in indirect types.*

- ***Plate heat exchanger (PHE)*** : corrugated stainless plates in a frame; the workhorse for pasteurizing, heating and chilling milk.
- ***Tubular heat exchanger*** : shell-and-tube or triple-tube; robust, handles higher pressure and particulates than a PHE.
- ***Scraped-surface heat exchanger (SSHE)*** : jacketed cylinder with a rotating scraper; for viscous or particulate products (ice-cream mix, cream).
- ***Steam-infusion / steam-injection*** : direct steam contact for very rapid heating (UHT).

5.2 Classification by direction of fluid flow

Arrangement	Description	Note
Parallel (co-current)	both fluids flow the same direction	lower mean ΔT
Counter-current	fluids flow in opposite directions	largest LMTD, most efficient
Cross flow	the two streams flow perpendicular	—

Heat exchangers are also classified as direct-contact vs indirect-contact, and by construction (plate, tubular, scraped-surface). Counter-current flow is used in HTST regeneration for maximum heat recovery.

Flow arrangements in heat exchangers

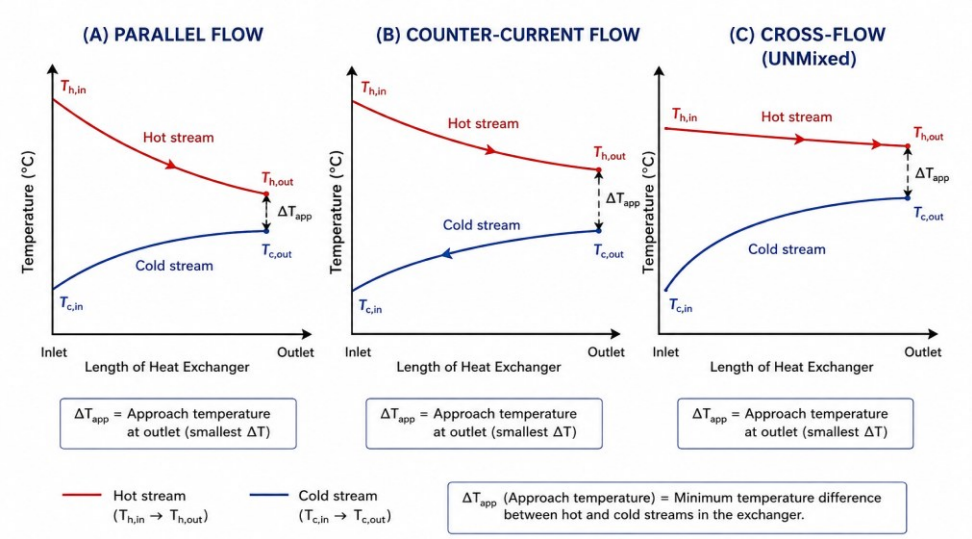


Fig. 5.5 Parallel, counter-current and cross flow

5.3 Plate heat exchanger — salient features

PREVIOUS YEAR QUESTIONS

- *Highlight the salient features of Plate Heat Exchangers used in dairy industry.*

[OPSC-CSE 2022-23 · P2/Q.7(a) · 10M]

A PHE is a stack of thin corrugated stainless-steel plates clamped in a frame, with gaskets defining alternate channels; hot and cold fluids flow counter-currently in adjacent channels. Salient features: very high heat-transfer coefficient (thin films + corrugation turbulence); large area in a compact volume; close temperature approach and built-in regeneration (~85–90 % recovery); easy to clean (CIP), dismantle and inspect; easy to expand (add plates); low hold-up and gentle treatment. Limitations: gasket temperature/pressure limits; unsuitable for very viscous or particulate products; gasket leakage risk.

5.4 Fouling of heat exchangers in milk processing

PREVIOUS YEAR QUESTIONS

- *What are the reasons for fouling of heat exchangers during milk processing?*

[IFoS 2018 · P2/5(a) · 8M]

Fouling : *deposition of a layer of solids from the milk onto the heat-transfer surface, which reduces the heat-transfer coefficient, raises pressure drop, and shortens the run before cleaning.*

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Reasons in milk processing: (1) heat denaturation of whey proteins (chiefly β-lactoglobulin), which unfold and deposit as a soft white film (Type A, ~70–110 °C); (2) precipitation of mineral salts, mainly calcium phosphate, which has inverse solubility (less soluble when hotter) and forms a hard grey deposit (Type B, > 110 °C); (3) high surface/product temperature and local hot spots (burn-on); (4) low flow velocity / long residence time and dead spots; (5) air bubbles on the surface; (6) high acidity or advanced age of milk. Consequences: falling heat-transfer efficiency, rising pressure, burnt flavour and microbial harbourage — so heat exchangers need regular CIP (alkali for protein/fat, acid for mineral scale).

5.5 *Cleaning-In-Place (CIP)*

Cleaning-In-Place (CIP) : *automated cleaning of dairy pipelines, tanks and heat exchangers without dismantling them, by circulating cleaning solutions through the assembled circuit. A typical CIP cycle: pre-rinse (warm water) → hot alkali wash (~1 % NaOH, ~75 °C, removes protein and fat deposits) → intermediate rinse → acid wash (nitric/phosphoric, removes mineral/calcium-phosphate scale) → final rinse → sanitize. CIP restores the fouled heat-transfer surfaces (§5.4), maintains hygiene and enables continuous high-throughput operation.*

6 DAIRY PRODUCTS: BUTTER, ICE CREAM, CHEESE, SHRIKHAND

6.1 *Butter*

PREVIOUS YEAR QUESTIONS

- *Draw the flowchart of making butter from milk in a continuous process.*
  [IFoS 2018 · P2/8(a) · 15M]
- *Various steps and processes involved in butter manufacturing with a process flow chart.*
  [OPSC·CSE 2020-21 · P2/Q.7(c) · 20M]
- *Starting from homogenization and cream separation, explain the operation of a butter manufacturing unit.*
  [OPSC·CSE 2015-16 · P2/Q.5(a) · 20M]

Butter : *a fat concentrate (≥ 80 % milk fat, ≤ 16 % moisture) made by churning cream, which causes phase inversion of the oil-in-water cream emulsion into the water-in-oil butter emulsion.*

Batch steps: cream separation → (neutralization of sour cream) → pasteurization of cream (~85–90 °C) → cooling and ageing/ripening (5 °C; add culture for ripened butter) → churning (agitation ruptures fat-globule membranes; fat clumps to butter grains; buttermilk drains) → washing → salting (~1.5–2.5 %) → working (kneads to a uniform mass, distributing moisture and salt) → packaging → cold storage. Continuous (Fritz) process: cream → high-speed churning cylinder → grain/buttermilk separation → squeezing/working (augers) with salting → continuous packaging.

Continuous butter making — flowchart

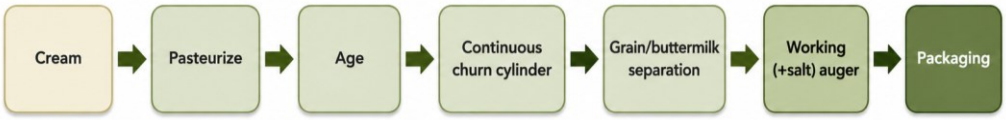


Fig. 5.6 Continuous butter-making flowchart

Common butter defects: rancid/oxidized flavour (lipolysis/oxidation), high moisture or free moisture (poor working), mottled/streaky colour (uneven salt), crumbly or greasy body (wrong churning temperature), and mould on surface (poor hygiene).

6.2 *Ice cream*

PREVIOUS YEAR QUESTIONS

- *Define Ice-cream. Write the method/flowchart of manufacturing, packaging, hardening and storage.*
  [IFoS 2021 · P2/5(c) · 8M]
- *Mention the ingredients of ice cream and describe in detail its preparation.*
  [IFoS 2024 · P2/6(a) · 15M]
- *Discuss advantages and limitations of ice-cream ingredients — milk fat, MSNF, sugar, stabilizer, emulsifier, total solids, flavour and colour.*
  [IFoS 2025 · P2/7(a) · 15M]
- *Role of constituents and unit operations in making ice cream / steps.*
  [OPSC·Forest 2023-24 · P2/Q.6(a) · 20M ; AP·PSC 2012 · Q.1(C)]

Ice cream : *a frozen dairy dessert made by freezing, while agitating and incorporating air, a pasteurized and homogenized, aged mix of milk fat, milk-solids-not-fat, sugar, stabilizer, emulsifier, flavour and colour.*

Ingredient (typical %)	*Role / advantage*	*Limitation of excess*
Milk fat (10–12%)	rich flavour, smooth texture, body	costly, high-calorie, slower whipping
MSNF (10–11%)	body, texture, whipping, cheap solids	sandiness (lactose), salty flavour
Sugar (14–16%)	sweetness, body, lowers freezing point	too soft, slower freezing, low overrun
Stabilizer (0.2–0.5%)	binds water, prevents coarse ice, melt-resist	gummy, soggy body
Emulsifier (0.1–0.3%)	disperses fat, dry smooth texture, whipping	stiff, greasy
Total solids (36–40%)	body, food value, yield	heavy, soggy, costly
Flavour & colour	palatability, appeal	artificial/harsh if excess

Manufacture: weigh/blend ingredients → pasteurize the mix → homogenize → age (~4 h at ~4 °C) → freeze in a continuous freezer (whip in air + partial freeze to soft, ~−5 °C — develops overrun) → add fruits/nuts → package → harden (blast freeze −25 to −30 °C) → store (−25 °C).

Overrun : *the increase in volume of ice cream over the volume of the mix, caused by air whipped in during freezing: Overrun % = (vol. ice cream − vol. mix)/vol. mix × 100. Typically 80–100 %. Too little → heavy/soggy; too much → fluffy and weak. (IFoS 2022 short note.)*

Ice-cream manufacture — flowchart



Fig. 5.7 Ice-cream manufacture flowchart

WORKED NUMERICAL — *Overrun (illustrative)* [demonstrates the overrun formula]

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Problem. *An ice-cream mix weighs 1.08 kg/L; after freezing the ice cream weighs 0.60 kg/L. Find the overrun.*

Given:

Weight of ice-cream mix = 1.08 kg/L

Weight of frozen ice cream = 0.60 kg/L

Formula:

Overrun (%) = [(Weight of mix − Weight of ice cream) / Weight of ice cream] × 100

Substituting the values:

$$\text{Overrun (\%)} = [(1.08 - 0.60) / 0.60] \times 100$$
$$= (0.48 / 0.60) \times 100$$
$$= 0.80 \times 100$$
$$= 80\%$$

ANSWER:

Overrun = 80%

Hence, the ice cream has an overrun of 80%.

Common ice-cream defects: coarse/icy texture (large ice crystals — low stabilizer, slow freezing, temperature fluctuation), sandy texture (lactose crystallization from excess MSNF), greasy/buttery (churned fat), shrinkage (excess overrun), and weak body (low total solids).

6.3 *Cheese (Cheddar)*

PREVIOUS YEAR QUESTIONS

- *What are the steps involved in making cheddar cheese from milk?*

[IFoS 2018 · P2/8(b) · part · 15M]

Cheese : *a product made by coagulating milk casein (by rennet and/or acid), draining the whey, and pressing and ripening the curd. Cheddar is a hard, ripened cheese distinguished by the cheddaring step.*

Cheddar cheese — steps: standardize & pasteurize milk → cool to setting temperature (~30–31 °C) → add starter culture (lactic, develops acid) → add rennet → coagulation (~30 min) → cutting the curd → cooking/scalding (heat to ~38–39 °C, expels whey) → draining whey → cheddaring (pile and repeatedly turn curd slabs so they mat and drain while acidity develops) → milling (cut slabs into small pieces) → salting (~1.5–2 %) → hooping and pressing → curing/ripening (months at ~4–10 °C).

Cheddar cheese — flowchart



Fig. 5.8 Cheddar cheese manufacture flowchart

6.4 *Shrikhand*

PREVIOUS YEAR QUESTIONS

- *Define Shrikhand. Discuss the standardised method of preparation of Shrikhand.*

[IFoS 2025 · P2/8(c) · 10M]

Shrikhand : *a sweetened, semi-soft, fermented milk product of western India made from chakka (the solid mass obtained by draining whey from dahi/curd), mixed with sugar and flavourings.*

Standardized method: standardize milk (~6 % fat) → heat/boil and cool to ~30 °C → inoculate with dahi (lactic) starter → set to curd (dahi) → break the curd and tie in a muslin cloth, hang/press to drain the whey → chakka (~50 % moisture) → knead the chakka with ground sugar (~40–45 % / roughly equal parts) → add cardamom, saffron, colour and chopped nuts → mix to a smooth homogeneous mass → package → cold-store (~5 °C).

Shrikhand — flowchart

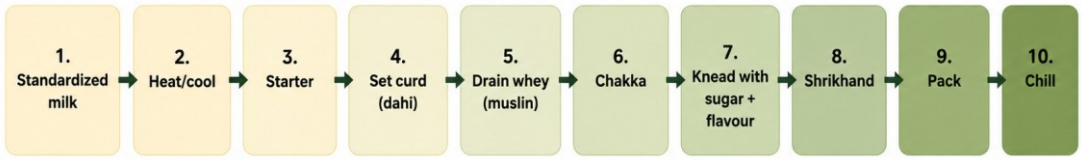


Fig. 5.9 Shrikhand manufacture flowchart

6.5 Cream freezing

PREVIOUS YEAR QUESTIONS

- *Why is freezing of cream done? Explain any two methods of cream freezing.*

[IFoS 2023 · P2/7(c) · 10M]

Why freeze cream: to preserve surplus cream during flush season for later use (butter, ice cream) when fresh supply is short; freezing arrests microbial growth and lipolytic/oxidative changes, extending storage far beyond chilling. (Cream is pasteurized, and often ~10 % sugar is added, before freezing to limit texture damage.) Two methods: (1) slow freezing — cream in cans/blocks at −18 to −29 °C in a cold store; (2) quick freezing — cream in small packages frozen rapidly in a plate or air-blast (or scraped-surface) freezer, giving small ice crystals and better reconstituted quality; stored at ≤ −18 °C.

6.6 Other indigenous dairy products (in brief)

- **Khoa/Khoya** : heat-desiccated whole milk — milk is boiled and continuously stirred in an open pan until ~65–70 % moisture is removed to a semi-solid mass; base for burfi, peda, gulabjamun.
- **Chhana & Paneer** : acid-heat coagulated milk products — hot milk is coagulated with a food acid (citric/lactic/sour whey), the curd drained; chhana (softer, for sweets like rasogolla/sandesh) and paneer (pressed, firmer, for culinary use).
- **Dahi (curd) & Lassi** : dahi = milk fermented with a lactic starter (Lactococcus/Lactobacillus) set at ~30 °C; lassi/buttermilk are its diluted/churned derivatives.

7 MILK POWDER: SPRAY & ROLLER DRYING

7.1 Milk powder — overview

Milk powder (dried milk) : *milk from which almost all water has been removed (to < 4–5 % moisture), giving a stable powder with long shelf-life and greatly reduced weight/volume. Main types: whole milk powder (WMP) and skim milk powder (SMP).*

General process: standardize → pasteurize → preheat/forewarm → concentrate in a multiple-effect (falling-film) evaporator to ~45–50 % total solids → dry (spray or roller) → cool → (agglomerate/instantize) → package. Pre-concentration cuts the water the dryer must remove, saving energy.

7.2 *Spray drying of milk*

PREVIOUS YEAR QUESTIONS

Describe how milk powder can be produced from liquid milk slurry in a spray dryer.

[IFoS 2019 · P2/7(b) · 15M]

Concentrated milk (~45–50 % TS) is atomized into a fine spray — by a rotary (centrifugal-disc) atomizer or a high-pressure nozzle — into a chamber through which hot air (150–200 °C inlet) flows. Each fine droplet has a huge surface area, so water evaporates in a few seconds while evaporative cooling keeps the particle cool (little heat damage). Dried powder is separated from the exhaust by a cyclone separator / bag filter (outlet air ~80–95 °C), cooled, optionally agglomerated/instantized, and packaged. Steps: concentrate → preheat → atomize → dry → cyclone separation → cool → (instantize) → pack. Spray drying gives a good-quality, soluble, free-flowing powder and is the most widely used method for milk.

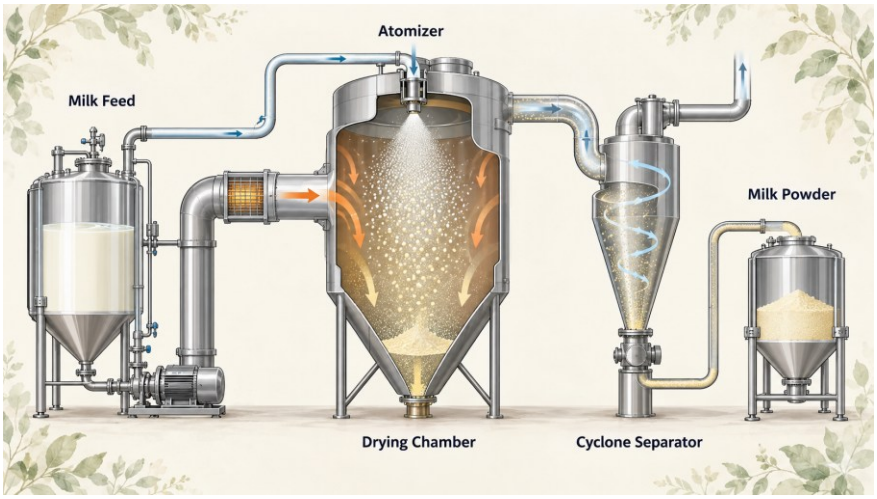
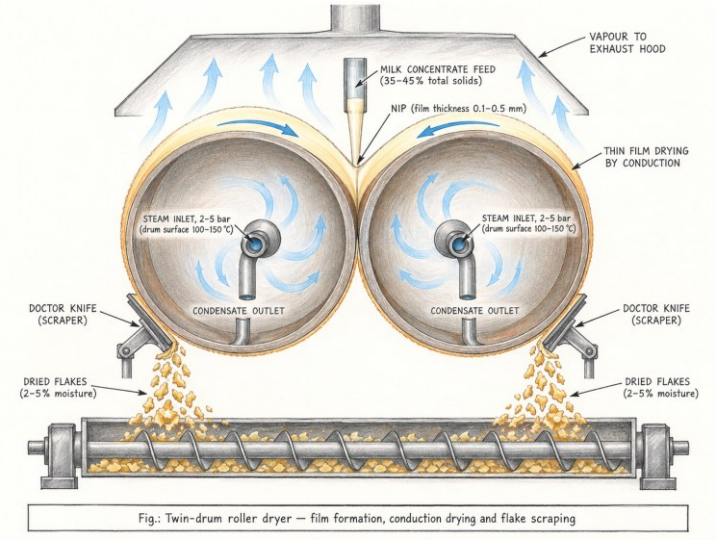


Fig. 5.10 Milk spray-drying plant

7.3 *Roller (drum) drying of milk*

Concentrated or whole milk is applied as a thin film on a steam-heated rotating drum; heat conducts through the drum wall, water evaporates, and the dried film is scraped off by a doctor knife and milled to powder. Single- or double-drum; a vacuum drum dries at lower temperature for heat-sensitive milk. Roller drying gives higher heat exposure → a cooked flavour and lower solubility, but is cheaper and simpler; it is now largely superseded by spray drying for drinking-milk powders.



7.4 *Spray vs roller drying in milk-powder manufacture*

PREVIOUS YEAR QUESTIONS

Differentiate between the working principle and application of Spray and Roller driers in Milk

Powder manufacture. [IFoS 2016 · P2/7(c) · 10M]

Feature	Spray drier	Roller (drum) drier
Heat transfer	convection (hot air)	conduction (hot drum)
Feed	atomized droplets of concentrate	thin film on drum
Temperature on product	low (evaporative cooling)	high (direct contact)
Product quality	excellent solubility, bland flavour	lower solubility, cooked flavour
Particle	hollow spherical	flaky, ground
Cost	higher capital	lower
Application	drinking-milk WMP/SMP, infant, instant	industrial powders, cost-sensitive

7.5 *Properties, instantization and defects of milk powder*

Key quality attributes: ***solubility index*** (undissolved sediment on reconstitution — lower is better; spray powder dissolves far better than roller), moisture (< 4 %), bulk density, particle size, and free-fat/wettability.

- ***Instantization / agglomeration*** : spray-dried powder is re-wetted with steam/fine mist so particles stick into porous clusters, then re-dried; the clusters wet and disperse quickly in water — giving 'instant' milk/coffee powders.
- ***Reconstitution & recombination*** : reconstituted milk = milk powder + water; recombined milk = SMP + milk fat + water, homogenized and pasteurized — used where fresh milk is scarce.
- ***Defects*** : poor solubility (over-heating in roller/high inlet temperature), scorched particles, oxidized/tallowy flavour (WMP, fat oxidation), lumpiness/caking (moisture pick-up), and stale flavour on storage.

8 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

Formula Sheet

$$\text{SNF in cream} = (100 - \%\text{fat_cream})/(100 - \%\text{fat_milk}) \times \%\text{SNF_milk}$$

$$\text{Centrifugal force } F = K \cdot W \cdot R \cdot N^2$$

$$\text{Separator start-up power: } m = \rho\pi(r_o^2 - r_i^2)L\ ;\ I = \tfrac{1}{2}m(r_o^2 + r_i^2)\ ;\ \omega = 2\pi N\ ;\ P = \tfrac{1}{2}I\omega^2/t$$

$$\text{Pearson's square: parts of a component} = |\text{other component\%} - \text{target\%}|\ (\div \text{total} \times \text{batch})$$

$$\text{Homogenizer power: } P = p \times Q \quad (\text{metric hp} = \text{kgf}\cdot\text{m}\cdot\text{s}^{-1} \div 75)$$

$$\text{Thermal kinetics: } D = t/S\ ;\ z = (T_2 - T_1)/(\log D_1 - \log D_2)\ ;\ E_a = 2.303 \cdot R \cdot T_1 T_2 / z$$

$$\text{Overrun \%} = (\text{vol. ice cream} - \text{vol. mix})/\text{vol. mix} \times 100$$

$$\text{Skimming efficiency} = (1 - \%\text{fat_skim}/\%\text{fat_milk}) \times 100$$

SUMMARY

Milk is a highly perishable triple system (emulsion + colloid + solution); processing makes it safe, stable and value-added. It is chilled to ≤ 4 °C on reception (bacteriostatic). Cream is separated centrifugally (skim to periphery, fat to axis; force 3000–6000× gravity) and milk is standardized to a set fat by Pearson's square. Homogenization forces milk through a narrow valve (turbulence + cavitation) to break fat globules (< 2 µm) so cream does not rise — first stage reduces size, second stage breaks clusters. Pasteurization (LTLT 63 °C/30 min, HTST 72 °C/15 s, UHT 135–150 °C/2–5 s) destroys pathogens; the HTST plate system regenerates 85–90 % of heat and uses a flow-diversion valve. Sterilization (> 100 °C, in-bottle or UHT) destroys spores for long ambient

life. Thermal death is logarithmic — D (90 % kill time) and z (10-fold change in D). Plate heat exchangers dominate dairy heating/chilling; fouling comes from whey-protein denaturation and calcium-phosphate precipitation. Products: butter (churning → phase inversion), ice cream (pasteurize–homogenize–age–freeze with overrun), cheddar cheese (rennet coagulation → cheddaring), shrikhand (chakka + sugar). Milk powder is made by concentrating then spray drying (soluble, bland) or roller drying (cheaper, cooked flavour).

LAST-NIGHT REVISION

- Milk: cow ~3.5–4% fat, buffalo ~6.5–7%; TS = fat + SNF; SNF ≈ 9%.
- Chilling ≤ 4–5 °C = bacteriostatic (arrests, not kills) → still pasteurize.
- Centrifugal separation: skim (heavy) to periphery, cream (light) to axis; $F = K \cdot W \cdot R \cdot N^2$; force 3000–6000× g.
- Pearson's square: parts = |other%−target%|; hold fat balance, prove the answer.
- Homogenization: high-pressure valve, turbulence + cavitation; 1st stage size, 2nd stage clusters; P = p×Q → 9.26 hp.
- Pasteurization: LTLT 63/30min, HTST 72/15s (+ FDV, 85–90% regeneration), UHT 135–150/2–5s.
- Sterilization > 100 °C kills spores; in-bottle 108–120 °C/20–30 min; UHT + aseptic pack.
- D = decimal reduction time; z = ΔT for 10× change in D; here D_{85}=0.5s, D_{71}=5s, z=14 °C, E_a≈169 kJ/mol.
- PHE: high U, compact, CIP-easy, regeneration. Fouling = whey-protein (Type A) + calcium phosphate (Type B).
- Butter = churn cream (phase inversion, ≥80% fat). Overrun % = (ice cream − mix)/mix ×100 (80–100%).
- Cheddar: set → starter → rennet → cut → cook → drain → CHEDDAR → mill → salt → press → ripen.
- Shrikhand = chakka (drained dahi) + ~40–45% sugar + cardamom/saffron.
- Milk powder: concentrate → spray dry (soluble, bland) or roller dry (cheaper, cooked). Spray = convection, roller = conduction.

CHAPTER

6

WASTE & BY-PRODUCT UTILIZATION

Rice husk & bran · Sugarcane bagasse · Plant residues & coir pith · Wealth from waste

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 3 (Agricultural Process Engineering). Chapter 6: waste and by-product utilization — rice husk, rice bran, sugarcane bagasse, plant residues and coir pith. Rice-bran oil extraction/refining and biomass densification (with the transport-cost numerical) are the most-asked themes.

Chapter Outline

1. **Agricultural Wastes & By-products: Scope**
2. **Rice-Milling By-products**
3. **Rice Bran & Bran Oil**
4. **Rice Husk Utilization**
5. **Sugarcane Bagasse & Sugar/Jaggery By-products**
6. **Biomass Densification**
7. **Plant Residues & Coir Pith**
8. **Formula Sheet · Summary · Last-Night Revision**

1 AGRICULTURAL WASTES & BY-PRODUCTS: SCOPE

1.1 Definitions

PREVIOUS YEAR QUESTIONS

- *Define agricultural wastes and by-products. How can these be utilized?*
  [UK·PSC ACF/RFO 2025 | Q.7(iii) | 10M]
- *What do you understand by agricultural by-product and wastes?*
  [OPSC·CSE 2016-17 | P2/5(a) | 20M]

Agricultural by-product : *a secondary product of value obtained in addition to the main product during crop production or processing (rice husk and bran, bagasse, oil-cake) — it has a definite use and economic worth.*

Agricultural waste : *the residual material left after harvesting or processing that is not the primary product and, if unused, is discarded (straw, stalks, shells, peels, effluents). The distinction is one of use — a 'waste' becomes a 'by-product' the moment a profitable use is found, the basis of 'wealth from waste'.*

mportance of by-product/waste utilization

Utilizing agro-residues matters on several counts: it turns a disposal liability into ***additional income*** for farmers and processors; recovers ***renewable energy*** (husk/bagasse power, biogas, ethanol) and substitutes fossil fuels and imports (*e.g.* bran oil); returns organic matter and nutrients to the soil (compost/biochar); creates ***rural employment***; and reduces the pollution of open burning and dumping. It is central to a circular, sustainable agro-economy.

1.2 Classification of agricultural wastes

- ***Crop/field residues*** : Straw, stalks, stubble, husk, cobs, leaves.
- ***Agro-processing by-products*** : Rice husk & bran, bagasse, molasses, press-mud, oil-cakes, peels and pomace, coir pith.
- ***Animal & dairy wastes*** : Dung, slurry, whey, blood, bones.

By nature they are also grouped as biodegradable vs non-biodegradable, and combustible (ligno-cellulosic) vs non-combustible.

1.3 The 'wealth from waste' principle and utilization routes

PREVIOUS YEAR QUESTIONS

- Explain the utilization of agricultural wastes and by-products / in which form best utilized.
  [OPSC·CSE 2016-17 | P2/5(a) | 20M; OPSC·CSE 2020-21 | P2/7(b) | 20]

Utilization follows the hierarchy reduce → reuse → recycle → recover (energy) → dispose. The main routes for agricultural residues are:

- ***Feed & fodder*** : Brans, oil-cakes, molasses, treated straw.
- ***Energy/fuel*** : Combustion, briquettes, gasification/producer gas, biogas, bio-ethanol, biochar.
- ***Manure & soil amendment*** : Composting, vermicomposting, green manure, biochar, coir pith.
- ***Industrial raw material*** : Silica/activated carbon (husk ash), particle board & paper (bagasse), furfural, edible oil (bran), pectin (peels).

- ***Cultivation substrate*** : Mushroom growing, potting/growing media (coir pith).
- ***Construction material*** : Husk-ash cement/bricks, bagasse board.

1.4 *Waste-disposal problem — factors and treatment*

PREVIOUS YEAR QUESTIONS

- *What are the factors to be considered in waste disposal problem? Write, in brief, regarding waste utilization and their treatment.* [OPSC·CSE 2015-16 | P2/8(b) | 20M]

Factors in the waste-disposal problem: the quantity/volume generated and its seasonality; nature (biodegradable vs toxic/hazardous, abrasive, bulky); moisture content (wet wastes rot, dry wastes burn); bulk density (low density → high transport/storage cost); location and collection logistics; environmental and pollution-control norms (air, water, land); economics (cost of collection/treatment vs value recovered); and reuse/recovery potential.

Treatment & disposal methods: composting/vermicomposting (biodegradable solids → manure); anaerobic digestion (biogas + slurry); combustion/incineration (energy recovery, volume reduction); densification (briquetting/pelleting); recycling into industrial products; and, as a last resort, sanitary landfilling. Liquid effluents (dairy, distillery) need effluent treatment before discharge.

1.5 *Biological treatment routes — composting and biogas*

Composting / vermicomposting — *aerobic microbial decomposition of biodegradable residues into a stable, humus-rich manure. The C:N ratio is lowered to ~20:1, pathogens and weed seeds are destroyed by the thermophilic phase, and the product improves soil structure and fertility. Vermicomposting uses earthworms for a faster, finer compost. Bulky/woody residues are shredded and N-supplemented (urea) to speed the process.*

Biogas (anaerobic digestion / biomethanation) — *anaerobic microbial breakdown of wet organic wastes (dung, press mud, vegetable waste, slurry) in a digester to yield biogas (~55–65 % CH_4 + CO_2) as fuel and a nutrient-rich digested slurry as manure. It suits high-moisture wastes that are unsuitable for combustion, and gives both energy and manure — a preferred route for wet agro-wastes.*

2 RICE-MILLING BY-PRODUCTS

2.1 *By-products generated in paddy milling*

PREVIOUS YEAR QUESTIONS

- *Which are the by-products generated during milling of paddy? Describe how the by-products can be profitably used.* [IFOS 2016 | P2/6(d) | 10M]

In rice milling the primary product is polished (white) rice; the operations of shelling (dehusking) and whitening/polishing generate the by-products:

By-product	*Approx. yield (% of paddy)*	*Origin*
Rice husk (hull)	~20–22 %	hard siliceous outer covering (shelling)
Rice bran + polish	~4–9 % (true bran 4–5)	outer layers of brown rice (whitening)
Germ (embryo)	part of bran	oil- and nutrient-rich
Broken rice	~15–25 %	broken kernels (grading)

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Rice polish / small grains	minor	inner bran + endosperm

Approximate mass balance: 100 kg paddy → ~72 kg rice (head + broken), ~20 kg husk, ~8 kg bran & polish.

2.2 *Profitable utilization of the by-products*

- ***Rice husk*** : Fuel for boilers/furnaces and gasifiers (producer gas); rice-husk ash → silica, activated carbon, insulation, pozzolana for cement/bricks; particle board; poultry litter. (§4)
- ***Rice bran*** : Edible rice-bran oil (after refining); high-value animal/poultry feed; defatted bran for food/feed; high-FFA oil for soap & fatty acids; wax and tocopherol. (§3)
- ***Broken rice*** : Rice flour, rice starch, brewing/distilling, baby foods, noodles, feed.
- ***Germ & polish*** : Germ oil and nutraceuticals; polish as high-energy feed/food supplement.

The rubber-roll (modern) mill gives the purest bran; huller mills give bran heavily contaminated with husk, which lowers its value — so complete exploitation of bran depends on its purity.

3 RICE BRAN & BRAN OIL

3.1 *Rice bran — nature, composition and types*

Rice bran *— the outer layers of brown rice (pericarp, aleurone, germ and part of the endosperm) removed during whitening; ~4–9 % of paddy (true bran 4–5 %). Rich in fat, protein, B- and E-vitamins and minerals.*

Types: raw bran (12–18 % oil, light, unstable), parboiled bran (20–28 % oil, darker/oilier) and defatted/deoiled bran (1–3 % oil). Purity depends on the mill — huller bran carries much husk, sheller less, and the modern rubber-roll mill gives almost pure bran.

Bran type	*Oil (%)*	*Character / use*
Raw bran	12–18	light, unstable; edible oil after quick stabilization
Parboiled bran	20–28	darker, oilier; higher oil yield, more stable
Defatted (deoiled) bran	1–3	dusty; protein/vitamin-rich food & feed ingredient

3.2 *Storage problem of rice bran and its reasons*

PREVIOUS YEAR QUESTIONS

Write the problem associated with storage of rice bran and its possible reasons.

[IFOS 2016 | P2/8(d) | 10M]

Problem: fresh bran deteriorates very rapidly — its free fatty acid (FFA) content rises sharply within hours to days, so the oil quickly becomes unfit for edible refining (usable only for soap/industrial grade) and the bran turns rancid.

Reason — lipase-catalysed hydrolysis (lipolysis) *— rice bran contains an active lipase enzyme, which on milling comes into intimate contact with the bran oil and hydrolyses the triglycerides into free fatty acids + glycerol, accelerated by moisture and warm temperature. Oxidative rancidity (lipoxidase/air) and insect/microbial activity add to spoilage. Hence bran must be stabilized or its oil extracted immediately.*

3.3 *Stabilization of rice bran*

PREVIOUS YEAR QUESTIONS

- What are the different methods of stabilization of rice bran? [IFOS 2023 | P2/6(b)(i) | 8M]

Stabilization : *inactivating the lipase (and lipoxidase) enzyme so the FFA rise is arrested, extending the safe storage life of bran and its oil.*

- ***Heat treatment (most effective/economic)*** : Dry heat — conduction (~90 °C, 20 min → ~2 months), infrared (110 °C, 10–15 min), convection, dielectric/microwave, frictional (expeller); wet heat — live steaming at 95–100 °C for 3–5 min then drying to ~3–5 % moisture (safe 3–4 months).
- ***Low-RH storage*** : Retards FFA rise, but only after drying bran to low moisture.
- ***Chemical / X–M process*** : Chemical treatments mostly ineffective (except HCl); simultaneous milling + hexane extraction (X–M) promising but expensive.

Method	*Condition*	*Safe storage*
Conduction (dry heat)	~90 °C, 20 min → 4–5 % moisture	~2 months
Infrared (dry heat)	110 °C, 10–15 min	~2 months (airtight)
Live steaming (wet heat)	95–100 °C, 3–5 min → dry to 3–5 %	3–4 months
Low-RH storage	after drying to low moisture	retards FFA rise

Indian stabilizers: Jadavpur University (wet-heat screw-conveyor steaming + pneumatic fluidized dryer + cyclone), CFTRI Mysore (conduction heat-jacketed revolving-drum toaster), and the PHTC/Chakraverty continuous stabilizer (steam-jacketed screw conveyor + steam-jacketed paddle dryer to 4–5 % moisture).

3.4 *Extraction of rice bran oil*

PREVIOUS YEAR QUESTIONS

- *Explain the process of extracting crude bran oil through batch-type solvent extraction method.* [IFOS 2024 | P2/8(b) | 12M]
- *Explain the process of extraction and refining of rice-bran oil / extraction of oil from rice bran* [IFOS 2023 | P2/6(b)(ii) | 7M; IFOS 2016 | P2/8(d) | Part]
- *Name various methods for extracting rice-bran oil. Describe solvent extraction and give its advantages.* [UK·PSC RFO 2021 | Q.8(iv) | 10M; UK·PSC ACF 2019 | Q.8(iv) | 10M; OPSC·CSE 2015-16 | P2/7(b) | 20M]

Two methods: mechanical expression (hydraulic press/expeller, 70–280 kg/cm²) — low oil yield, now largely abandoned; and solvent extraction (usually n-hexane, b.p. 66–70 °C) — universally used for its high oil output. Solvent systems are batch, semicontinuous and continuous; the batch system is exclusively suited to rice-bran oil (simple, low cost).

- ***Mechanical (expeller) extraction*** : The stabilized bran is pressed in a hydraulic press or screw expeller at 70–280 kg/cm²; simple and solvent-free, but leaves a high residual oil (8–12 %) in the cake, so the yield is low — hence solvent extraction is preferred commercially.
- ***Solvent extraction (preferred)*** : Dissolves the oil in n-hexane, giving very low residual oil (1–3 %) and high yield; solvent is recovered and reused. Described below.

MODEL Q Batch solvent extraction — steps: **(1)** Pretreatment — steam/dry the stabilized bran to 6–8 % moisture (reduces fines, hardens/enlarges particles, aids oil release and percolation). **(2)** Charging — load into (typically five) stationary batch extraction vessels, each with a thick sugar-bag false bottom as filter

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(~0.5 t bran). **(3)** Extraction — n-hexane percolates through the bed and dissolves the oil → miscella. **(4)** Miscella recovery — steam at ~2 atm forces out miscella → strainer → heat exchanger → stripper/distillation → crude bran oil. **(5)** Desolventizing — bottom steam drives residual solvent out of the meal; all solvent condensed and recycled. **(6)** Discharge — deoiled meal (1–3 % oil, 8–12 % moisture). Cycle ≈ 2½ h; capacity ≈ 24–25 t/day.***

Advantages of solvent extraction: high oil yield (very low residual oil, 1–3 %, in meal); better-quality oil; suitable for low-oil materials like bran; solvent recovered and reused; continuous large-scale operation possible.

Solvent-extraction systems: the ***batch*** system (above) is simplest and best suited to rice bran; the ***semicontinuous*** and ***continuous*** systems give higher capacity and are used for oilseeds generally — the continuous system first pelletizes the steam-treated bran (6–8 mm pellets) to enlarge particle size and eliminate fines, but needs high power and investment.

◆ **WORKED NUMERICAL — *Rice-bran oil yield (illustrative)*** **[demonstrates by-product yield]**

Problem. *Estimate the rice-bran oil obtainable per tonne of paddy. Assume bran = 8 % of paddy, oil content of (raw) bran = 16 %, and solvent-extraction recovery = 95 %.*

Given:

Paddy = 1 tonne = 1000 kg

Bran content = 8% of paddy

Oil content in raw bran = 16%

Solvent-extraction recovery = 95%

Step 1: Calculate bran obtained from 1 tonne of paddy

$$\text{Bran obtained} = 1000 \times 8/100$$

$$= 80 \text{ kg}$$

Step 2: Calculate total oil present in the bran

$$\text{Oil present in bran} = 80 \times 16/100$$

$$= 12.8 \text{ kg}$$

Step 3: Calculate recoverable oil at 95% extraction efficiency

$$\text{Recoverable rice-bran oil} = 12.8 \times 95/100$$

$$= 12.16 \text{ kg}$$

Answer: Approximately **12.16 kg, or about 12.2 kg, of rice-bran oil can be obtained from 1 tonne of paddy.**

Shortcut Calculation:

$$\text{Rice-bran oil} = 1000 \times 0.08 \times 0.16 \times 0.95$$

$$= \mathbf{12.16 \text{ kg per tonne of paddy}}.$$

▣ ***Batch solvent extraction of rice-bran oil***

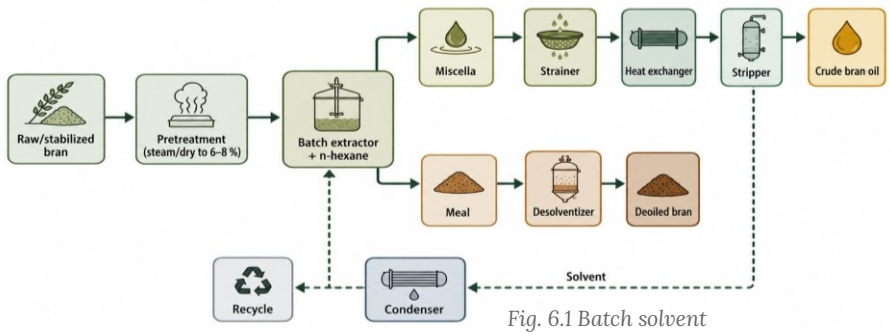


Fig. 6.1 Batch solvent

3.5 Refining of crude rice-bran oil into edible grade

PREVIOUS YEAR QUESTIONS

- *Explain the refining of rice-bran oil* [IFOS 2023 | P2/6(b)(ii) | 7M]

Crude bran oil is the most difficult vegetable oil to refine (high FFA, gums, wax, colour, odour). Steps: (1) dewaxing & degumming (remove hard wax, gums, mucilages); (2) neutralization (alkali removes FFA as soapstock); (3) decolorization/bleaching (activated earth/carbon removes colour); (4) deodorization (steam under vacuum removes odour and unsaponifiables); (5) winterization (chilling removes soft wax → clear salad oil).

Refining of crude rice-bran oil

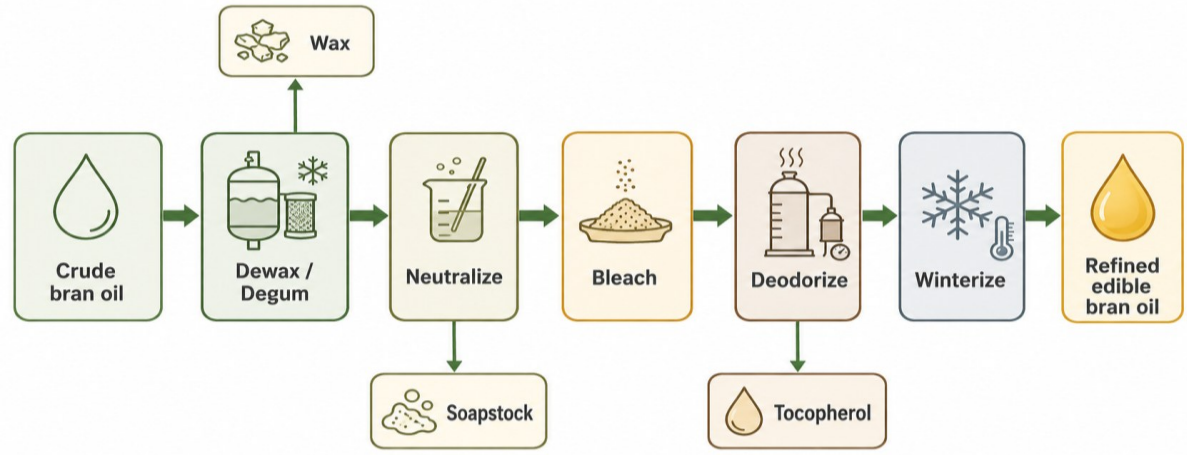


Fig. 6.2 Refining of crude rice-bran oil

3.5 Uses of bran, bran oil and its constituents

Refined edible oil (low linolenic + high tocopherol → stable, heart-healthy; salad/cooking oil and, on hydrogenation, shortenings); high-FFA crude oil → soft/liquid soaps and fatty acids (stearic, oleic); protective coatings (paints, varnishes, lacquers); plasticizers; tocopherol (vitamin E); rice-bran wax (a carnauba substitute, m.p. 72–84 °C); and defatted bran as a protein/vitamin-rich food and feed ingredient.

4 RICE HUSK UTILIZATION

4.1 Rice husk — nature and the disposal problem

PREVIOUS YEAR QUESTIONS

- What is rice husk? [IFOS 2019 | P2/5(c) | 8M]

Rice husk (hull) : *the hard, siliceous outer covering of the paddy grain, removed during shelling; about one-fifth (~20 %) of paddy weight (India ~20 million t/year).*

It is a problem by-product because it is abrasive, of low nutritive value, of low bulk density (~100–120 kg/m³, bulky), and high in ash (~20 %, mostly silica). Composition (% d.b.): cellulose ~38, lignin ~22, pentosans ~18, ash ~20 (of which ~94 % is SiO_2). Its calorific value (~13–15 MJ/kg) makes it a useful solid fuel.

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Property / RHA constituent	Value
Husk as % of paddy	~20 %
Bulk density	~100–120 kg/m³ (ρ = 0.37M + 97.44)
Ash content	~20 % (d.b.)
RHA — SiO_2	~94.5 %
RHA — K_2O / Na_2O / CaO	~1.1 / 0.8 / 0.25 %
Calorific value	~13–15 MJ/kg

4.2 Energy generation from rice husk

PREVIOUS YEAR QUESTIONS

Describe how energy can be generated from rice husk. [IFOS 2019 | P2/5(c) | 8M]

- ***Direct combustion*** : Husk burnt in husk-fired furnaces/boilers to give hot air/flue gas (drying, parboiling) and steam (steam engines/turbines → power). Most rice mills burn husk to raise parboiling steam.
- ***Gasification*** : Husk partially combusted with limited air in a gasifier (downdraft/fluidized-bed) → producer gas ($CO + H_2 + CH_4$), burnt in an engine/generator for electricity or as thermal fuel.
- ***Densification*** : Husk briquettes/pellets as a dense, easily handled solid fuel.
- ***Biomass power plants*** : Dedicated husk-fired (or co-fired) power stations.

Husk combustion proceeds in three stages: moisture removal (< 150 °C), devolatilization with fast-flaming combustion of volatiles (220–375 °C), and slow smouldering combustion of fixed carbon (> 375 °C). The residue is rice-husk ash (RHA) — itself a valuable co-product.

▣ Rice-husk energy routes

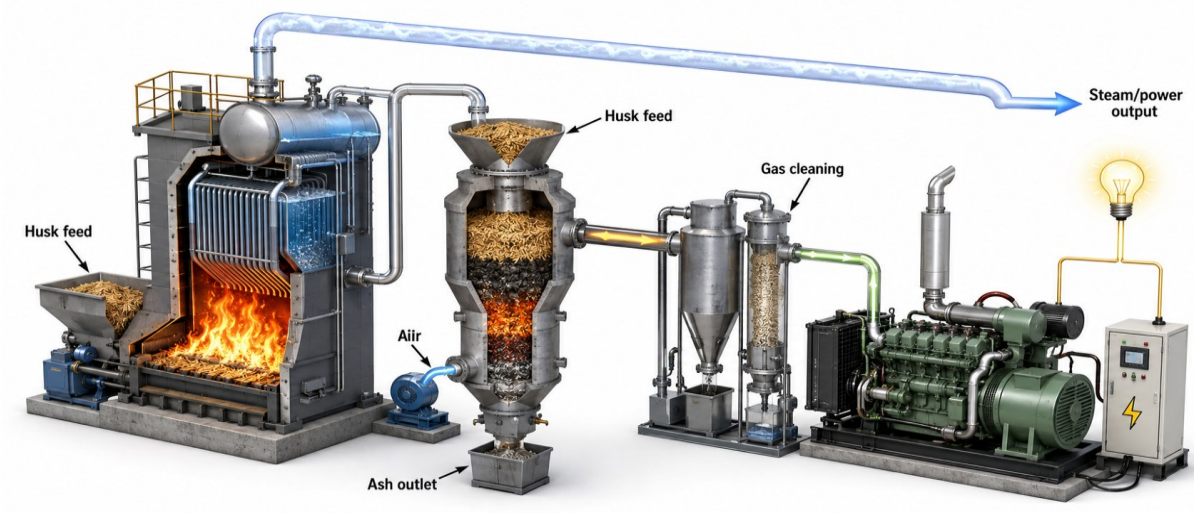


Fig. 6.3 Rice-husk energy: combustion and gasification

Gasification & producer gas — *in a gasifier the husk is burnt with a restricted air supply so that, instead of full combustion, it is partially oxidised to a combustible producer gas (CO, H_2, CH_4 with N_2 and CO_2; calorific value ~4–5 MJ/m³). Gasifier types: updraft, downdraft (cleanest gas, common for engines) and fluidized-bed (high throughput). The cleaned gas runs an internal-combustion engine/generator for electricity or is used as a thermal fuel for drying.*

4.3 Rice-husk ash (RHA) and silica

Burning husk leaves ~20 % ash that is ~94 % silica (SiO_2). Controlled low-temperature combustion gives reactive amorphous silica; high-temperature burning gives less-reactive crystalline silica. Uses of RHA: pozzolana / supplementary cementitious material (blended cement, high-strength concrete); refractory and insulation bricks; source of pure amorphous silica and silicon, silica gel, activated carbon, ceramics and abrasives.

◆ **WORKED NUMERICAL — *Silica from rice husk (illustrative)*** [demonstrates ash/silica yield]

Problem. *Estimate the silica obtainable from 1 tonne of rice husk. Assume ash = 20 % of husk and SiO_2 = 94.5 % of the ash.*

Given:

Rice husk = 1 tonne = 1000 kg

Ash content = 20% of husk

SiO_2 content = 94.5% of ash

Step 1: Calculate ash obtained from 1 tonne of rice husk

$$\text{Ash obtained} = 1000 \times 20/100$$
$$= 200 \text{ kg}$$

Step 2: Calculate silica (SiO_2) present in the ash

$$\text{Silica obtained} = 200 \times 94.5/100$$
$$= 189 \text{ kg}$$

Answer: Approximately **189 kg of silica (SiO_2)** can be obtained from **1 tonne of rice husk**.

Shortcut Calculation:

$$\text{Silica} = 1000 \times 0.20 \times 0.945$$
$$= \textbf{189 kg per tonne of rice husk}.$$

4.4 *Other technological solutions for husk utilization*

PREVIOUS YEAR QUESTIONS

- *Write different technological solutions available for utilization of rice husk.*

[IFOS 2016 | P2/8(c) | 10M]

Route	*Products*
Energy	combustion (heat/steam/power), gasification (producer gas), briquettes
Ash/silica	pozzolana cement, silica, silicon, activated carbon, insulation
Building materials	husk-cement, particle/panel board, lightweight concrete
Chemicals	furfural (from pentosans), adsorbents/oil-sorbents, filtering & pressing aids
Agriculture	poultry litter & bedding, mushroom substrate, compost/biochar, pesticide carrier
Feed	chemically-treated husk as roughage

5 SUGARCANE BAGASSE & SUGAR/JAGGERY BY-PRODUCTS

5.1 *By-products of the sugar and jaggery industries*

PREVIOUS YEAR QUESTIONS

- Explain the by-products generation from sugarcane in sugar and jaggery industries.

[IFOS 2022 | P2/6(b) | 15M]

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By-product	Yield (% cane)	Nature & main uses
Bagasse	~30 %	fibrous residue after juice extraction; fuel/cogeneration, paper, board, ethanol
Molasses	~4–5 %	mother-liquor after crystallization; distillery alcohol, yeast, feed
Press mud / filter cake	~3 %	clarification mud; manure/compost, wax, biogas
Bagasse/boiler fly ash	minor	cement, bricks, soil amendment

In the jaggery (gur) industry (small scale) the main by-products are bagasse (almost entirely burnt as furnace fuel to boil the juice), scum/skimmings (used as feed) and small quantities of molasses/sheera. Because the jaggery furnace burns its own bagasse, an efficient furnace makes the unit energy self-sufficient; surplus bagasse (from improved crushers) can be sold or briquetted, and the sheera used for distillation or feed — extending wealth-from-waste to the decentralised gur sector.

5.2 *Utilization of bagasse*

PREVIOUS YEAR QUESTIONS

- Describe how sugarcane bagasse can be utilized, not going as waste. [IFOS 2016 | P2/7(d) | 10M]
- Utilize by-products such as bagasse and coir pith. [UK·PSC RFO 2012 | Q.8(iii) | 10M]

- ***Fuel & power (cogeneration)*** : Bagasse is the mill's own boiler fuel, raising steam and electricity; high-pressure boilers export surplus power to the grid.
- ***Paper & pulp*** : A major non-wood pulp for paper, newsprint and board.
- ***Boards & composites*** : Particle board, fibreboard, hardboard, insulation board.
- ***Chemicals*** : Furfural (from pentosans), alpha-cellulose, xylitol, CMC.
- ***Others*** : Cellulosic ethanol (§5.3), treated bagasse as feed, mushroom substrate, biochar, bedding.

◆ **WORKED NUMERICAL — *Bagasse cogeneration power (illustrative)*** **[demonstrates energy from bagasse]**

Problem. *A sugar mill crushes 2000 t of cane per day. Estimate the electrical power that its bagasse can cogenerate. Assume bagasse = 30 % of cane, calorific value = 2250 kcal/kg (wet), and overall boiler-to-electricity efficiency = 20 %.*

Given:

Cane crushed = 2000 tonnes/day

Bagasse produced = 30% of cane

Calorific value of wet bagasse = 2250 kcal/kg

Overall boiler-to-electricity efficiency = 20%

Step 1: Calculate bagasse produced per day

$$\text{Bagasse} = 2000 \times 30/100$$

$$= 600 \text{ tonnes/day}$$

$$= 600{,}000 \text{ kg/day}$$

Step 2: Calculate total thermal energy in bagasse

$$\text{Thermal energy} = 600{,}000 \times 2250$$

$$= 1{,}350{,}000{,}000 \text{ kcal/day}$$

Step 3: Calculate energy converted into electricity

$$\text{Electrical energy equivalent} = 1{,}350{,}000{,}000 \times 20/100$$

$$= 270{,}000{,}000 \text{ kcal/day}$$

Using:

1 kcal ≈ 0.001162 kWh

Electrical energy generated:

= 270,000,000 × 0.001162

≈ 313,740 kWh/day

Step 4: Calculate average electrical power

Power = 313,740 / 24

≈ 13,073 kW

= **13.07 MW**

Answer: The sugar mill can theoretically cogenerate approximately **13 MW of electrical power** from its bagasse under the given assumptions.

Shortcut Calculation:

Power = [2000 × 1000 × 0.30 × 2250 × 0.20 × 0.001162] / 24

= **≈ 13.1 MW**

5.3 *Alcohol (ethanol) from sugarcane bagasse*

PREVIOUS YEAR QUESTIONS

- What are the steps involved in producing alcohol from sugarcane bagasse? [IFOS 2018 | P2/5(d) | 8M]

Bagasse is ligno-cellulosic, so its cellulose and hemicellulose must first be broken down to fermentable sugars — second-generation (cellulosic) ethanol. Steps: (1) size reduction/preparation; (2) pretreatment — break the lignin–cellulose bond and open the fibre by steam explosion, dilute-acid or alkali treatment; (3) hydrolysis (saccharification) — acid or enzymatic (cellulase) hydrolysis of cellulose/hemicellulose to fermentable sugars (glucose, xylose); (4) fermentation — yeast (Saccharomyces) ferments the sugars to ethanol + CO_2; (5) distillation & dehydration to anhydrous (fuel-grade) ethanol.

▣ *Ethanol from sugarcane bagasse*

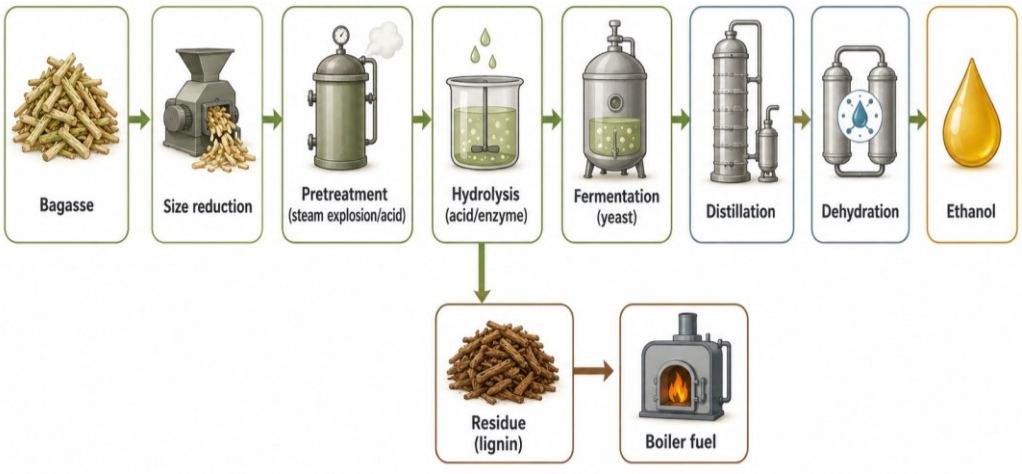


Fig: Cellulosic ethanol

5.4 *Molasses and press mud*

- ***Molasses*** :— → Distillery: fermentation and distillation to ethanol/alcohol (potable, industrial, fuel), plus yeast, citric acid, rum and cattle feed.
- ***Press mud (filter cake)*** : → Compost/manure (nutrient-rich), sugarcane wax extraction, biogas, and boiler fuel.

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- ***Bagasse fly ash*** : → Cement, bricks, soil amendment.

The distillery that ferments molasses produces a highly polluting liquid effluent — spent wash (very high BOD/COD). It is treated by anaerobic digestion (recovering biogas), then aerobic treatment, or concentrated and incinerated; the potash-rich ash and treated slurry are used as manure — closing the material loop.

5.5 *Wealth from waste — the sugar-industry flowchart*

PREVIOUS YEAR QUESTIONS

Show potential utilization of sugarcane-industry waste for generation of wealth from waste through a process flowchart. [IFOS 2022 | P2/6(b) | 15M]

Sugar-industry wealth-from-waste flowchart

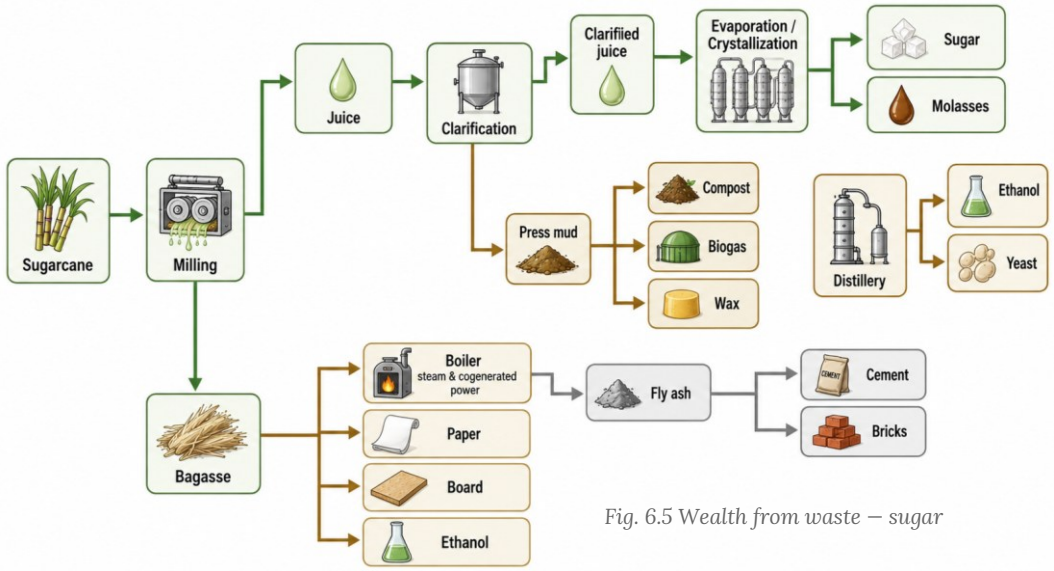


Fig. 6.5 Wealth from waste — sugar

6 BIOMASS DENSIFICATION

6.1 *The low-bulk-density problem*

PREVIOUS YEAR QUESTIONS

The biomass generated from various crops has usually low bulk density and poses huge problems in transportation and storage. State how this problem can be solved. List the technologies available. Describe any one in detail. [IFOS 2020 | P2/6(a) | 15M]

Loose crop biomass — straw, husk, stalks, stover — has a very low bulk density (~40–100 kg/m³), so a given mass occupies a large volume. This makes transport and storage bulky and costly, handling and furnace-feeding difficult, and causes dust and wind losses.

6.2 *Solution — densification*

Densification — *compacting loose biomass under high pressure into dense, uniform units (briquettes or pellets), raising bulk density many-fold (to ~400–1200 kg/m³). Benefits: much lower transport and storage cost per tonne, easier mechanised handling/feeding, uniform size and higher energy density, and reduced dust/wind loss.*

Technologies available: (1) briquetting — piston/ram press and screw press/extruder; (2) pelleting — pellet mill (die-and-roller); (3) baling; (4) cubing; (5) roller/tablet compaction. Densification may be binderless (high pressure softens the natural lignin, which binds the particles) or use an added binder.

6.3 Briquetting (described in detail)

Loose biomass is dried to ~8–12 % moisture and size-reduced, then compressed at high pressure and temperature so that the lignin plasticises and binds the particles into a dense briquette without an external binder. Two main machines: piston (ram) press — a reciprocating ram forces biomass through a tapered die → solid cylindrical briquettes (robust, high capacity); and screw press/extruder — a rotating screw continuously compresses and extrudes biomass through a heated die → higher-density briquette with a central hole and carbonised outer surface (burns better). Process flow: raw biomass → drying → size reduction → (pre-heating) → high-pressure compaction → cooling/curing → briquettes.

▣ Briquetting machine (screw & piston press)

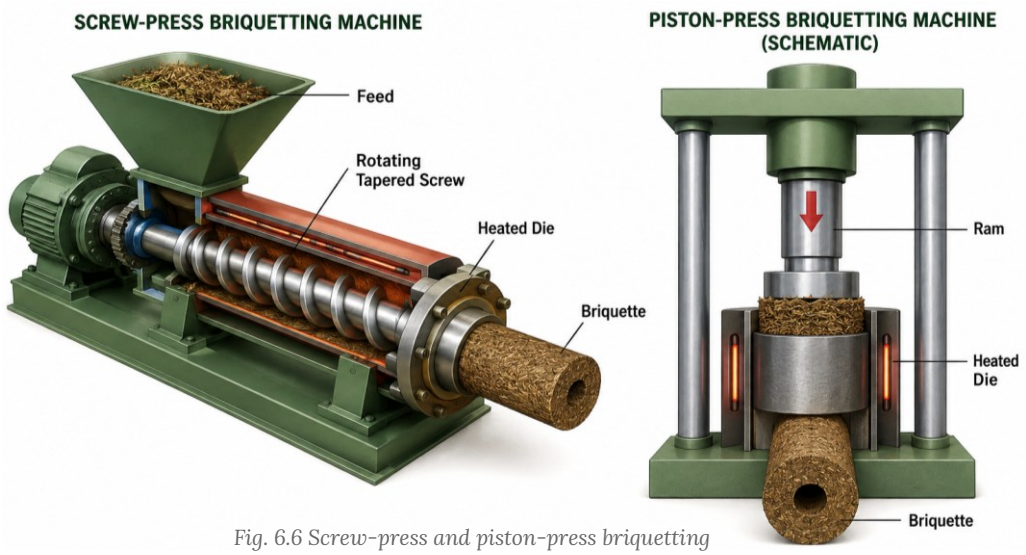


Fig. 6.6 Screw-press and piston-press briquetting

Briquetting vs pelleting; factors affecting quality

Feature	Briquetting	Pelleting
Product size	large (Ø 40–100 mm)	small (Ø 6–12 mm)
Machine	piston/screw press	die-and-roller pellet mill
Pressure/binder	very high, usually binderless	moderate, binder often used
Use	industrial/boiler fuel	stoves, feed, co-firing, export

Factors affecting densified-product quality: feed moisture (~8–15 %), particle size, applied pressure and temperature, lignin content (natural binder), die geometry, and residence time. Correct moisture and pressure give dense, durable, low-fines briquettes/pellets.

6.4 Worked numerical — transport-cost saving by densification

◆ **WORKED NUMERICAL — *Transport-cost saving by densification*** **[IFoS 2020 · P2/6(a) · part · 15M]**

Problem. *Calculate the percent saving per kg in transport cost of chopped wheat straw carried by truck from city A to B in loose vs densified form. Bulk density: loose 80 kg/m³, densified 400 kg/m³; transport cost ₹2000 per truck; truck volume 10 m³.*

Given:
Bulk density of loose straw = 80 kg/m^3

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Bulk density of densified straw = 400 kg/m^3
Truck volume = 10 m^3
Transport cost per truck = ₹2000

Step 1: Quantity of loose straw carried per truck

Loose straw carried = 80 × 10

= 800 kg

Transport cost per kg = 2000 / 800

= ₹2.50/kg

Step 2: Quantity of densified straw carried per truck

Densified straw carried = 400 × 10

= 4000 kg

Transport cost per kg = 2000 / 4000

= ₹0.50/kg

Step 3: Saving in transport cost per kg

Saving = 2.50 − 0.50

= ₹2.00/kg

Step 4: Percentage saving

Percentage saving = [(2.50 − 0.50) / 2.50] × 100

= (2.00 / 2.50) × 100

= 80%

Answer: Densification of chopped wheat straw results in an approximately 80% saving in transport cost per kg, reducing the cost from ₹2.50/kg to ₹0.50/kg.

7 PLANT RESIDUES & COIR PITH

7.1 *Plant (crop) residues – nature and utilization*

PREVIOUS YEAR QUESTIONS

- *Describe how best and in which form the agricultural waste and by-product (rice husk, rice bran, plant residues) can be utilized.* [OPSC-CSE 2020-21 | P2/7(b) | 20M]
- *Describe the waste and by-product utilization of rice husk, rice bran, plant residues and coir pith.* [OPSC-CSE 2017-18 | P2/8(b) | 20M]

Plant/crop residues *– the vegetative material left after harvesting: straw, stalks, stover, stubble, leaves, cobs, shells and haulms (rice & wheat straw, maize/sorghum stalks and cobs, cotton stalks, groundnut shells). Large quantities are produced annually in India.*

- ***Feed & fodder*** : Cereal straws and stover, often after urea/ammonia treatment to improve digestibility.
- ***Energy*** : Direct combustion, briquettes/pellets, gasification, biogas, biochar.
- ***Manure & soil improvement*** : In-situ incorporation (organic matter, nutrient recycling), composting/vermicomposting, mulching, green manure.
- ***Mushroom & industrial*** : Paddy/wheat straw as mushroom substrate; paper & pulp, particle/fibre board, packaging, furfural.

Biochar (pyrolysis) *– heating residues in the absence (or limited supply) of air (pyrolysis, ~350–600 °C) yields biochar (a stable carbon-rich solid), plus bio-oil and syngas. Biochar applied to soil improves water- and nutrient-holding capacity and sequesters carbon for the long term – a value-added, climate-friendly use of crop residues.*

Crop-residue (stubble) burning *– in-field burning of residues (notably paddy straw in NW India)*

causes severe air pollution, loss of soil nutrients/organic matter and microbe damage. Solutions: in-situ (Happy/Super Seeder sowing through residue, mulching, incorporation) and ex-situ use (baling → fodder, biomass power, compressed biogas, board) — converting residue to value instead of smoke.

7.2 *Coir pith*

PREVIOUS YEAR QUESTIONS

Utilize by-products such as rice-husk, rice-bran, sugarcane-bagasse and coir pith.

[UK·PSC RFO 2012 | Q.8(iii) | 10M]

Coir pith (coir dust / cocopeat) *— the light, spongy, corky residue left after extracting coir fibre from coconut husk (~50–70 % of the husk). It accumulates in huge heaps and is slow to decompose because of its high lignin, very high C:N ratio (~100–120:1), high potassium and phenolics, and acidic nature — so raw pith is a disposal problem and, if applied fresh, immobilises soil nitrogen.*

- ***Soil-less growing medium (cocopeat)*** : Compressed pith blocks with excellent water-holding, aeration and porosity — for nursery, horticulture, greenhouse and hydroponic cultivation and seed germination.
- ***Composted coir pith / manure*** : Biocomposting (pith + urea + the fungus Pleurotus) degrades lignin and lowers the C:N ratio to ~20–30:1 in a few weeks → soil conditioner and manure; also vermicomposted.
- ***Soil conditioner & others*** : Improves structure and moisture of sandy/degraded soils; component of potting mixtures, fuel briquettes, hardboard, and (minor) activated carbon.

Treatment before use: raw pith is washed to remove excess salts/potassium and composted (to lower C:N and phenolics) before agricultural/horticultural use.

	Best-value use
Rice husk	fuel/gasification + husk-ash silica
Rice bran	edible bran oil + defatted-bran feed
Bagasse	cogeneration power + paper/board
Plant residues	feed, in-situ manure, biomass energy
Coir pith	composted cocopeat growing medium / soil conditioner

◆ *Source: Sahay & Singh, Ch. 8 (crop residues & by-products); Chakraverty–Mujumdar Handbook (biomass); coir-pith data from ICAR/CCRI (supplemented — not in supplied books).*

8 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

Formula Sheet & key data

Mass per truck = bulk density × truck volume

Transport cost per kg = cost per truck ÷ mass per truck

% saving = (cost_loose − cost_densified)/cost_loose × 100

Key data: husk ≈ 20 % of paddy (RHA ≈ 94 % SiO_2) ; bran 4–9 % (raw oil 12–18 %, parboiled 20–28 %, deoiled 1–3 %) ; bagasse ≈ 30 % of cane ; coir pith C:N ≈ 100:1 → composted ≈ 20–30:1

SUMMARY

A waste becomes a by-product the moment a profitable use is found — 'wealth from waste' — following reduce → reuse → recycle → recover → dispose. Paddy milling yields husk (~20 %), bran (~4–9 %), germ and broken rice. Rice bran is the most valuable by-product: its lipase rapidly raises FFA (storage problem), so it is stabilized by heat treatment (dry conduction/IR or wet steaming) and its oil extracted — chiefly by batch n-hexane solvent extraction (pretreat to 6–8 % moisture → extract → strip miscella → desolventize meal), then refined (dewax/degum → neutralize → bleach → deodorize → winterize) to edible oil, with wax and tocopherol

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as by-products. Rice husk (siliceous, low bulk density) is used for energy (combustion, gasification) with rice-husk ash (~94 % silica) as pozzolana/silica source. Sugarcane gives bagasse (cogeneration, paper, board, cellulosic ethanol), molasses (distillery alcohol) and press mud (compost/biogas) — a full wealth-from-waste chain. Low-bulk-density biomass is densified by briquetting/pelleting, which sharply cuts transport cost (80 % per kg in the worked case). Plant residues serve as feed, in-situ manure and biomass energy (avoiding stubble burning), and coir pith, after washing and biocomposting (C:N 100:1 → 20–30:1), becomes a prized cocopeat growing medium and soil conditioner.

LAST-NIGHT REVISION

- By-product = useful secondary product; waste = discarded residue; wealth from waste hierarchy: reduce→reuse→recycle→recover→dispose.
- Paddy milling: husk ~20 %, bran ~4–9 %, germ, broken rice.
- Bran storage problem = rapid FFA rise from lipase hydrolysis; fix = stabilize (heat: conduction 90 °C/20 min, IR, or steaming 95–100 °C).
- Bran oil: mechanical (expeller) vs solvent (n-hexane, bp 66–70 °C, high yield). Batch: pretreat 6–8 % → extract → miscella → strip → crude oil; meal 1–3 % oil.
- Refining order: dewax/degum → neutralize → bleach → deodorize → winterize. By-products: wax, tocopherol.
- Rice husk: abrasive, low density, ~20 % ash (94 % SiO_2). Energy = combustion + gasification; RHA = pozzolana/silica.
- Bagasse (~30 % cane): cogeneration, paper/board, furfural, cellulosic ethanol. Molasses → distillery alcohol; press mud → compost/biogas.
- Cellulosic ethanol: size-reduce → pretreat (steam explosion) → hydrolyse (acid/enzyme) → ferment (yeast) → distil.
- Densification (briquetting/pelleting) raises bulk density → cuts transport/storage cost. Numerical: loose 80 vs dense 400 kg/m^3 → 80 % saving/kg.
- Plant residues: feed, in-situ manure (avoid stubble burning), biomass energy, mushroom substrate.
- Coir pith: high lignin, C:N ~100:1, high K; wash + biocompost (Pleurotus + urea) → cocopeat growing medium/soil conditioner.

CHAPTER

7

ELECTRONIC DEVICES

Rectifiers · Amplifiers · Oscillators · Multivibrators

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 4 (Instrumentation & Computer Applications). Chapter 7: electronic devices and their characteristics — rectifiers, amplifiers, oscillators and multivibrators. The PN-junction diode, transistor amplifiers, operational amplifiers and a brief sensor introduction are developed in full so that every past and likely future question is answerable.

Chapter Outline

1. **Semiconductors & the PN-Junction Diode**
2. **Rectifiers & Filters**
3. **Transistor Amplifiers**
4. **Operational Amplifiers**
5. **Oscillators**
6. **Multivibrators**
7. **Sensors & Transducers (brief)**
8. **Formula Sheet · Summary · Last-Night Revision**

1 SEMICONDUCTORS & THE PN-JUNCTION DIODE

1.1 Energy bands and semiconductors

In a solid, the discrete electron energy levels of individual atoms broaden into ***energy bands***. The highest filled band is the ***valence band*** and the next (conduction) band holds free electrons; the gap between them is the ***forbidden energy gap (E_g)***. This gap decides the material class: a ***conductor*** has overlapping bands (no gap), an ***insulator*** a large gap (~6–7 eV), and a ***semiconductor*** a small gap.

> ***Semiconductor*** — *a material whose conductivity lies between a conductor and an insulator, with a small forbidden gap — Si ≈ 1.1 eV, Ge ≈ 0.7 eV. At 0 K it behaves as an insulator; with rising temperature, light or doping, valence electrons cross the gap, creating free electrons and holes, so conductivity rises (negative temperature coefficient of resistance).*

Silicon and germanium are tetravalent and form covalent bonds. When a covalent bond breaks (by thermal energy), it releases a free electron and leaves a vacancy — a ***hole***, which behaves as a positive charge carrier. Conduction is thus by both electrons and holes.

It is worth understanding hole conduction clearly. A hole is not a real particle but the ***absence of an electron*** in a covalent bond. When a nearby valence electron jumps to fill a hole, the hole effectively moves to the position the electron left. Under an applied field, electrons drift one way and holes appear to drift the opposite way, both contributing to current. In a pure semiconductor electrons and holes are always created in pairs (thermal generation) and continually disappear in pairs (recombination); at a given temperature a dynamic equilibrium fixes the intrinsic carrier concentration n_i. Because more bonds break as temperature rises, n_i and hence conductivity increase with temperature — the opposite of a metal, giving semiconductors a negative temperature coefficient of resistance. This same temperature sensitivity is exploited in the thermistor (a temperature sensor) and is the reason electronic devices need thermal stabilisation.

1.2 Intrinsic and extrinsic semiconductors

- ***Intrinsic (pure)*** : Equal numbers of free electrons and holes (n = p = n_i); low conductivity that rises with temperature.
- ***N-type (extrinsic)*** : Doped with a pentavalent impurity (P, As, Sb) — each donor atom contributes one free electron. Electrons are the majority carriers, holes the minority; the material is electrically neutral.
- ***P-type (extrinsic)*** : Doped with a trivalent impurity (B, Al, Ga) — each acceptor atom creates one hole. Holes are the majority carriers, electrons the minority.

Doping raises conductivity enormously and, unlike temperature, in a controlled way — the basis of all semiconductor devices. Current in a semiconductor flows by two mechanisms: ***drift*** (carriers moved by an electric field) and ***diffusion*** (carriers moving from high to low concentration).

A little more detail on doping makes the diode easy to understand. In N-type material each pentavalent donor atom sits in the lattice using four of its five valence electrons in covalent bonds; the fifth is loosely held and, at room temperature, is donated as a free electron — so electrons vastly outnumber holes (majority vs minority). In P-type material each trivalent acceptor atom completes only three bonds, leaving one bond incomplete — a hole ready to accept an electron — so holes are the majority carriers. Crucially, each doped crystal remains electrically neutral overall, because the extra free carriers are balanced by the fixed charges of the ionised donor/acceptor atoms. It is the meeting of these two differently-doped materials that produces the rectifying action of the junction.

1.3 Formation of the PN junction

PREVIOUS YEAR QUESTIONS

What is PN junction? Draw and explain its characteristics with diagram.

[OPSC· Forest 2023 | P2/5(a) | 20M]

PN junction – *formed when a P-type and an N-type semiconductor are grown in a single crystal. At the junction, majority electrons (N-side) and holes (P-side) diffuse across and recombine, uncovering immobile donor (+) and acceptor (−) ions. This ion layer — the depletion region — has no free carriers and sets up an internal barrier potential (Si ≈ 0.7 V, Ge ≈ 0.3 V) that opposes further diffusion, establishing equilibrium.*

The formation of the junction deserves a careful step-by-step picture. The instant the P and N materials are joined, there is a huge concentration difference of carriers across the boundary, so electrons diffuse from N to P and holes diffuse from P to N. As each majority carrier crosses and recombines, it leaves behind an uncovered fixed ion — positive donor ions on the N-side, negative acceptor ions on the P-side. These immobile ions form a thin layer, swept clear of free carriers, called the depletion (or space-charge) region. The exposed ions set up an internal electric field — and hence a potential difference, the barrier potential — pointing from N to P, which opposes further diffusion. Diffusion continues only until this barrier is strong enough to stop the net flow; the junction then sits in equilibrium with no external current. The barrier potential (about 0.7 V for silicon, 0.3 V for germanium) is exactly the voltage an external source must overcome to make the diode conduct.

The depletion region behaves like a charged capacitor (junction/transition capacitance), and its width and barrier height change with the applied bias — the key to diode action, described next.

▣ PN junction and depletion region

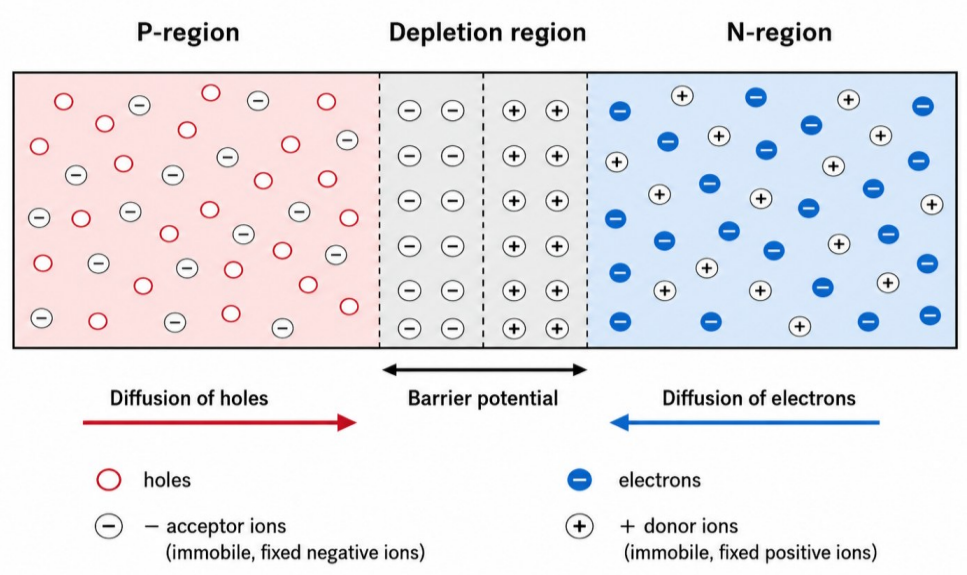


Fig. 7.1 PN junction with depletion region

1.4 Biasing the junction

- ***Forward bias (P → +, N → −)*** : The source opposes the barrier, narrowing the depletion region and lowering the barrier; beyond the knee/cut-in voltage (~0.7 V Si, 0.3 V Ge) majority carriers cross freely and a large forward current flows. Forward resistance is low.

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- ***Reverse bias (P → −, N → +)*** : The source aids the barrier, widening the depletion region; only a tiny reverse saturation (leakage) current (minority carriers) flows, nearly independent of voltage — until, at the breakdown voltage, current rises sharply. Reverse resistance is very high.

To see why the diode conducts one way only, follow the carriers. Under ***forward bias***, the external battery pushes holes in the P-region toward the junction and electrons in the N-region toward the junction; this neutralises some of the uncovered ions, so the depletion region narrows and the barrier falls. Once the applied voltage exceeds the barrier (the knee voltage), majority carriers pour across and recombine continuously, and the battery keeps re-supplying them — a large, steadily rising forward current flows, limited mainly by the external resistance. Under ***reverse bias***, the battery pulls majority carriers away from the junction, so the depletion region widens and the barrier rises; majority carriers cannot cross. Only the few thermally-generated minority carriers are swept across, giving a very small reverse saturation current that is almost independent of voltage (it depends on temperature, roughly doubling every 10 °C). If the reverse voltage is raised enough, the strong field either rips electrons directly out of bonds (Zener breakdown, thin heavily-doped junctions, below ~6 V) or accelerates carriers hard enough to knock out others in a chain (avalanche breakdown, above ~6 V), and the reverse current suddenly becomes large. Ordinary diodes must not be operated in breakdown, but the Zener diode is designed to work there safely (§1.6).

▣ *Diode symbol and biasing*

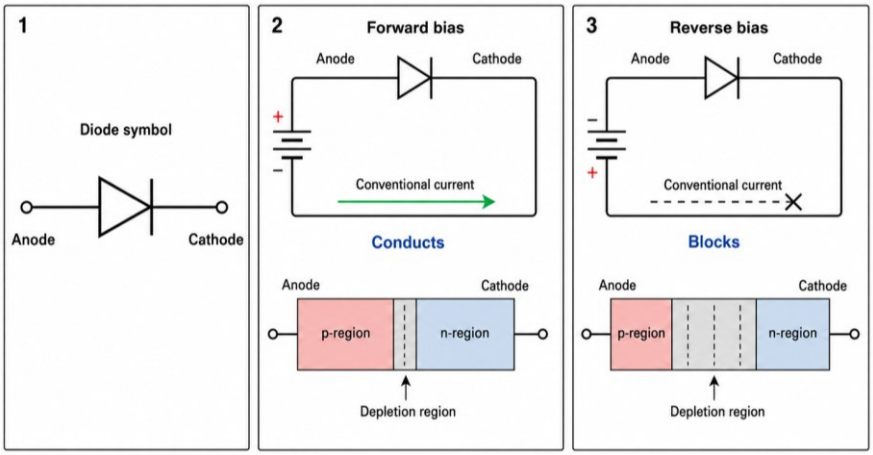


Fig. 7.1b Diode symbol; forward and reverse bias

1.5 V–I characteristics and the diode equation

▣ *Diode V–I characteristic*

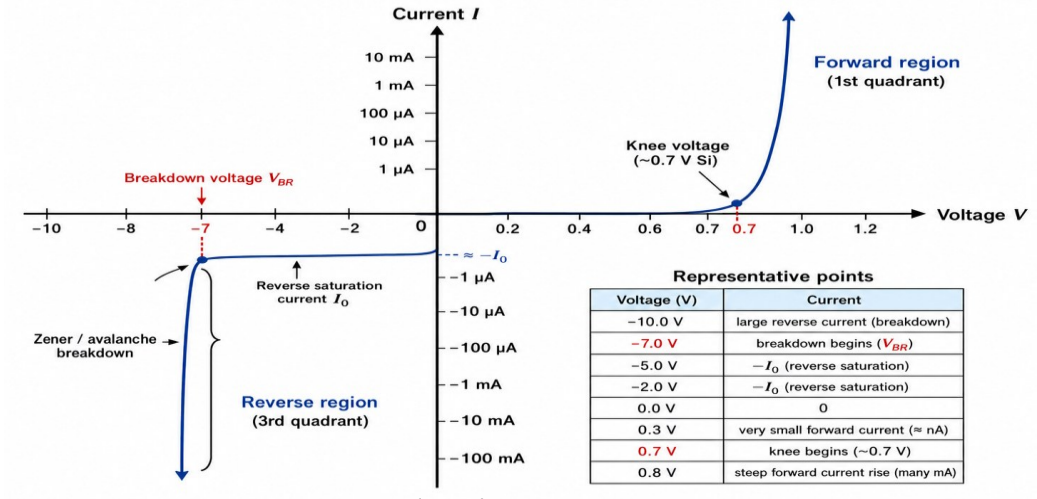


Fig. 7.2 Diode V–I characteristic

Diode (Shockley) equation: $I = I_0\,(e^{\{V/\eta V_T\}} - 1)$

I_o = reverse saturation current; $V_T = kT/q \approx 26$ mV at 300 K; η = 1 (Ge) to 2 (Si) ideality factor.

The V–I characteristic is the single most important graph for the diode, so read it carefully. In the ***forward region***, almost no current flows until the applied voltage reaches the cut-in (knee) voltage — about 0.7 V for silicon, 0.3 V for germanium — because until then the barrier is not fully overcome. Beyond the knee the current rises very steeply and almost exponentially (following the diode equation), so a small further increase in voltage gives a large increase in current; the diode then behaves almost like a closed switch with a small fixed drop. In the ***reverse region***, the current is only the tiny reverse saturation current I_o and stays practically constant as the reverse voltage increases — the diode behaves like an open switch — until the breakdown voltage is reached, where the curve turns sharply downward and a large reverse current flows.

Breakdown is of two kinds. ***Zener breakdown*** occurs in heavily-doped, thin junctions at low reverse voltages (below ~6 V): the very intense field pulls electrons straight out of their covalent bonds (field emission). ***Avalanche breakdown*** occurs in lightly-doped junctions at higher voltages (above ~6 V): minority carriers are accelerated so hard that they collide with atoms and knock out more carriers, which in turn free still more — a cumulative avalanche. Both give a nearly constant voltage during breakdown, which is the property used for voltage regulation.

Diode resistances & ratings — *static (DC) resistance $R = V/I$; dynamic (AC) resistance $r_d = \Delta V/\Delta I = \eta V_T/I$; key ratings are the cut-in voltage, maximum forward current, Peak Inverse Voltage (PIV) and junction capacitance.*

1.6 The Zener diode and voltage regulation

Zener diode — *a heavily-doped diode designed to operate in reverse breakdown, where it holds a nearly constant voltage (the Zener voltage V_Z) over a wide range of current. Placed in reverse across the load with a series resistor R_s, it acts as a shunt voltage regulator — the series resistor absorbs the excess voltage and the Zener draws whatever current keeps $V_out = V_Z$ steady against supply and load changes.*

The regulating action is worth following. The unregulated input (say from a rectifier-filter) is always higher than the desired output; the series resistor R_s drops the excess, and the Zener — in reverse breakdown across the load — pins the output at V_Z. Now suppose the input voltage rises: the current through R_s tends to increase, but almost all of the extra current is taken by the Zener (whose voltage barely changes on its steep breakdown curve), so the extra is dropped across R_s and the output stays at V_Z. Conversely, if the load draws more current, the Zener simply gives up some of its own current to the load, again holding the output steady. In effect the Zener acts as a 'shunt' that automatically absorbs or releases current to keep the voltage across it — and hence across the load — constant against both supply (line) and load changes. R_s must be chosen so that the Zener always keeps at least its minimum operating current under the worst-case (highest-load, lowest-input) condition, yet never exceeds its power rating under the lightest load.

Series resistor: $R_s = (V_in - V_Z)/(I_Z + I_L)$; $I_L = V_Z/R_L$

◆ **WORKED NUMERICAL — *Zener regulator design*** **[demonstrates the regulator equation]**

Problem. *A 9 V Zener regulates a 1 kΩ load from a 15 V supply, with a chosen Zener current of 10 mA. Find the series resistor and the Zener power.*

Given:

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Supply voltage, Vs = 15 V
Zener voltage, Vz = 9 V
Load resistance, RL = 1 kΩ
Zener current, Iz = 10 mA

Step 1: Calculate Load Current

$$IL = Vz / RL$$

$$IL = 9 / 1000$$

$$IL = 0.009\ A = 9\ mA$$

Step 2: Calculate Current through Series Resistor

The current through the series resistor is the sum of load current and Zener current.

$$IR = IL + Iz$$

$$IR = 9\ mA + 10\ mA$$

$$IR = 19\ mA = 0.019\ A$$

Step 3: Calculate Series Resistor

Voltage across the series resistor:

$$VR = Vs - Vz$$

$$VR = 15 - 9$$

$$VR = 6\ V$$

Therefore,

$$Rs = VR / IR$$

$$Rs = 6 / 0.019$$

$$Rs = 315.8\ \Omega \approx 316\ \Omega$$

Series resistor, Rs ≈ 316 Ω

A standard practical value of about **330 Ω** may be used.

Step 4: Calculate Zener Power

$$Pz = Vz \times Iz$$

$$Pz = 9 \times 0.010$$

$$Pz = 0.09\ W$$

$$Pz = 90\ mW$$

Final Answer:

Series Resistor = 316 Ω (approximately 330 Ω standard value)

Zener Power = 90 mW

1.7 *Diode types and applications*

Beyond the rectifier diode: ***Zener*** (voltage regulation), **LED** (light emission), ***photodiode*** (light detection), ***varactor*** (voltage-variable capacitance, tuning), and **Schottky** (fast, low forward drop). Circuit applications include rectification (Section 2), clipping, clamping and voltage multiplication.

- ***Clipper (limiter)*** : Uses a diode to remove (clip) the part of a waveform above or below a set level — for waveshaping and over-voltage protection.
- ***Clamper (DC restorer)*** : Uses a diode and capacitor to shift a waveform's DC level up or down without changing its shape.
- ***Optoelectronic diodes*** : The LED converts current to light (indicators, displays, optocouplers); the photodiode/solar cell converts light to current (light sensing, energy) — the sensor link to instrumentation.

2 RECTIFIERS & FILTERS

2.1 *Rectification and the DC power supply*

PREVIOUS YEAR QUESTIONS

- Explain the working principle of rectifier, amplifier and oscillators. [OPSC· CSE 2015-16 | P2/5(d) | 20M]

Rectifier — *a circuit that converts alternating current (AC) into pulsating direct current (DC) using the one-way conduction of the PN-junction diode. It is the heart of a DC power supply: transformer (steps the AC up/down) → rectifier (AC → pulsating DC) → filter (smooths the ripple) → regulator (holds the output constant).*

▣ *Regulated DC power supply — block diagram*

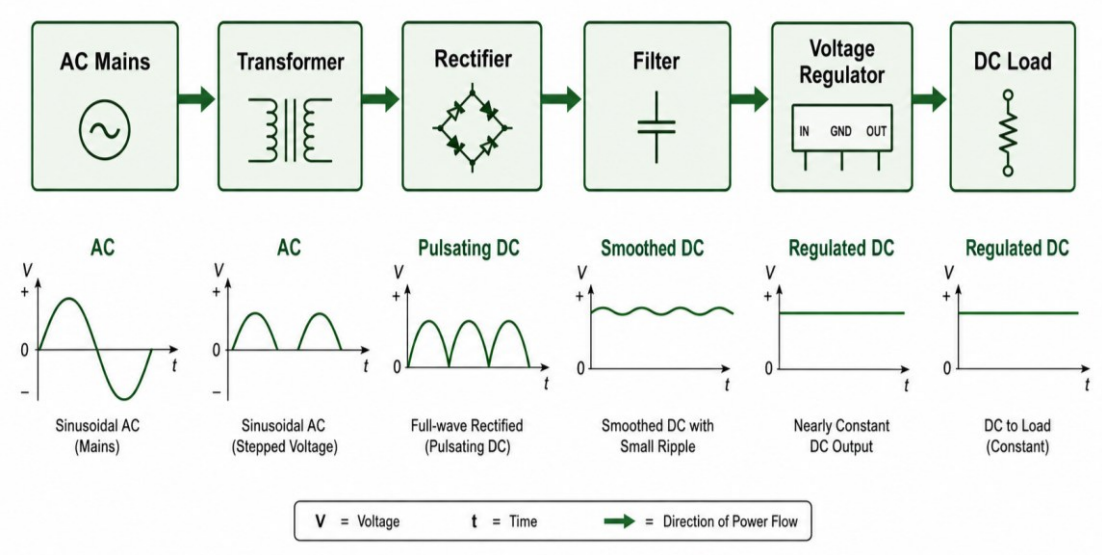


Fig. 7.2b Regulated DC power-supply block diagram

2.2 *Half-wave rectifier*

PREVIOUS YEAR QUESTIONS

- Draw the circuit diagram of a half-wave rectifier and describe its functioning and characteristics. [UK·PSC RFO 2021 | Q.8(i) | 10M; UK·PSC ACF 2019 | Q.8(i) | 10M]

Circuit: transformer secondary → a single diode → load R_L. In the positive half-cycle the diode is forward-biased and conducts, so current flows through the load; in the negative half-cycle it is reverse-biased and blocks. The load thus sees only the positive half-cycles — a pulsating DC.

Let us follow the action in detail. The transformer first steps the mains AC down to the required peak V_m and provides isolation. During the positive half-cycle the diode's anode is positive with respect to its cathode, so the diode is forward-biased, conducts, and (for an ideal diode) passes the whole positive half-cycle to the load — the load voltage follows the input sine. During the negative half-cycle the diode is reverse-biased and blocks; no current flows and the load voltage is zero, while the full peak input appears across the diode (this is the peak inverse voltage the diode must withstand, PIV = V_m). The result is a series of positive humps with gaps between them — a unidirectional but very lumpy 'pulsating DC'. Although it flows in only one direction, it is far from steady; its usefulness is measured by its average (DC) value, V_dc = V_m/π ≈ 0.318 V_m, which is what a DC meter would read. Because output appears for only one half of each cycle, the ripple is very large and the efficiency low — hence the derivations below.

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Derivation of the characteristics

Let the load current be i = I_m sin ωt for 0 ≤ ωt ≤ π and 0 for π ≤ ωt ≤ 2π. Then:

$$I_{dc} = (1/2\pi)\int_0^{\pi} I_m \sin \omega t \, d(\omega t) = I_m/\pi = 0.318\, I_m \quad (V_{dc} = V_m/\pi)$$

$$I_{rms} = \sqrt{[(1/2\pi)\int_0^{\pi} I_m^2 \sin^2 \omega t \, d(\omega t)]} = I_m/2$$

$$\text{Ripple factor } \gamma = \sqrt{[(I_{rms}/I_{dc})^2 - 1]} = \sqrt{[(\pi/2)^2 - 1]} = 1.21$$

$$\text{Efficiency } \eta = P_{dc}/P_{ac} = (I_{dc})^2/(I_{rms})^2 = (I_m/\pi)^2/(I_m/2)^2 = 4/\pi^2 = 40.6\ \%$$

$$\text{PIV} = V_m\ ;\ \text{ripple frequency} = f\ (50\ \text{Hz})\ ;\ \text{TUF} = 0.287$$

Drawbacks: low efficiency (40.6 %), very high ripple (1.21), only half the input used, low TUF, and DC saturation of the transformer core — so half-wave rectifiers are used only for small, non-critical loads.

▣ *Half-wave rectifier — circuit & waveform*

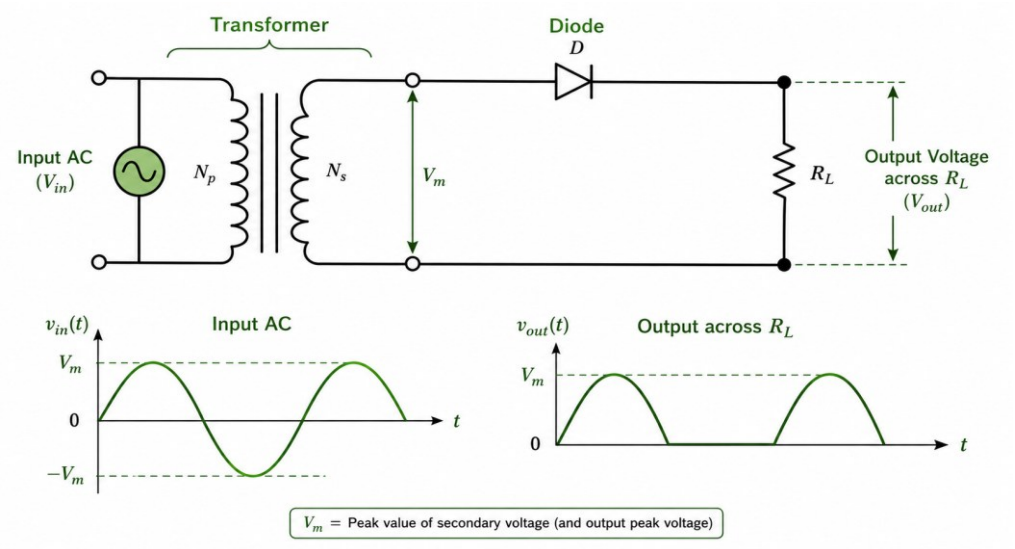


Fig. Half-wave rectifier

◆ **WORKED NUMERICAL — *Half-wave rectifier output*** **[demonstrates the formulas]**

Problem. *A half-wave rectifier feeds R_L = 1 kΩ from a secondary of peak voltage V_m = 100 V (ideal diode). Find I_m, I_dc, V_dc, I_rms and PIV.*

Given:

Load resistance, $R_l = 1\ k\Omega = 1000\ \Omega$
Peak secondary voltage, $V_m = 100\ V$
Diode is ideal.

1. **Peak Current (I_m)**

For an ideal half-wave rectifier,

$$I_m = V_m / R_l$$
$$I_m = 100 / 1000$$
$$I_m = 0.1\ A = 100\ mA$$

Therefore,

$$I_m = 100\ mA$$

2. **DC Current (I_dc)**

For a half-wave rectifier,

$$I_{dc} = I_m / \pi$$

$$I_dc = 100 / 3.1416$$
$$I_dc = 31.83 \text{ mA}$$
Therefore,
$$I_dc \approx 31.8 \text{ mA}$$

3. DC Output Voltage (V_dc)

For a half-wave rectifier,
$$V_dc = V_m / \pi$$
$$V_dc = 100 / 3.1416$$
$$V_dc = 31.83 \text{ V}$$
Therefore,
$$V_dc \approx 31.8 \text{ V}$$

4. RMS Current (I_rms)

For a half-wave rectifier,
$$I_rms = I_m / 2$$
$$I_rms = 100 / 2$$
$$I_rms = 50 \text{ mA}$$
Therefore,
$$I_rms = 50 \text{ mA}$$

5. Peak Inverse Voltage (PIV)

For a half-wave rectifier,
$$PIV = V_m$$
$$PIV = 100 \text{ V}$$
Therefore,
$$PIV = 100 \text{ V}$$

FINAL ANSWER

$$I_m = 100 \text{ mA}$$
$$I_dc = 31.8 \text{ mA}$$
$$V_dc = 31.8 \text{ V}$$
$$I_rms = 50 \text{ mA}$$
$$PIV = 100 \text{ V}$$

2.3 *Full-wave rectifier — centre-tap type*

PREVIOUS YEAR QUESTIONS

Diagrammatically explain the working of full-wave centre-tap rectifier.

[OPSC · Forest 2023-24 | P2/7(b) | 20M]

Circuit: a centre-tapped transformer feeds two diodes into a common load, with the load returned to the centre tap. In the positive half-cycle the upper half of the secondary makes D1 conduct; in the negative half-cycle the lower half makes D2 conduct — and both drive current through the load in the same direction, so both half-cycles appear in the output (full-wave). Each diode conducts on alternate half-cycles.

The centre tap is the key idea: it divides the secondary into two equal halves whose voltages are always in anti-phase (when the top end is positive with respect to the centre, the bottom end is negative, and vice-versa). During the positive half-cycle the top of the secondary is positive, so D1 is forward-biased and conducts while

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D2 is reverse-biased and off; current flows from the top half, through D1, through the load, and back to the centre tap. Half a cycle later the polarities reverse: the bottom of the secondary is now positive, so D2 conducts and D1 is off; current flows from the bottom half, through D2, and through the load — but note it passes through the load in the same direction as before. Thus the load receives a current pulse on every half-cycle, and the output is a series of positive humps with no gaps. Because output now appears for both halves of every cycle, the average value doubles to V_dc = 2V_m/π ≈ 0.637 V_m and the ripple is much smaller than in the half-wave case. The penalty is that when one diode conducts, the other sees the sum of both half-secondary peaks across it, so its PIV = 2V_m.

$$I_{dc} = 2I_m/\pi = 0.637\, I_m \quad (V_{dc} = 2V_m/\pi)\ ;\ I_{rms} = I_m/\sqrt{2}$$

$$\text{Ripple factor } \gamma = \sqrt{[(I_{rms}/I_{dc})^2 - 1]} = 0.48\ ;\ \text{Efficiency } \eta = 8/\pi^2 = 81.2\ \%$$

$$PIV = 2V_m\ ;\ \text{ripple frequency} = 2f\ (100\ Hz)\ ;\ TUF = 0.672$$

Merits: twice the DC output, far lower ripple (0.48) and double the efficiency (81.2 %) of half-wave; the ripple is at 2f, so easier to filter. Limits: needs a centre-tapped transformer, and each diode must withstand PIV = 2V_m (the sum of both half-secondary peaks).

▣ *Full-wave centre-tap rectifier*

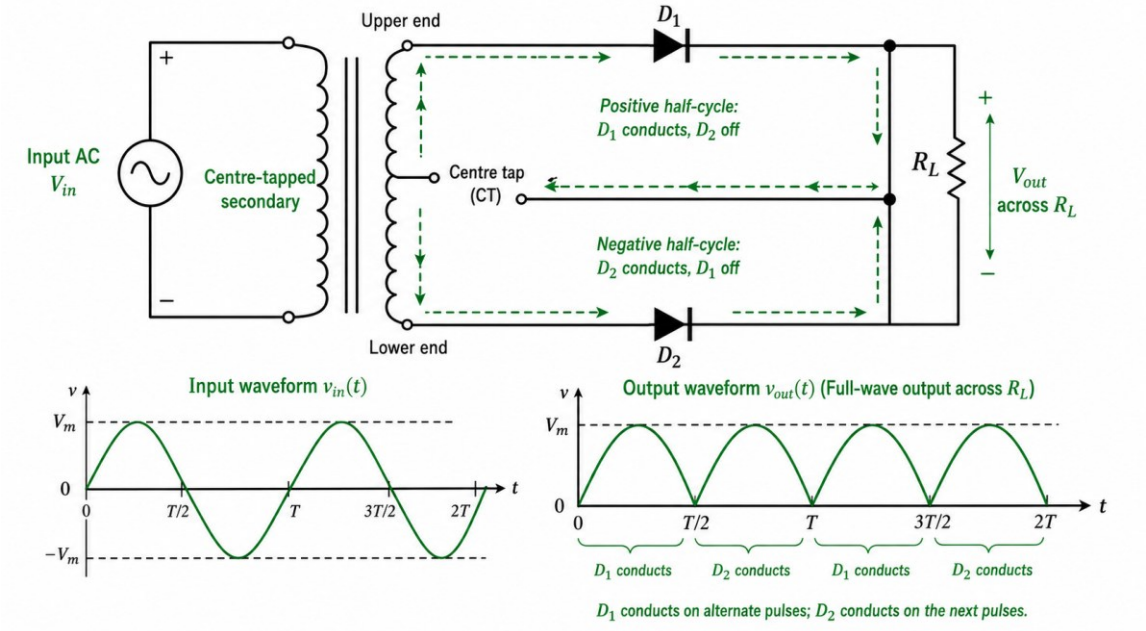


Fig. 7.4 Full-wave centre-tap

2.4 *Full-wave bridge rectifier*

PREVIOUS YEAR QUESTIONS

- Explain the design of a full-wave bridge rectifier. What is meant by ripple effect? Explain the role of a smoothing capacitor in a rectifier circui.[OPSC · CSE 2024-25 | P2/18 | 20M]
- Describe the principle of operation of a single-phase full-wave bridge rectifier.
  [OPSC · CSE 2022-23 | P2/12 | 10M]

Circuit: four diodes arranged as a bridge across the transformer secondary and the load — no centre tap needed. In the positive half-cycle the diagonal pair D1 & D2 are forward-biased and conduct; in the negative

half-cycle D3 & D4 conduct. In both half-cycles the current through the load is in the same direction, giving full-wave rectified DC.

Trace the current path to see the elegance of the bridge. In the positive half-cycle, one end of the secondary is positive: the current leaves that end, passes through diode D1, flows down through the load (top to bottom), returns through diode D2 to the other end of the secondary — while D3 and D4 are reverse-biased and off. In the negative half-cycle the secondary polarity reverses: now the current passes through D3, again flows down through the load in the same top-to-bottom direction, and returns through D4, while D1 and D2 are off. The vital point is that whichever pair conducts, the current is routed through the load in the same direction, so both half-cycles are rectified without needing a centre-tapped transformer. The output average is the same as the centre-tap type (2V_m/π), but because the full secondary voltage now appears across the load, the PIV borne by each diode is only V_m — half that of the centre-tap circuit — a major practical advantage, along with the simpler transformer and the best transformer utilization. The only cost is that two diodes conduct in series each half-cycle, so there are two diode voltage drops (about 1.4 V in silicon) instead of one — negligible except at very low output voltages.

MODEL Q Design essentials: a step-down transformer giving the required peak secondary voltage V_m; four diodes each rated for PIV ≥ V_m and average current ≥ I_dc/2 (with margin); the load R_L; and a smoothing (filter) capacitor across the load to reduce the ripple. Ratings are chosen with a safety margin on PIV and forward current, and a heat sink if the current is large.***

$V_{dc} = 2V_m/\pi = 0.637\ V_m$; $\gamma = 0.48$; $\eta = 81.2\ \%$; PIV $= V_m$; ripple freq $= 2f$; TUF $= 0.812$

Advantages over the centre-tap type: no centre-tapped transformer (a simpler, cheaper transformer); PIV is only V_m (half that of the centre-tap); and the best transformer utilization (TUF 0.812). Limitation: four diodes, and two diodes conduct in series each half-cycle (two diode drops) — a small extra loss. The bridge is the most widely used rectifier.

▣ *Full-wave bridge rectifier*

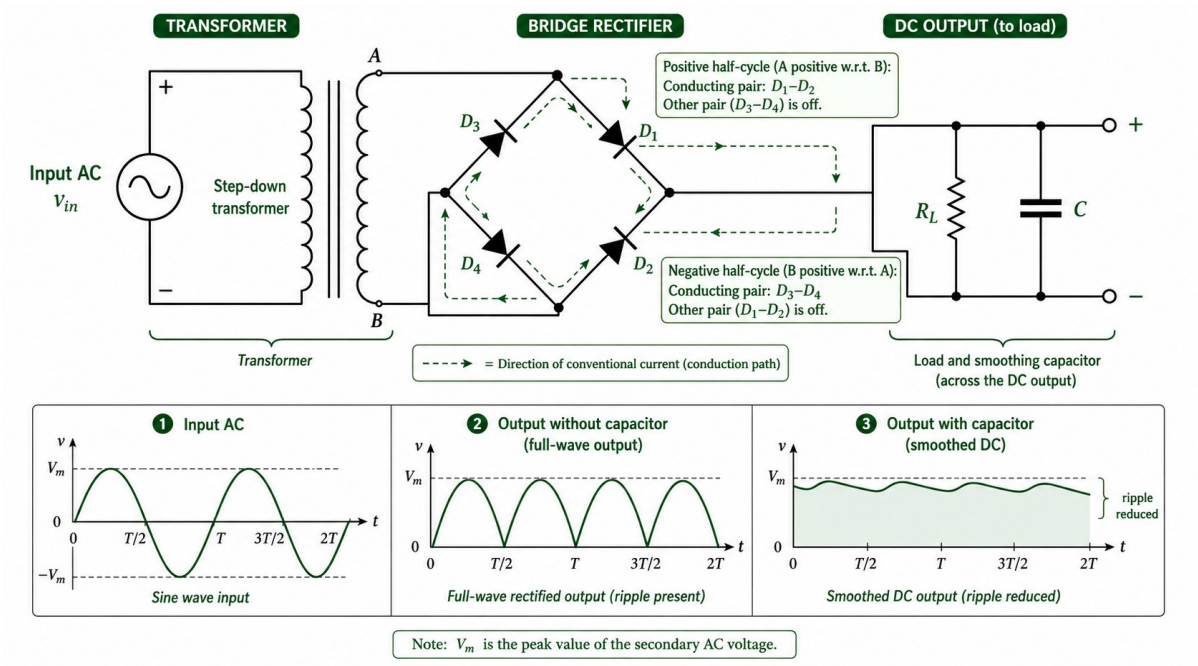


Fig. 7.5 Full-wave bridge rectifier

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◆ **WORKED NUMERICAL — *Bridge rectifier output & ripple*** [demonstrates the formulas]

Problem. *A bridge rectifier has V_m = 20 V and R_L = 100 Ω. Find V_dc, I_dc, ripple, efficiency and PIV; and the ripple with a 470 µF smoothing capacitor (mains f = 50 Hz).*

Given:

Peak secondary voltage, Vm = 20 V
Load resistance, RL = 100 Ω
Mains frequency, f = 50 Hz
Smoothing capacitor, C = 470 µF
Assume **ideal diodes**.

1. DC Output Voltage

For a full-wave bridge rectifier:

$$V_{dc} = 2V_m / \pi$$

$$V_{dc} = (2 \times 20) / 3.1416$$

$V_{dc} = 12.73$ V

2. DC Load Current

$$I_{dc} = V_{dc} / R_L$$

$$I_{dc} = 12.73 / 100$$

$$I_{dc} = 0.1273 \text{ A}$$

$I_{dc} = 127.3$ mA

3. Ripple Factor without Capacitor

For a full-wave rectifier:

Ripple factor, r = 0.482 ≈ 0.483

Therefore,

Ripple factor = 0.483 = 48.3%

4. Rectification Efficiency

Maximum rectification efficiency of a full-wave rectifier:

$$\eta = 8 / \pi^2$$

$$\eta = 0.811$$

$\eta \approx 81.1\%$

(Usually quoted as approximately **81.2%**.)

5. Peak Inverse Voltage (PIV)

For a bridge rectifier:

PIV per diode = Vm

Therefore,

PIV = 20 V per diode

6. Ripple with 470 µF Smoothing Capacitor

For a full-wave rectifier with capacitor filter:

$$r = 1 / (4\sqrt{3}\, f R_L C)$$

Substituting:

$$r = 1 / [4 \times 1.732 \times 50 \times 100 \times 470 \times 10^{-6}]$$

$$r \approx 0.0614$$

Therefore,

Ripple factor with capacitor ≈ 0.0614 = 6.14%

The ripple frequency is:

$$fr = 2f = 2 \times 50$$

fr = 100 Hz

For a more practical estimate, the capacitor-filtered DC voltage is approximately:

$$V_{dc} \approx 18.1\ V$$

Hence,

$$V_{r(pp)} \approx I_{dc} / (2fC)$$

$$V_{r(pp)} \approx 3.85\ V$$

So the approximate **peak-to-peak ripple voltage is 3.85 V**.

Final Answer

Quantity	Value
DC output voltage, Vdc	**12.73 V**
DC load current, Idc	**127.3 mA**
Ripple factor without capacitor	**0.483 or 48.3%**
Rectification efficiency	**≈ 81.2%**
PIV per diode	**20 V**
Ripple factor with 470 μF capacitor	**0.0614 or 6.14%**
Ripple frequency	**100 Hz**
Approx. peak-to-peak ripple voltage	**3.85 V**

2.5 *Ripple factor, efficiency and TUF*

PREVIOUS YEAR QUESTIONS

- What is the significance of ripple factor in the design of bridge rectifier?

[OPSC · CSE 2022-23 | P2/12(b) | 5M]

Ripple factor (γ) *— the ratio of the RMS value of the AC (ripple) component to the DC component of the output: $\gamma = (I_{ac,rms})/(I_{dc}) = \sqrt{[(I_{rms}/I_{dc})^2 - 1]}$. It measures how much unwanted AC remains superimposed on the DC — the lower the ripple factor, the purer (smoother) the DC.*

The idea behind the ripple factor is simple but important. A rectifier output can be thought of as two parts added together: a steady DC level (the useful average value) and a fluctuating AC component (the unwanted ripple) riding on top of it. The ripple factor is just the size of that AC ripple relative to the DC level. If the output were perfectly smooth DC, the AC part would be zero and γ = 0; the larger the wobble, the larger γ. This is why a half-wave rectifier (γ = 1.21) is so poor — the ripple is actually bigger than the DC value — while a full-wave/bridge rectifier (γ = 0.48) is much better because its output never drops to zero and pulses twice as often. Significance: ripple factor quantifies rectifier quality and the filtering effort required. Sensitive electronic loads (radios, amplifiers, digital circuits) need a very low ripple — often below 1 % — because ripple appears as an audible hum or as errors in a circuit. So a low ripple factor is a central design target, achieved first by choosing a full-wave/bridge circuit (lower γ and a higher ripple frequency, 2f, which is easier to filter) and then by adding a filter. The ripple factor also directly decides how large the smoothing capacitor must be for a given load.

Efficiency & TUF *— rectifier efficiency $\eta = P_{dc}/P_{ac}$ (DC power delivered ÷ AC input power); 40.6 % (half-wave) and 81.2 % (full-wave/bridge). Transformer Utilization Factor (TUF) = P_{dc}/(transformer*

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VA rating) — how well the transformer is used: 0.287 (HW), 0.672 (centre-tap), 0.812 (bridge, best).

Voltage regulation — the change in DC output from no-load to full-load, expressed as % regulation = (V_NL − V_FL)/V_FL × 100 — smaller is better (a stiffer supply). A rectifier-filter alone regulates poorly, so a voltage regulator (Zener or IC) is added. A voltage-multiplier (e.g. a diode-capacitor doubler/tripler) is a special rectifier that gives a DC output several times V_m for high-voltage, low-current needs.

◆ **WORKED NUMERICAL — Percent voltage regulation** [demonstrates the regulation formula]

Problem. A power supply gives 13 V at no load and 12 V at full load. Find its percent regulation.

Given:

No-load voltage, VNL = 13 V

Full-load voltage, VFL = 12 V

Percent regulation is:

$$\% \text{ Regulation} = [(VNL - VFL) / VFL] \times 100$$

$$\% \text{ Regulation} = [(13 - 12) / 12] \times 100$$

$$\% \text{ Regulation} = (1 / 12) \times 100$$

$$\% \text{ Regulation} = 8.33\%$$

Final Answer: Percent Regulation = 8.33%

2.6 *Filters — smoothing the output*

PREVIOUS YEAR QUESTIONS

Explain the role of a smoothing capacitor in a rectifier circuit. [OPSC · CSE 2024-25 | P2/18 | 20M]

A rectifier output is pulsating DC (a DC level plus ripple). A filter removes the ripple to give near-constant DC by storing energy at the peaks and releasing it in the troughs (capacitor), or by opposing current change (inductor).

The smoothing capacitor is the most common and important filter, so understand its action fully. A capacitor stores charge and resists any sudden change in voltage across it. Connected directly across the load, it charges up almost to the peak voltage each time the rectifier output rises to a crest. When the rectifier output then falls (toward the trough between pulses), the capacitor — now charged higher than the falling rectifier voltage — takes over and supplies the load itself, discharging slowly through it. It behaves like a small reservoir that fills at each peak and empties gently between peaks, so the load voltage never sags all the way down; the deep troughs are 'filled in' and the output becomes a much flatter DC with only a small saw-tooth ripple. The larger the capacitance, the more charge it stores and the more slowly it discharges (the time constant CR_L is larger), so the ripple is smaller; likewise a higher ripple frequency (full-wave, 2f) and a larger load resistance both reduce ripple — exactly as the formula γ ≈ 1/(2√3·f·C·R_L) shows. The trade-off is that the diodes now conduct only in short, sharp bursts to refill the capacitor at each peak, so they must handle a high repetitive peak current.

Smoothing (shunt) capacitor — a capacitor connected across the load. During each voltage peak it charges up to the peak; between peaks, when the rectifier output falls, it discharges slowly through the load, filling in the dips. This reservoir action flattens the output and sharply reduces the ripple. Ripple falls as C, the ripple frequency f and R_L increase.

Capacitor filter (full-wave): $\gamma \approx 1/(2\sqrt{3}\cdot f\cdot C\cdot R_L)$ (f = ripple frequency)

Filter	Action	Output / use
Capacitor (shunt)	charges at peak, discharges between peaks	simple, good for light loads; ripple rises with load
Inductor / choke (series)	opposes current change, blocks AC	good for heavy loads
LC (L-section)	choke then capacitor	low, load-independent ripple
π-filter (C–L–C)	capacitor input + LC section	smoothest output; high peak-diode current

A complete supply chains transformer → bridge rectifier → filter → regulator (a Zener or IC regulator, §1.6) to give a steady, ripple-free, load-independent DC.

2.7 Comparison of rectifiers

Parameter	Half-wave	FW centre-tap	FW bridge
Diodes	1	2	4
V_dc	0.318 V_m	0.637 V_m	0.637 V_m
Ripple factor	1.21	0.48	0.48
Max efficiency	40.6 %	81.2 %	81.2 %
PIV	V_m	2V_m	V_m
Ripple frequency	f	2f	2f
TUF	0.287	0.672	0.812
Transformer	simple	centre-tapped	simple

3 AMPLIFICATION AND AMPLIFYING ELEMENTS

3.1 Amplification and amplifying elements

PREVIOUS YEAR QUESTIONS

- Define electrical amplifying elements and discuss their voltage amplification, current amplification and gain. [IFOS 2025 | P2/5(d) | 8M]
- Discuss in detail about (i) amplifiers. [IFOS 2022 | P2/5(e)(i) | 8M]

Amplifier — *a circuit that increases the amplitude (voltage, current or power) of a signal without changing its waveform, by drawing energy from a DC supply under the control of the small input signal.*

Electrical amplifying elements — *active devices that provide gain: the vacuum triode/tube (historical), the bipolar junction transistor (BJT), the field-effect transistor (FET/MOSFET) and the operational amplifier (Section 4). The transistor is the basic amplifying element — a small input controls a much larger output.*

3.2 The bipolar junction transistor (BJT)

BJT is a three-layer, two-junction device — NPN or PNP — with three regions: the **emitter** (heavily doped, supplies carriers), the **base** (very thin, lightly doped) and the **collector** (moderately doped, large, collects

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carriers). For amplification the emitter–base junction is forward-biased and the collector–base junction reverse-biased (active region). A small base current then controls a large collector current.

The mechanism of transistor action is worth spelling out, because it is the heart of amplification. Take an NPN transistor in the active region. The forward-biased emitter–base junction lets the heavily-doped emitter inject a large stream of electrons into the base. The base is made ***very thin and lightly doped*** on purpose, so very few of these electrons find a hole to recombine with there; the vast majority (typically 98–99 %) diffuse straight across the base and are swept into the collector by the strong field of the reverse-biased collector–base junction. Thus almost the entire emitter current appears as collector current, and only a tiny fraction leaves as base current — which is exactly why a ***small base current controls a much larger collector current***. A small change in the input (base) current produces a β-times-larger change in the output (collector) current; passing that current through a load resistor develops a large, faithful, amplified copy of the input voltage. The transistor does not create energy — it uses the small input to control the release of energy from the DC supply.

$$\beta\ (=h_{FE}) = I_C/I_B\ ;\ \alpha = I_C/I_E\ ;\ I_E = I_B + I_C\ ;\ \beta = \alpha/(1-\alpha)$$

β ≈ 50–300 (current gain); α ≈ 0.95–0.99.

▣ *BJT structure and symbols*

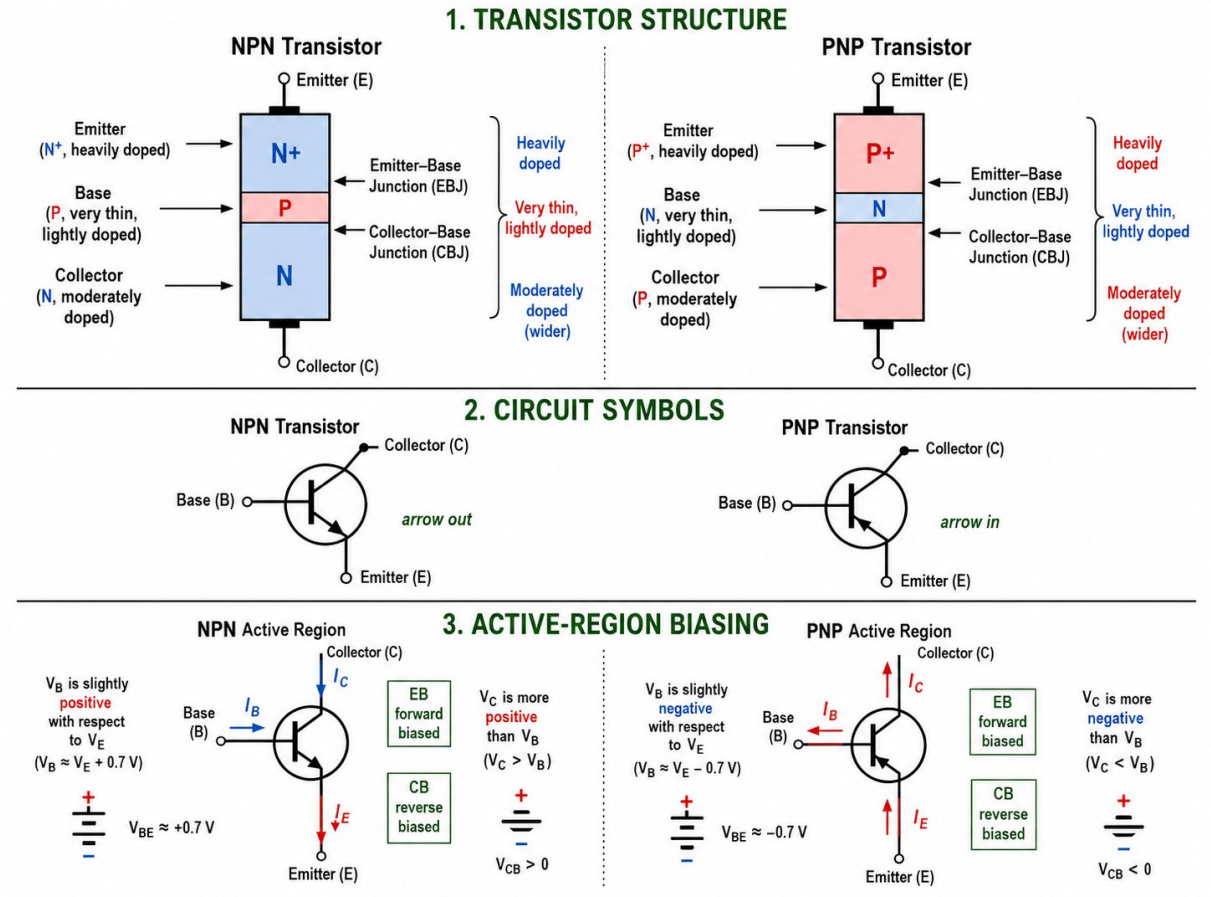


Fig. 7.5b BJT structure, symbols and biasing

◆ **WORKED NUMERICAL — *Transistor currents*** **[demonstrates β, α relations]**

Problem. *An NPN transistor has β = 100 and base current I_B = 40 μA. Find I_C, I_E and α.*

Given:

Current gain, $\beta = 100$
Base current, $I_B = 40\ \mu A$

1. **Collector Current (I_C)**

We know,

$$I_C = \beta \times I_B$$
$$I_C = 100 \times 40\ \mu A$$
$$I_C = 4000\ \mu A$$
$$I_C = 4\ mA$$

Therefore,

$$I_C = 4\ mA$$

2. **Emitter Current (I_E)**

We know,

$$I_E = I_C + I_B$$
$$I_E = 4\ mA + 0.04\ mA$$
$$I_E = 4.04\ mA$$

Therefore,

$$I_E = 4.04\ mA$$

3. **Current Gain α**

The relation between α and β is:

$$\alpha = \beta / (\beta + 1)$$
$$\alpha = 100 / 101$$
$$\alpha \approx 0.990$$

Therefore,

$$\alpha \approx 0.99$$

FINAL ANSWER

$$I_C = 4\ mA$$
$$I_E = 4.04\ mA$$
$$\alpha \approx 0.99$$

3.3 *Field-effect transistors (FET/MOSFET)*

FET — *a field-effect transistor is a voltage-controlled, unipolar amplifying element in which the gate voltage controls the drain current through a channel — unlike the current-controlled, bipolar BJT. Types: JFET (junction FET) and MOSFET (metal-oxide-semiconductor FET, enhancement or depletion). Terminals: gate (G), drain (D), source (S).*

FETs offer very high input impedance (the gate draws almost no current), low noise, small size and easy fabrication — the MOSFET is the workhorse of modern ICs and digital logic. Its gain figure is the ***transconductance*** $g_m = \Delta I_D / \Delta V_{GS}$; voltage gain of a common-source stage ≈ $g_m \cdot R_D$. FET amplifier configurations (common-source, common-gate, common-drain/source-follower) parallel the BJT's CE/CB/CC.

Feature	*BJT*	*FET*
Control	current (I_B)	voltage (V_{GS})
Carriers	bipolar (electrons + holes)	unipolar (one type)
Input impedance	low–medium	very high
Noise / thermal stability	higher noise	low noise, more stable

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Gain parameter	β = I_C/I_B	g_m = ΔI_D/ΔV_GS

3.4 Transistor configurations

Configuration	V-gain	I-gain	Input Z	Output Z	Phase	Use
Common-emitter (CE)	high	high (β)	medium	high	180°	general amplification
Common-base (CB)	high	<1 (α)	low	high	0°	high-frequency
Common-collector (CC)	<1	high	high	low	0°	impedance matching / buffer

3.5 DC load line, Q-point and biasing

For faithful (distortion-free) amplification the transistor must stay in the active region over the whole input swing. The ***DC load line*** (drawn on the output characteristics from the equation V_CE = V_CC − I_C·R_C) fixes the possible operating points; the chosen quiescent point — the ***Q-point*** — should sit near the middle of the active region. Fixing it requires ***biasing***.

- ***Fixed (base) bias*** : A single base resistor; simple but Q-point drifts with β and temperature.
- ***Voltage-divider (self) bias*** : A base potential divider plus an emitter resistor; the emitter resistor provides negative feedback that stabilises the Q-point against β and temperature — the standard, most stable biasing.

Why biasing matters is easy to appreciate. The AC signal to be amplified is small and swings both positive and negative, but a transistor can only respond to a forward base current in one direction — so if the transistor were simply off with no signal, the negative half of the input would be lost and the output badly distorted. Biasing solves this by setting a steady DC operating point (the Q-point) that keeps the transistor comfortably in the active region even with no signal; the AC input then merely rides up and down about this point, so the whole waveform is amplified faithfully. For distortion-free output the Q-point is placed near the centre of the load line, giving the signal maximum room to swing in both directions before the transistor is driven into saturation (fully on) or cut-off (fully off). A further practical problem is that β and leakage currents change with temperature, which would shift the Q-point and could cause thermal runaway; voltage-divider bias with an emitter resistor counters this by negative feedback (if I_C tries to rise, the emitter voltage rises, which reduces the base–emitter forward voltage and pulls I_C back), keeping the operating point stable — which is why it is the standard biasing scheme.

3.6 Voltage, current and power gain; the single-stage amplifier

$$A_v = V_{out}/V_{in}\ ;\ A_i = I_{out}/I_{in}\ ;\ A_p = P_{out}/P_{in} = A_v \times A_i$$

$$\text{Gain in decibels: } A_{dB} = 20\log_{10}(V_{out}/V_{in}) = 10\log_{10}(P_{out}/P_{in})$$

In a single-stage RC-coupled CE amplifier, the AC input is coupled through a capacitor to the base; the amplified signal appears at the collector (inverted, 180°) and is coupled out through another capacitor. Coupling and emitter-bypass capacitors pass the AC while preserving the DC bias. Transistor amplifier behaviour is analysed with the ***h-parameter (hybrid) small-signal model*** (h_ie, h_fe, h_re, h_oe). Expressing gain in decibels is convenient because cascaded-stage gains add in dB.

▣ Common-emitter (voltage-divider bias) amplifier

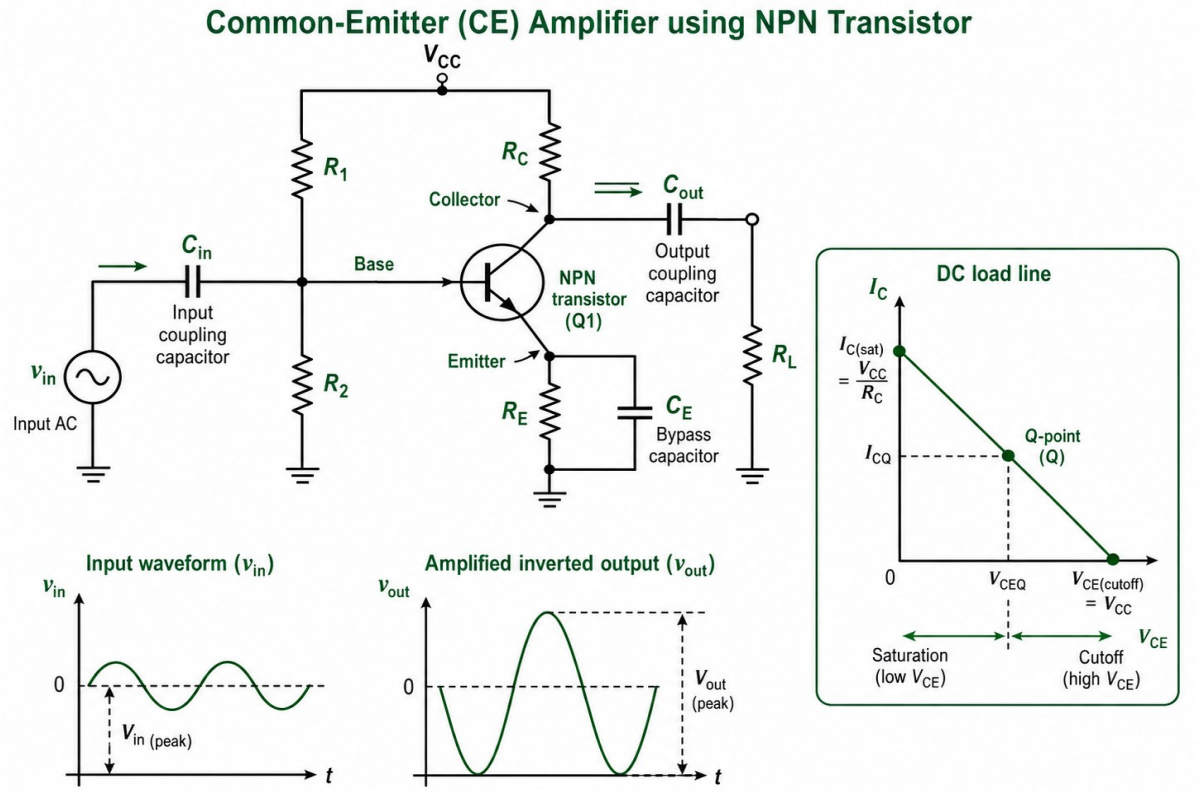


Fig. 7.6 Common-emitter amplifier with voltage-divider bias

3.7 *Classes of amplifiers*

- **Class A** : Device conducts the full cycle (Q-point at centre); lowest distortion but low efficiency (theoretical max 25 % for series-fed, 50 % for transformer-coupled); small-signal/preamplifier stages.
- **Class B** : Each device conducts half the cycle; used in push-pull pairs; efficiency up to 78.5 %; suffers crossover distortion.
- **Class AB** : Conducts slightly more than half a cycle — a compromise that removes crossover distortion; the usual audio power-output stage.
- **Class C** : Conducts less than half a cycle; highest efficiency (> 78 %) but heavy distortion; used only with a tuned load (RF amplifiers, transmitters).

The classes trade distortion against efficiency, and the reason is the conduction angle — the fraction of the input cycle for which the device is turned on. In Class A the transistor is biased to conduct for the whole 360° of the cycle, so it reproduces the entire waveform with the least distortion; but it draws current even when there is no signal, wasting power as heat, so its efficiency is low (25 % series-fed, 50 % transformer-coupled). In Class B each transistor conducts for only 180° (one half-cycle), drawing almost no current with no signal, so efficiency is high (up to 78.5 %); two transistors are used in a push-pull pair, one handling each half-cycle, but where they hand over there is a small 'crossover' distortion. Class AB biases the pair to conduct just over 180° each, so they overlap slightly at the hand-over and the crossover distortion disappears — the standard for audio power output. Class C conducts for less than 180°, giving the highest efficiency of all but severe distortion, so it is usable only with a tuned (resonant) load that reconstructs the sine wave — as in radio-frequency amplifiers and transmitters. In short, the more of the cycle the device conducts, the cleaner but less efficient the amplifier.

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▣ *Amplifier classes — conduction angle*

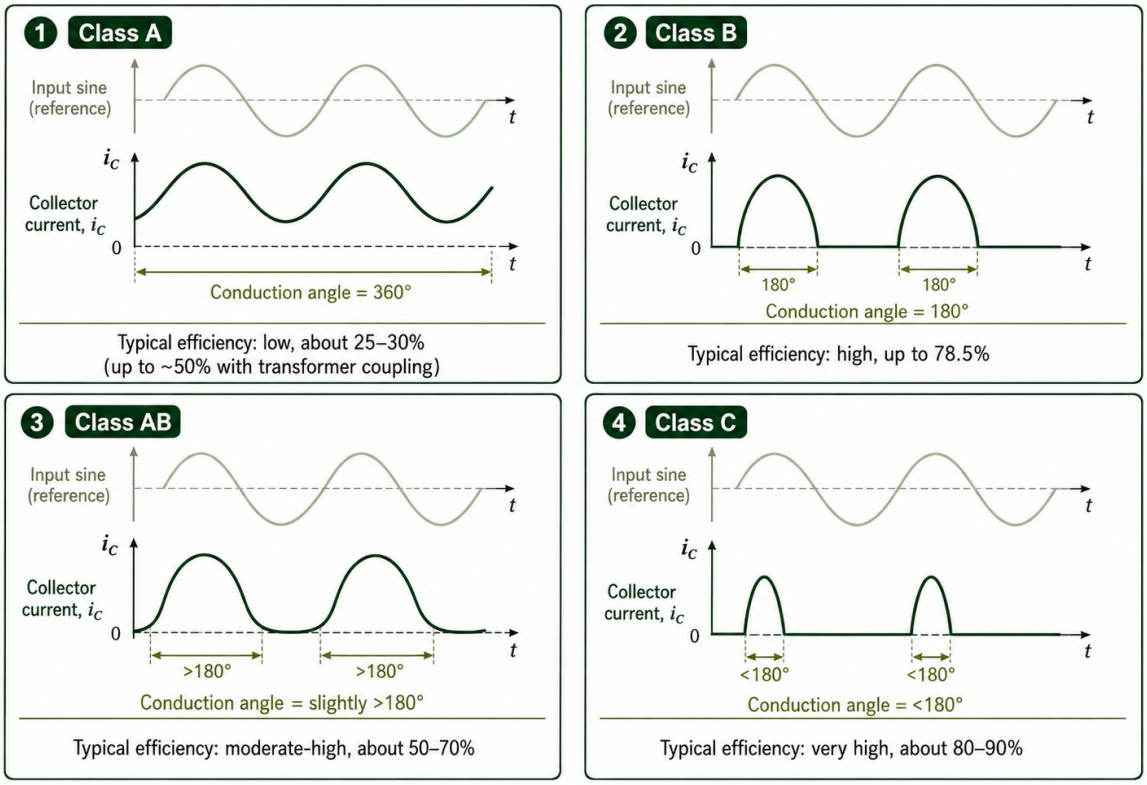


Fig. 7.6c Conduction angle of amplifier classes A/B/AB/C

3.8 *Frequency response, multistage amplifiers and feedback*

Gain varies with frequency: roughly constant in the mid-band, falling at low frequency (coupling and bypass capacitors) and high frequency (junction and stray capacitances). The ***bandwidth*** lies between the lower and upper −3 dB (half-power) cut-off frequencies. To get more gain, stages are ***cascaded (multistage)*** — overall gain is the product of the stage gains (sum in dB) — using RC, transformer or direct coupling.

Negative feedback — *feeding a fraction β of the output back out-of-phase to the input. Closed-loop gain* $A' = A/(1 + A\beta)$ — *a little gain is traded for greater gain stability (against device and temperature changes), reduced distortion and noise, wider bandwidth and controllable input/output impedance. It is the opposite of the positive feedback used in oscillators.*

◆ **WORKED NUMERICAL — *Cascaded amplifier gain*** **[demonstrates gain & dB]**

Problem. *A three-stage amplifier has stage voltage gains 10, 20 and 50. Find the overall gain and express it in dB.*

Overall gain $A_v = 10 \times 20 \times 50 = 10\,000$.

In decibels = 20 $\log_{10}(10\,000)$ = 80 dB (equivalently 20 + 26 + 34 = 80 dB — the dB gains add).

4 OPERATIONAL AMPLIFIERS

4.1 *The operational amplifier and its ideal characteristics*

PREVIOUS YEAR QUESTIONS

What are the advantages of operational amplifiers over discrete devices? State the typical

specifications of a general-purpose operational amplifier. Explain: Input offset voltage; Input offset current; Slew rate. [OPSC·CSE 2024-25 | P2/12 | 15M]

▣ *Op-amp symbol, block diagram and configurations*

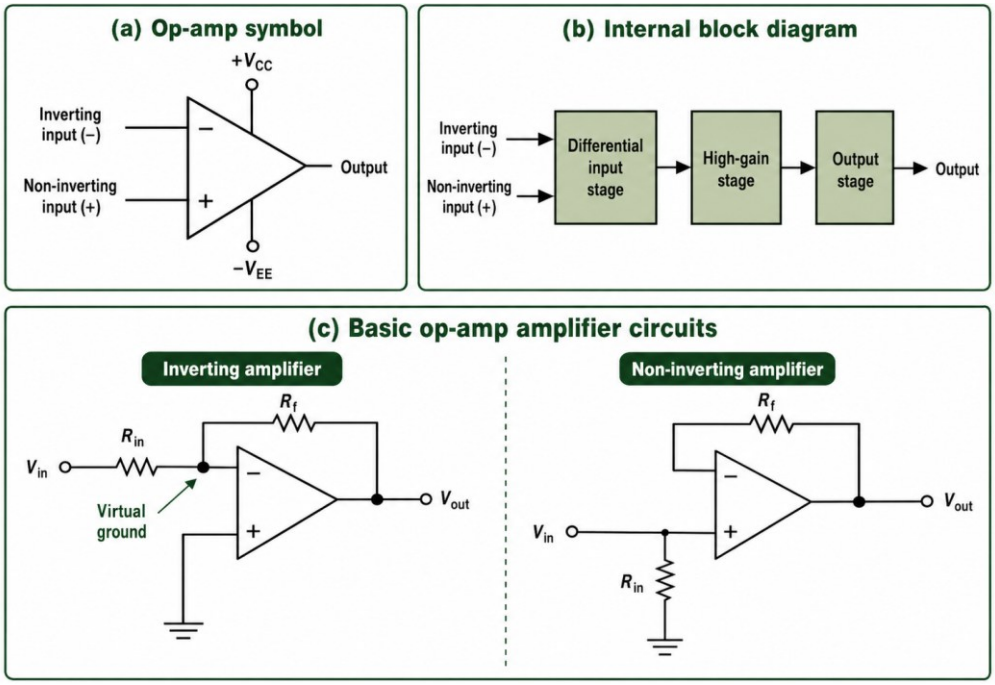


Fig. 7.6b Op-amp symbol, blocks and basic configurations

Operational amplifier (op-amp) — *a high-gain, direct-coupled differential amplifier IC with two inputs (inverting − and non-inverting +) and one output. Internally it has a differential input stage, a high-gain intermediate stage and a low-impedance output stage. Originally built to perform mathematical operations (add, subtract, integrate, differentiate), it is the universal analog building block.*

Ideal op-amp — *infinite open-loop voltage gain, infinite input impedance, zero output impedance, infinite bandwidth, infinite CMRR, and zero offset/drift. Real op-amps approach these closely, which is why their behaviour is set almost entirely by external components.*

4.2 *Advantages over discrete devices*

Very high gain in a single small, cheap IC; performance set predictably by external resistors (negative feedback) rather than by device parameters; compact, reliable and low-power; excellent temperature stability; and enormous versatility — the same device amplifies, adds, subtracts, integrates, differentiates, compares and filters. This makes analog design far simpler, more accurate, more stable and more economical than building the equivalent from discrete transistors.

4.3 *Typical specifications of a general-purpose op-amp (μA741)*

Parameter	*Typical (741) value*	*Meaning*
Open-loop voltage gain	~2×10^5	gain without feedback
Input impedance	~2 MΩ	how little it loads the source
Output impedance	~75 Ω	how stiffly it drives a load

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CMRR	~90 dB	rejection of common-mode signals
Slew rate	~0.5 V/µs	max output rate of change
Input offset voltage	~2 mV	input needed to zero the output
Input offset current	~20 nA	difference of the two bias currents
Gain–bandwidth product	~1 MHz	gain × bandwidth is constant
Supply	±15 V	dual supply

4.4 Key terminologies

Input offset voltage (V_io) — *the small differential DC voltage that must be applied between the two inputs to make the output exactly zero (ideally 0; ~2 mV for a 741). It arises from mismatch in the input-stage transistors and drifts with temperature; it can be nulled with an offset-null potentiometer.*

Input offset current (I_io) — *the difference between the two input bias currents, |I_B1 − I_B2| (ideally 0; ~20 nA for a 741). Together with the source resistance it produces a small output error.*

Slew rate (SR) — *the maximum rate of change of the output voltage, dV_o/dt|max, in V/µs (~0.5 V/µs for a 741). It limits how fast/large the output can swing: the largest undistorted sine of peak V_p is limited to f_max = SR/(2πV_p). CMRR (common-mode rejection ratio) = differential gain ÷ common-mode gain, in dB — the ability to reject signals common to both inputs (vital for noise rejection).*

4.5 Op-amp configurations and applications

Before the circuits, understand why an op-amp with feedback is so easy to analyse. The op-amp's open-loop gain is enormous (~200 000), so to produce any sensible (finite) output the voltage difference between its two inputs must be almost zero — the output moves to whatever value drives that difference to nearly nothing. When negative feedback connects the output back to the inverting input, the op-amp automatically adjusts its output to keep the two inputs at essentially the same voltage. This gives the two 'golden rules' used to analyse any op-amp circuit: (i) no current flows into either input (the input impedance is nearly infinite), and (ii) the two inputs sit at the same voltage (a 'virtual short'). In the inverting amplifier the non-inverting input is grounded, so rule (ii) forces the inverting input to 0 V as well — a 'virtual ground' — even though it is not physically connected to ground. These two rules alone give the gain of every op-amp circuit.

Take the inverting amplifier as the worked case. The input voltage V_in drives a current V_in/R_in toward the virtual-ground node. By rule (i) none of this current enters the op-amp, so all of it must flow on through the feedback resistor R_f into the output. The output therefore has to sit at whatever voltage drives exactly that current through R_f, namely V_o = −(R_f/R_in)·V_in — the gain is simply the resistor ratio, set by the designer and independent of the transistor-level details inside the chip. The same reasoning gives 1 + R_f/R_in for the non-inverting amplifier, −R_f·Σ(V/R) for the summing amplifier, and the integrator/differentiator relations when R_f or R_in is replaced by a capacitor. This is exactly why the op-amp is so powerful: predictable, stable behaviour set entirely by a couple of external components.

Analysis uses the two golden rules of an ideal op-amp with negative feedback: (i) no current flows into the inputs, and (ii) the two inputs are at the same voltage (a virtual short; for the inverting amplifier the inverting input is a virtual ground).

Inverting: $A_v = -R_f/R_{in}$; Non-inverting: $A_v = 1 + R_f/R_{in}$; Voltage follower: $A_v = 1$

Circuit	Output
Summing amplifier	$V_o = -R_f(V_1/R_1 + V_2/R_2 + \ldots)$ — analog adder

Difference amplifier	$V_o = (R_f/R)(V_2 - V_1)$ — subtractor
Integrator	$V_o = -(1/RC)\int V_{in}\,dt$
Differentiator	$V_o = -RC\,(dV_{in}/dt)$
Comparator	output → +/−V_{sat} as $V_+ \gtrless V_-$ (open-loop, no feedback)

Op-amps also build active filters (low-pass, high-pass, band-pass — RC networks with op-amp gain, avoiding bulky inductors), precision rectifiers (that rectify millivolt signals below a diode drop), Schmitt triggers and even oscillators (a Wien-bridge op-amp oscillator). The instrumentation amplifier — a precision three-op-amp difference amplifier with very high input impedance, high CMRR and accurately-set gain — is the standard front-end for amplifying the small differential signals from bridge sensors (strain gauges, RTDs) in agricultural instrumentation.

◆ **WORKED NUMERICAL — *Op-amp circuits*** **[demonstrates the gain relations]**

Problem. *For an inverting amplifier* $V_{in} = 0.5$ V *with* $R_{in} = 10$ kΩ, $R_f = 100$ kΩ; *and a summing amplifier with* $V_1 = 1$ V, $V_2 = 2$ V *and* $R_1 = R_2 = R_f = 10$ kΩ.

Given two cases:

1. Inverting Amplifier

$V_{in} = 0.5$ V

$R_{in} = 10$ kΩ

$R_f = 100$ kΩ

2. Summing Amplifier

$V_1 = 1$ V

$V_2 = 2$ V

$R_1 = R_2 = R_f = 10$ kΩ

3. INVERTING AMPLIFIER

For an inverting amplifier,

Voltage Gain, $A_v = -R_f / R_{in}$

$A_v = -100\ k\Omega / 10\ k\Omega$

$A_v = -10$

Output voltage,

$V_{out} = A_v \times V_{in}$

$V_{out} = -10 \times 0.5$

$V_{out} = -5$ V

Therefore,

$V_{out} = -5$ V

2. SUMMING AMPLIFIER

For an inverting summing amplifier,

$V_{out} = -R_f [(V_1 / R_1) + (V_2 / R_2)]$

Since,

$R_1 = R_2 = R_f = 10$ kΩ

Therefore,

$V_{out} = -(V_1 + V_2)$

$V_{out} = -(1 + 2)$

$V_{out} = -3$ V

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Therefore,

$V_{out} = -3$ V

FINAL ANSWER

Inverting Amplifier:

Voltage Gain, $A_v = -10$

Output Voltage, $V_{out} = -5$ V

Summing Amplifier:

Output Voltage, $V_{out} = -3$ V

◆ **WORKED NUMERICAL — *Slew-rate-limited frequency*** **[demonstrates slew rate]**

Problem. *A 741 (SR = 0.5 V/µs) must deliver a 10 V-peak sine wave. Find the maximum undistorted frequency.*

$f_{max} = SR/(2\pi V_p) = 0.5\times10^6/(2\pi\times10) \approx 7.96$ kHz.

Given:

Slew Rate, SR = 0.5 V/µs

Peak output voltage, $V_p = 10$ V

For a sinusoidal output,

$SR = 2\pi f_{max} V_p$

Therefore,

$f_{max} = SR / (2\pi V_p)$

Substituting the values:

$f_{max} = 0.5 / (2 \times 3.1416 \times 10)$ MHz

$f_{max} = 0.00796$ MHz

$f_{max} = 7.96$ kHz

Therefore,

$f_{max} \approx 8$ kHz

FINAL ANSWER

Maximum undistorted frequency, $f_{max} \approx 7.96$ kHz ≈ 8 kHz

5 OSCILLATORS

5.1 *Oscillator, and how it differs from an amplifier*

PREVIOUS YEAR QUESTIONS

- How does an oscillator differ from an amplifier?
  [UK·PSC RFO 2021 | Q.8 | 10M; UK·PSC ACF 2019 | Q.8 | 10M]
- Explain the working principle of oscillators. [OPSC·CSE 2015-16 | P2/5(d) | 20M]

Oscillator — *a circuit that generates a continuous, repetitive AC waveform (sinusoidal, square, etc.) of a desired frequency without any external input signal, converting DC power into AC. It is essentially an amplifier that supplies its own input through positive feedback.*

Feature	*Amplifier*	*Oscillator*
Input	needs an external input	needs no external input (self-starts from noise)

Function	amplifies an existing signal	generates its own signal
Feedback	usually negative (for stability)	positive (regenerative)
Frequency	set by the input	set by a frequency-selective network

5.2 *Positive feedback and the Barkhausen criterion*

An oscillator is an amplifier (gain A) with a feedback network (factor β) returning part of the output to the input in phase (positive feedback). With feedback the gain is $A_f = A/(1 - A\beta)$; when $A\beta \to 1$ the gain becomes infinite and the circuit sustains an output with no input — oscillation. For steady oscillations the Barkhausen criterion must hold:

Barkhausen criterion: (1) loop gain $|A\cdot\beta| = 1$; (2) total loop phase shift = 0° (or 360°)

Let us understand physically why these two conditions are needed. Imagine feeding the amplifier's own output back to its input. For the fed-back signal to reinforce (not cancel) the signal already there, it must arrive ***in phase*** — that is the phase condition (0° or 360° around the loop). And for the oscillation to sustain itself at a constant amplitude, the signal returning to the input must be exactly as large as the signal that produced it — no more, no less — which means the loop gain $|A\beta|$ must equal 1. If $|A\beta|$ were less than 1 the oscillation would die away; if more than 1 it would grow without limit. In a real oscillator the designer arranges $|A\beta|$ to be slightly greater than 1 at switch-on, so oscillations build up spontaneously from the tiny electrical noise always present; as the amplitude grows, the amplifier gently runs into its natural limits (its gain falls a little at large signals), and the loop gain automatically settles back to exactly 1, holding a steady output. A frequency-selective RC or LC network is placed in the loop so that the phase condition is met at only one frequency — and that is the single frequency at which the circuit oscillates.

5.3 *Classification and common oscillators*

- ***RC oscillators (audio/LF)*** : RC phase-shift (a CE amplifier's 180° plus a three-section RC network's 180° = 360°), $f = 1/(2\pi RC\sqrt{6})$; and Wien-bridge (RC lead–lag, 0° phase), $f = 1/(2\pi RC)$ — low distortion, the standard audio oscillator.
- ***LC oscillators (radio/HF)*** : Hartley (tapped inductor) and Colpitts (tapped capacitor), each with an LC tank, $f = 1/(2\pi\sqrt{(LC)})$; also Clapp and tuned-collector.
- ***Crystal oscillator*** : Uses the sharp piezoelectric resonance of a quartz crystal (modelled as a series R-L-C with a parallel capacitance) for an extremely stable, precise frequency (a Q of 10^4–10^6 gives frequency stability better than 1 in 10^6) — used in clocks, microprocessors and radio transmitters.
- ***Non-sinusoidal*** : Relaxation oscillators / multivibrators producing square and pulse waveforms (Section 6).

In an LC oscillator the tank circuit sets the frequency and the transistor replaces the energy lost each cycle. In the Hartley the feedback is tapped from a split inductor; in the Colpitts from a split capacitor. RC oscillators are preferred at audio frequencies (LC components would be bulky), LC at radio frequencies, and crystals where frequency must be rock-stable.

RC phase-shift: $f = 1/(2\pi RC\sqrt{6})$; Wien-bridge: $f = 1/(2\pi RC)$; LC (Hartley/Colpitts): $f = 1/(2\pi\sqrt{(LC)})$

▣ *RC and LC oscillators*

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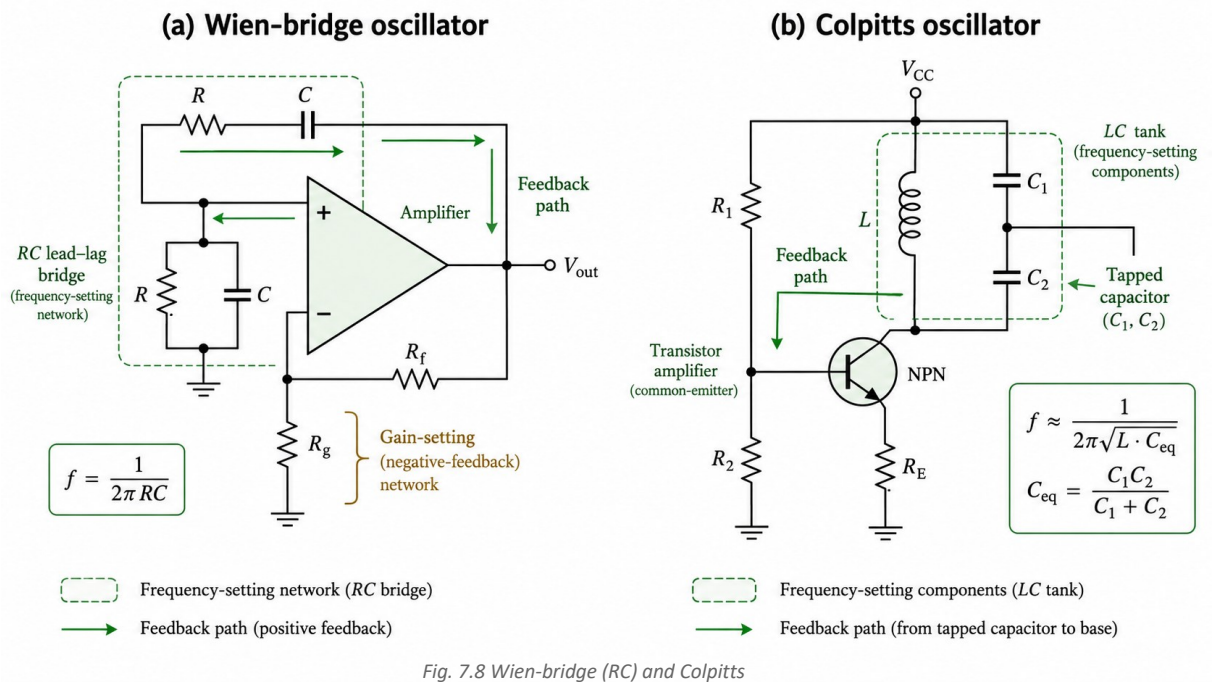


Fig. 7.8 Wien-bridge (RC) and Colpitts

Applications: carrier and clock generation, radio/TV transmitters and receivers, function generators, and excitation sources for AC bridges and LVDTs in instrumentation.

◆ **WORKED NUMERICAL — *Oscillator frequency*** **[demonstrates the formulas]**

Problem. *For R = 10 kΩ, C = 10 nF find the Wien-bridge frequency; compare with an RC phase-shift oscillator and an LC oscillator (L = 1 mH, C = 100 pF).*

Given:

R = 10 kΩ = 10,000 Ω

C = 10 nF = 10×10^{-9} F

For LC oscillator:

L = 1 mH = 1×10^{-3} H

C = 100 pF = 100×10^{-12} F

1. WIEN-BRIDGE OSCILLATOR

For a Wien-bridge oscillator,

$f = 1 / (2\pi RC)$

Substituting the values:

$f = 1 / [2\pi \times 10{,}000 \times 10 \times 10^{-9}]$

f = 1591.5 Hz

Therefore,

f ≈ 1.59 kHz

2. RC PHASE-SHIFT OSCILLATOR

For a three-section RC phase-shift oscillator with equal R and C,

$f = 1 / (2\pi RC\sqrt{6})$

Using the same values:

$f = 1 / [2\pi \times 10{,}000 \times 10 \times 10^{-9} \times \sqrt{6}]$

f ≈ 649.7 Hz

Therefore,

$$f \approx 650 \text{ Hz}$$

3. LC OSCILLATOR

For an LC oscillator,

$$f = 1 / [2\pi\sqrt{(LC)}]$$

Substituting the values:

$$f = 1 / [2\pi\sqrt{(1 \times 10^{-3} \times 100 \times 10^{-12})}]$$

$$f \approx 503{,}300 \text{ Hz}$$

Therefore,

$$f \approx 503.3 \text{ kHz}$$

COMPARISON

Wien-bridge oscillator = 1.59 kHz
RC phase-shift oscillator = 0.65 kHz
LC oscillator = 503.3 kHz

FINAL ANSWER

Wien-bridge frequency ≈ 1.59 kHz
RC phase-shift frequency ≈ 650 Hz
LC oscillator frequency ≈ 503.3 kHz

Thus, the LC oscillator operates at a much higher frequency than the two RC oscillators.

6 MULTIVIBRATORS

6.1 *Multivibrator*

PREVIOUS YEAR QUESTIONS

Discuss in detail about (ii) multivibrators. [IFOS 2022| P2/5(e)(ii) | 8M]

Multivibrator *– a two-stage regenerative switching circuit (a relaxation oscillator) that generates non-sinusoidal (square, rectangular or pulse) waveforms by switching between two states. Two active devices (transistors, logic gates, op-amp or a 555 IC) are cross-coupled so that when one is ON the other is OFF; RC timing elements set the switching.*

6.2 *The three types*

Type	*Stable states*	*Trigger*	*Output / use*
Astable (free-running)	none	none (self-oscillating)	continuous square wave — clock / oscillator
Monostable (one-shot)	one	one trigger per pulse	single fixed-width pulse — timing / delay
Bistable (flip-flop)	two	trigger to change each way	holds a state (latch) — memory / counting

- ***Astable*** : No stable state; continuously flips between two quasi-stable states → a steady square wave with no external trigger.
- ***Monostable*** : One stable state; a trigger flips it to a quasi-stable state for a fixed time (set by RC), then it returns automatically — one output pulse per trigger (555: T = 1.1 RC).
- ***Bistable*** : Two stable states; each trigger toggles it and it stays there — the flip-flop, the basic 1-bit memory element.

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The three types differ only in how many of their states are stable, which comes from how the two coupling paths are made (resistive coupling gives a stable state, capacitive coupling gives a temporary one). In the ***monostable*** (one-shot), one coupling is resistive (giving one permanently stable state) and the other capacitive; the circuit rests quietly in its stable state until an external trigger flips it into the temporary (quasi-stable) state. It stays there only as long as the capacitor takes to charge — a fixed time set by RC — then flips back on its own. So each trigger produces exactly one output pulse of precise, fixed width (555: T = 1.1RC), which is why the monostable is used for timing, fixed delays and pulse-width generation. In the ***bistable***, both couplings are resistive, so both states are permanently stable; a trigger flips it to the other state, where it stays indefinitely until the next trigger. Because it 'remembers' which state it is in, the bistable is the flip-flop — the fundamental 1-bit memory cell used in counters, registers and every sequential digital system.

6.3 Transistor astable multivibrator

Two cross-coupled common-emitter transistors are RC-coupled: while one transistor is ON (saturated), its coupling capacitor charges through the base resistor of the OFF transistor until that transistor's base reaches its turn-on voltage and it switches ON — which turns the first OFF. The cycle repeats, giving a continuous square wave.

The switching is regenerative, which is what makes the transitions so fast and clean. Suppose transistor Q1 is ON (its collector is low) and Q2 is OFF (its collector is high). The coupling capacitor linking Q1's collector to Q2's base slowly charges through Q2's base resistor; Q2's base voltage rises exponentially toward the turn-on level. The instant it reaches ~0.7 V, Q2 begins to conduct — its collector voltage falls, and this falling voltage is coupled through the other capacitor to Q1's base, turning Q1 harder OFF, which raises Q1's collector, which drives Q2 harder ON, and so on. This cumulative (positive-feedback) action snaps the circuit over almost instantly to the opposite state: Q2 now ON, Q1 OFF. The process then repeats in mirror image. Each transistor stays ON for a time set by the RC charging of the opposite capacitor, so the collector voltages are two anti-phase square waves; the period is $T = 0.69(R_1C_1 + R_2C_2)$. Because it needs no external trigger and has no stable resting state, the astable free-runs as a square-wave/clock generator.

Time period $T = 0.69(R_1C_1 + R_2C_2) \approx 1.38\ RC$ (symmetric) ; frequency $f = 1/T$

▣ Transistor astable multivibrator

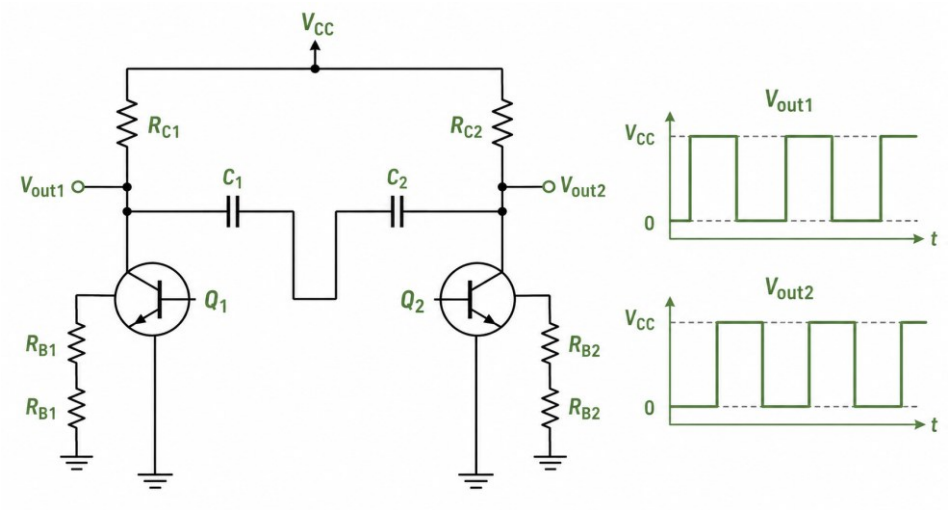


Fig. 7.7 Transistor astable multivibrator

6.4 The 555 timer, Schmitt trigger and flip-flops

Modern multivibrators are usually built from the 555 timer IC (or gates/op-amp). Internally the 555 has two comparators, an S-R flip-flop and a discharge transistor. As an astable it gives $f = 1.44/((R_1 + 2R_2)C)$ with duty cycle $(R_1+R_2)/(R_1+2R_2)$; as a monostable it gives one pulse of width $T = 1.1\ RC$ per trigger.

▣ Multivibrator output waveforms

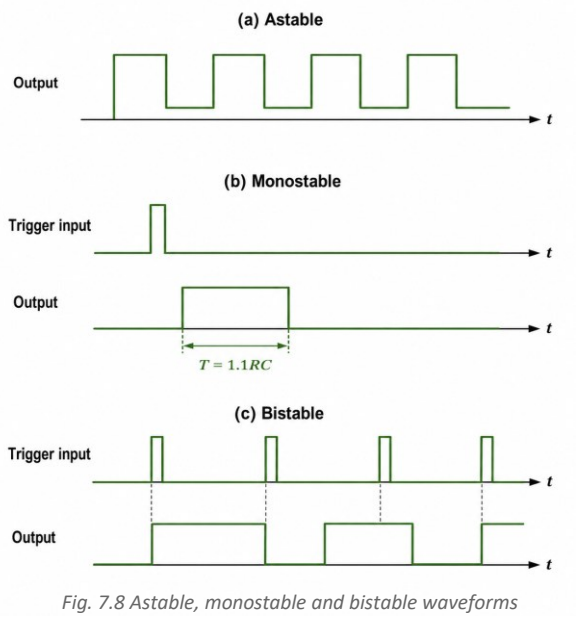


Fig. 7.8 Astable, monostable and bistable waveforms

Schmitt trigger – *a bistable circuit with two different switching thresholds (hysteresis) that converts a slow or noisy input into a clean, sharp square/pulse output – used for waveshaping and 'cleaning' signals at the input of digital systems.*

Bistables are realised as flip-flops — the basic 1-bit memory elements and the building blocks of counters, shift registers and all sequential digital circuits:

Flip-flop	*Function*
S-R	Set / Reset; S=R=1 is forbidden
J-K	like S-R but J=K=1 toggles (master-slave avoids race)
D (data)	output follows the D input at the clock edge — a latch
T (toggle)	T=1 toggles each clock — used in counters (÷2)

6.5 Applications and worked numericals

Applications: clock/timing generation, pulse shaping and delay, square-wave and pulse generators, frequency division and counting, and (bistable) memory/registers — the foundation of all sequential digital systems used in data acquisition and control.

◆ **WORKED NUMERICAL – *Multivibrator timing*** **[demonstrates the timing formulas]**

Problem. *A 555 astable has $R_1 = R_2 = 10\ k\Omega$, $C = 10\ nF$; a 555 monostable has $R = 10\ k\Omega$, $C = 10\ \mu F$; a transistor astable has $R = 10\ k\Omega$, $C = 100\ nF$.*

Given:

555 Astable:

$R_1 = 10\ k\Omega$

$R_2 = 10\ k\Omega$

$C = 10\ nF$

555 Monostable:

$R = 10\ k\Omega$

$C = 10\ \mu F$

Transistor Astable:

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R = 10 kΩ

C = 100 nF

1. 555 Astable Multivibrator

For a 555 astable:

High time,

$$tH = 0.693 (R_1 + R_2) C$$

$$tH = 0.693 \times (10\ k\Omega + 10\ k\Omega) \times 10\ nF$$

$$tH = 0.1386\ ms$$

Low time,

$$tL = 0.693\ R_2\ C$$

$$tL = 0.693 \times 10\ k\Omega \times 10\ nF$$

$$tL = 0.0693\ ms$$

Total time period,

$$T = tH + tL$$

$$T = 0.1386 + 0.0693$$

$$T = 0.2079\ ms$$

Frequency,

$$f = 1 / T$$

$$f = 1 / (0.2079 \times 10^{-3})$$

$f \approx 4.81\ kHz$

Duty cycle,

$$\text{Duty Cycle} = [(R_1 + R_2) / (R_1 + 2R_2)] \times 100$$

$$\text{Duty Cycle} = [20 / 30] \times 100$$

Duty Cycle ≈ 66.7%

2. 555 Monostable Multivibrator

Pulse width is:

$$T = 1.1\ RC$$

$$T = 1.1 \times 10\ k\Omega \times 10\ \mu F$$

$$T = 1.1 \times 10^4 \times 10 \times 10^{-6}$$

T = 1.1 s

Thus, the output pulse remains HIGH for approximately **1.1 seconds** after triggering.

3. Transistor Astable Multivibrator

For a symmetrical transistor astable multivibrator:

Half-cycle time,

$$t \approx 0.693\ RC$$

$$t = 0.693 \times 10\ k\Omega \times 100\ nF$$

$$t = 0.693\ ms$$

Total period,

$$T \approx 2 \times 0.693\ RC$$

$$T \approx 1.386\ RC$$

$$T = 1.386 \times 10\ k\Omega \times 100\ nF$$

T ≈ 1.386 ms

Frequency,

$f = 1 / T$

$f = 1 / (1.386 \times 10^{-3})$

$f \approx 721.5$ Hz $\approx$ 722 Hz

Final Answer

Circuit	Result
555 Astable high time	**0.1386 ms**
555 Astable low time	**0.0693 ms**
555 Astable period	**0.2079 ms**
555 Astable frequency	**4.81 kHz**
555 Astable duty cycle	**66.7%**
555 Monostable pulse width	**1.1 s**
Transistor astable period	**1.386 ms**
Transistor astable frequency	**≈ 722 Hz**

7 SENSORS & TRANSDUCERS (BRIEF)

PREVIOUS YEAR QUESTIONS

What is a sensor? [OPSC·CSE 2015-16| P2/5(d) | 20M]

Sensor — *a device that detects or responds to a physical quantity (temperature, pressure, light, strain, flow, level, force) and produces a corresponding measurable output, usually an electrical signal. A sensor is essentially an input transducer.*

Transducer — *a device that converts one form of energy or signal into another; in measurement it converts a physical (non-electrical) quantity into an electrical signal (or vice-versa for an actuator/output transducer).*

Common sensors: thermocouple, RTD and thermistor (temperature); strain gauge and load cell (strain/force/weight); LVDT (displacement); piezoelectric element (pressure/force); photodiode and LDR (light).

Classification of transducers

- ***Active vs passive*** : Active (self-generating) produce their own output emf (thermocouple, piezoelectric, photovoltaic); passive need external excitation and vary a parameter — R, L or C (strain gauge, RTD, LVDT, capacitive sensor).
- ***Primary/secondary; analog/digital*** : Primary sense the quantity directly, secondary convert a primary output further; output may be analog (continuous) or digital (discrete, e.g. encoders).

Link to this chapter: a sensor's output is usually weak, AC or noisy, so it is processed by the very devices covered here — amplifiers boost the small signal, rectifiers convert AC sensor/bridge outputs to DC, oscillators provide excitation/carrier signals (for LVDTs and AC bridges), and op-amps do signal conditioning: sensor → signal conditioning (amplifier · rectifier · filter · op-amp) → display/recording/control. The detailed measurement systems (level, flow, strain, force, torque, power, pressure, vacuum, temperature) belong to Chapter 8 (Instrumentation).

▣ *Generalised measurement system*

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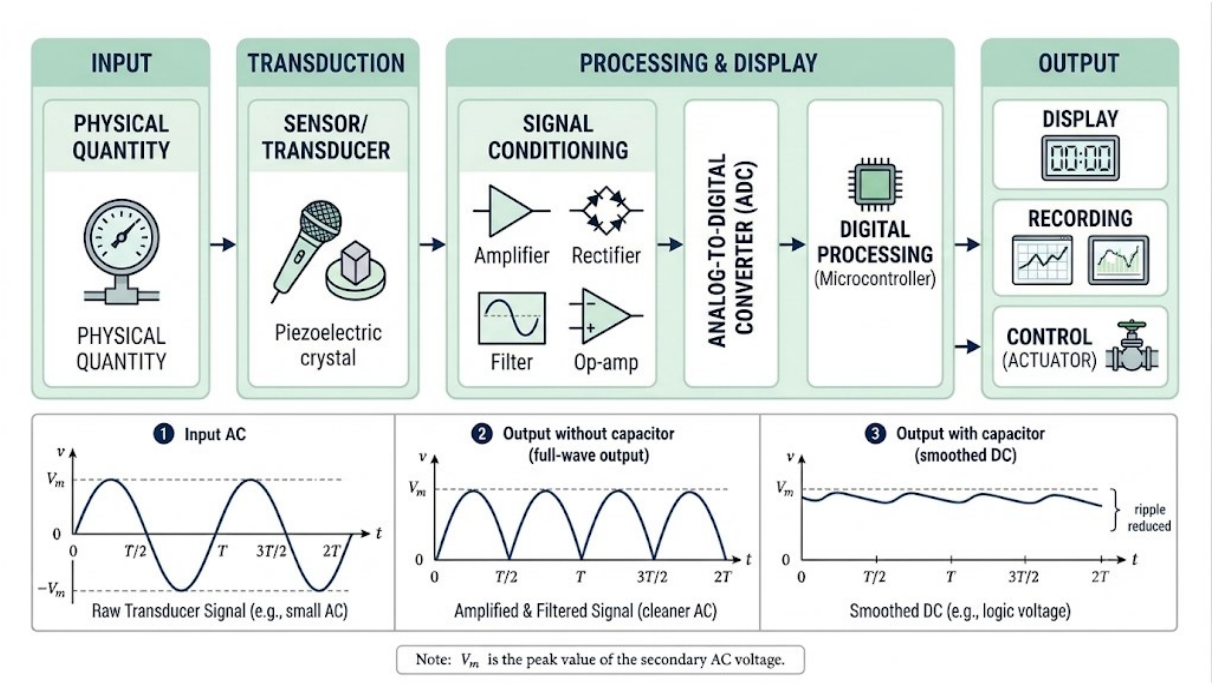


Fig. 7.9 Generalised measurement system — where electronic devices fit

◆ *Source: Sawhney, Electrical & Electronic Measurements & Instrumentation (transducers); detailed treatment → Chapter 8.*

8 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

Formula Sheet

Diode: $I = I_0(e^{V/\eta V_T} - 1)$; $V_T \approx 26$ mV ; barrier ≈ 0.7 V (Si), 0.3 V (Ge)

Zener regulator: $R_s = (V_{in} - V_Z)/(I_Z + I_L)$; $I_L = V_Z/R_L$

Half-wave: $V_{dc} = V_m/\pi$; $I_{rms} = I_m/2$; $\gamma = 1.21$; $\eta = 40.6$ % ; PIV = V_m ; $f_r = f$

Full-wave: $V_{dc} = 2V_m/\pi$; $I_{rms} = I_m/\sqrt{2}$; $\gamma = 0.48$; $\eta = 81.2$ % ; PIV = $2V_m$ (CT)/V_m (bridge) ; $f_r = 2f$

Ripple: $\gamma = \sqrt{((I_{rms}/I_{dc})^2 - 1)}$; capacitor filter $\gamma \approx 1/(2\sqrt{3}\cdot f\cdot C\cdot R_L)$

BJT: $\beta = I_C/I_B$; $\alpha = I_C/I_E$; $\beta = \alpha/(1-\alpha)$; load line $V_{CE} = V_{CC} - I_C R_C$

Gain: $A_v = V_o/V_{in}$; $A_p = A_v\cdot A_i$; $A_{dB} = 20\log(V_o/V_{in})$; feedback $A' = A/(1+A\beta)$

Op-amp: inverting $-R_f/R_{in}$; non-inverting $1 + R_f/R_{in}$; $f_{max} = SR/(2\pi V_p)$

Oscillator: Barkhausen $|A\beta|=1$, phase 0/360° ; Wien $1/(2\pi RC)$; RC-φ $1/(2\pi RC\sqrt{6})$; LC $1/(2\pi\sqrt{LC})$

Multivibrator: astable $T = 1.38RC$; 555 astable $f = 1.44/((R_1+2R_2)C)$; 555 mono $T = 1.1RC$

SUMMARY

A semiconductor (Si/Ge, small band gap) is doped into N-type (electrons) or P-type (holes); joining them forms a PN junction with a depletion region and ~0.7 V barrier. The diode conducts in forward bias (beyond the knee) and blocks in reverse (until breakdown) — a one-way valve; a Zener diode regulates voltage in reverse breakdown. Rectifiers convert AC to pulsating DC: half-wave (1 diode, γ = 1.21, η = 40.6 %, PIV = V_m), full-wave centre-tap (2 diodes, γ = 0.48, η = 81.2 %, PIV = $2V_m$) and bridge (4 diodes, γ = 0.48, PIV = V_m, best TUF). The ripple factor measures leftover AC; a smoothing capacitor across the load slashes it ($\gamma \approx 1/(2\sqrt{3}\cdot f\cdot C\cdot R_L)$); a regulator then holds the output steady. Amplifiers raise signal amplitude — the BJT (β =

I_C/I_B) in a biased CE stage gives voltage/current/power gain (dB adds when cascaded), classified into classes A/B/AB/C; negative feedback trades gain for stability and bandwidth. The op-amp is a high-gain differential IC whose gain is set by external resistors (inverting −R_f/R_in, non-inverting 1+R_f/R_in), characterised by offset voltage/current, slew rate and CMRR, and used as adder, subtractor, integrator, differentiator and comparator. Oscillators generate AC without input using positive feedback meeting the Barkhausen criterion (|Aβ| = 1, phase 0°) — RC (Wien, phase-shift), LC (Hartley, Colpitts) and crystal types. Multivibrators are switching circuits — astable (square wave), monostable (one-shot) and bistable (flip-flop/memory), commonly built with a 555. Sensors/transducers convert physical quantities to electrical signals that these devices condition — linking Chapter 7 to the instrumentation of Chapter 8.

LAST-NIGHT REVISION

- Semiconductor: Si 1.1 eV, Ge 0.7 eV; N-type = electrons, P-type = holes; junction barrier ~0.7 V (Si).
- Diode: forward conducts >0.7 V; reverse blocks (leakage) until breakdown (Zener <6 V, avalanche >6 V).
- Zener regulator: $R_s = (V_{in}-V_Z)/(I_Z+I_L)$.
- HW: $V_{dc}=V_m/\pi$, γ=1.21, η=40.6 %, PIV=V_m, $f_r=f$. FW: $V_{dc}=2V_m/\pi$, γ=0.48, η=81.2 %, $f_r=2f$.
- PIV: centre-tap $2V_m$, bridge V_m. Bridge = no centre tap, lowest PIV, best TUF (0.812).
- Ripple factor = RMS AC/DC = $\sqrt{((I_{rms}/I_{dc})^2-1)}$; lower = purer; cap filter $\gamma \approx 1/(2\sqrt{3}fCR_L)$.
- BJT: β=I_C/I_B (50–300); active region = EB forward, CB reverse; voltage-divider bias most stable.
- Gain: $A_p=A_v \cdot A_i$; dB=20log; cascaded multiply (dB add). CE = 180° phase. Classes A/B/AB/C.
- Op-amp: high gain, resistor-set; offset V (~2 mV), offset I (~20 nA), slew (~0.5 V/µs); $f_{max}=SR/(2\pi V_p)$.
- Inverting $-R_f/R_{in}$; non-inv $1+R_f/R_{in}$; summing $V_o=-R_f \Sigma(V/R)$; virtual ground.
- Oscillator vs amplifier: no input, positive feedback. Barkhausen |Aβ|=1, phase 0/360°. Wien $1/(2\pi RC)$.
- Multivibrators: astable (0 stable, square), monostable (1, one-shot T=1.1RC), bistable (2, flip-flop). 555 astable $f=1.44/((R_1+2R_2)C)$.
- Sensor = input transducer (physical→electrical); active (self-gen) vs passive (R/L/C); conditioned by

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CHAPTER

8

DIGITAL CIRCUITS & MICROPROCESSORS

Logic gates · Combinational & sequential circuits · 8085 · Data acquisition & control

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 4 (Instrumentation & Computer Applications). Chapter 8: digital circuits — sequential and combinational systems; application of microprocessors in data acquisition and control of agricultural engineering processes. Logic gates, the 8085 microprocessor, microcontrollers, PLC/PAC and specific agri-engineering applications are developed in detail.

Chapter Outline

1. **Digital Fundamentals & Logic Gates**
2. **Combinational Circuits**
3. **Sequential Circuits**
4. **Combinational vs Sequential Circuits**
5. **Microprocessors & Microcontrollers**
6. **Data Acquisition & Control Systems**
7. **Microprocessor Programming & Agri-Engineering Applications**
8. **Formula/Fact Sheet · Summary · Last-Night Revision**

1 DIGITAL FUNDAMENTALS & LOGIC GATES

1.1 Analog vs digital signals

Digital signal — *a signal that takes only two discrete levels — HIGH (logic 1) and LOW (logic 0) — as opposed to an analog signal, which varies continuously over a range. Digital electronics processes information coded in these two states (binary).*

▣ ***Analog vs digital signal***

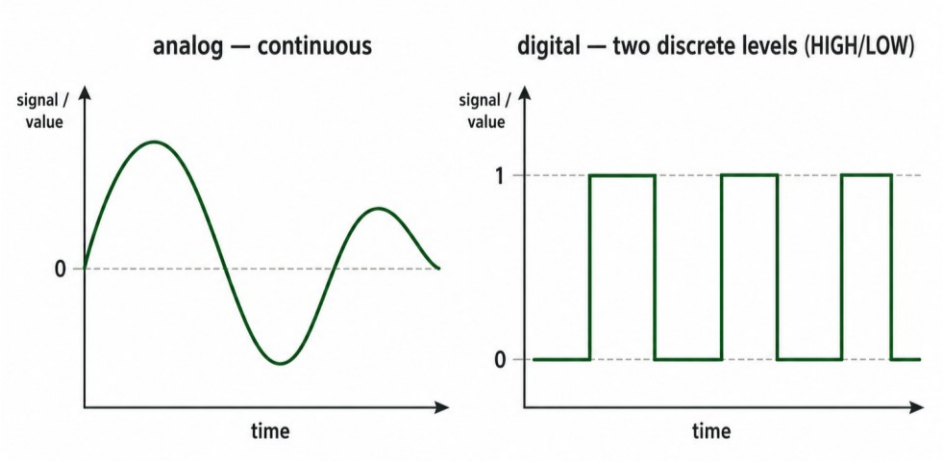


Fig. 8.1 Analog vs digital signal

The two-state nature is the source of digital electronics' great strengths. Because a circuit only has to decide 'is it high or low?', small amounts of noise or drift do not corrupt the information — the signal is regenerated cleanly at every stage — so digital systems are far more ***noise-immune, accurate, repeatable and easy to store and process*** than analog ones. They are also easily built from mass-produced integrated circuits and are programmable. The price is that real-world quantities (temperature, pressure, flow) are analog, so they must be converted to digital form (by an ADC) before a digital system can process them, and often converted back (by a DAC) to drive an analog actuator — the theme of Section 6.

1.2 Number systems and logic levels

Digital systems use the ***binary*** number system (base 2, digits 0 and 1) because the two digits map directly onto the two circuit states. Groups of bits are handled compactly in ***hexadecimal*** (base 16). A single binary digit is a bit; eight bits make a byte. In positive logic, a higher voltage (e.g. +5 V) represents logic 1 and a lower voltage (≈0 V) logic 0.

A few coding ideas recur in agricultural instruments. ***BCD (binary-coded decimal)*** codes each decimal digit as four bits, which is convenient for driving numeric displays; ***ASCII*** codes letters and symbols for keyboards, printers and data transmission. Data are moved and stored in fixed-size words (8, 16, 32 bits); the word length of a processor is one measure of its power. Understanding these representations is needed to see how a sensor reading becomes a number the processor stores and a value the user reads.

◆ **WORKED NUMERICAL — *Number-system conversion (illustrative)*** [demonstrates binary/hex]

Problem. *Convert $(1011)_2$ and $(11010)_2$ to decimal, and 200_{10} to hexadecimal.*

1. **Convert $(1011)_2$ to decimal**

$$(1011)_2$$

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$= 1\times2^3 + 0\times2^2 + 1\times2^1 + 1\times2^0$

$= 8 + 0 + 2 + 1$

$= \mathbf{11}$

Therefore,

$\mathbf{(1011)_2 = (11)_{10}}$

2. Convert $(11010)_2$ to decimal

$(11010)_2$

$= 1\times2^4 + 1\times2^3 + 0\times2^2 + 1\times2^1 + 0\times2^0$

$= 16 + 8 + 0 + 2 + 0$

$= \mathbf{26}$

Therefore,

$\mathbf{(11010)_2 = (26)_{10}}$

3. Convert 200_{10} to hexadecimal

$200 \div 16 = 12$, remainder 8

$12 \div 16 = 0$, remainder 12 $(12 = C)$

Reading the remainders upwards: C 8

Therefore,

$\mathbf{(200)_{10} = (C8)_{16}}$

FINAL ANSWER

$\mathbf{(1011)_2 = (11)_{10}}$

$\mathbf{(11010)_2 = (26)_{10}}$

$\mathbf{(200)_{10} = (C8)_{16}}$

1.3 *Logic gates*

PREVIOUS YEAR QUESTIONS

What are the functions of combinational digital logic gates?

[UK·PSC RFO 2021 | Q.8(ii) | 10M; UK·PSC ACF 2019 | Q.8(ii) | 10M]

***Logic gate** : the basic building block of all digital circuits — an electronic circuit that performs one logical (Boolean) operation on one or more binary inputs to produce a single binary output according to a fixed truth table.*

There are three basic gates — **AND, OR *and* NOT** — and four derived gates — **NAND, NOR, XOR *and* XNOR**. Their functions (what output each produces) are summarised below; the truth table lists the output for every possible input combination.

Gate	*Function / output*
AND	output = 1 only when ALL inputs are 1 (logical product, Y = A·B)
OR	output = 1 when ANY input is 1 (logical sum, Y = A + B)
NOT (inverter)	output is the complement of the input (Y = $\bar{A}$)
NAND	AND followed by NOT — output = 0 only when all inputs 1 (universal gate)
NOR	OR followed by NOT — output = 1 only when all inputs 0 (universal gate)
XOR (exclusive-OR)	output = 1 when inputs are unequal (Y = A⊕B)
XNOR	output = 1 when inputs are equal (equality/comparator)

It helps to picture each gate as a simple decision-maker. The **AND** gate is like two switches in series — the lamp lights only if both are closed; it is used wherever several conditions must all be true at once (an 'enable'). The

OR gate is two switches in parallel — the lamp lights if either is closed; it flags that any one of several conditions is present (an alarm). The **NOT** gate simply reverses a level. The **XOR** gate outputs 1 only when its inputs differ, which makes it the natural element for binary addition (the sum bit) and for comparators and parity checkers. From these, more useful blocks are assembled.

NAND and NOR are called ***universal gates*** because any logic function whatsoever can be built using only NAND gates or only NOR gates — so a manufacturer can make one type of gate in bulk and realise any circuit, an important economy. Gate behaviour is described and simplified using ***Boolean algebra*** — an algebra of the two values 0 and 1 with laws such as A+0=A, A·1=A, A+Ā=1 and the two De Morgan theorems, (A·B)' = A'+B' and (A+B)' = A'·B'. Before a circuit is built, its Boolean expression is minimised (by algebra or a Karnaugh map) so that it uses the fewest gates, which lowers cost, power and delay.

▣ ***Logic gates — symbols and truth tables***

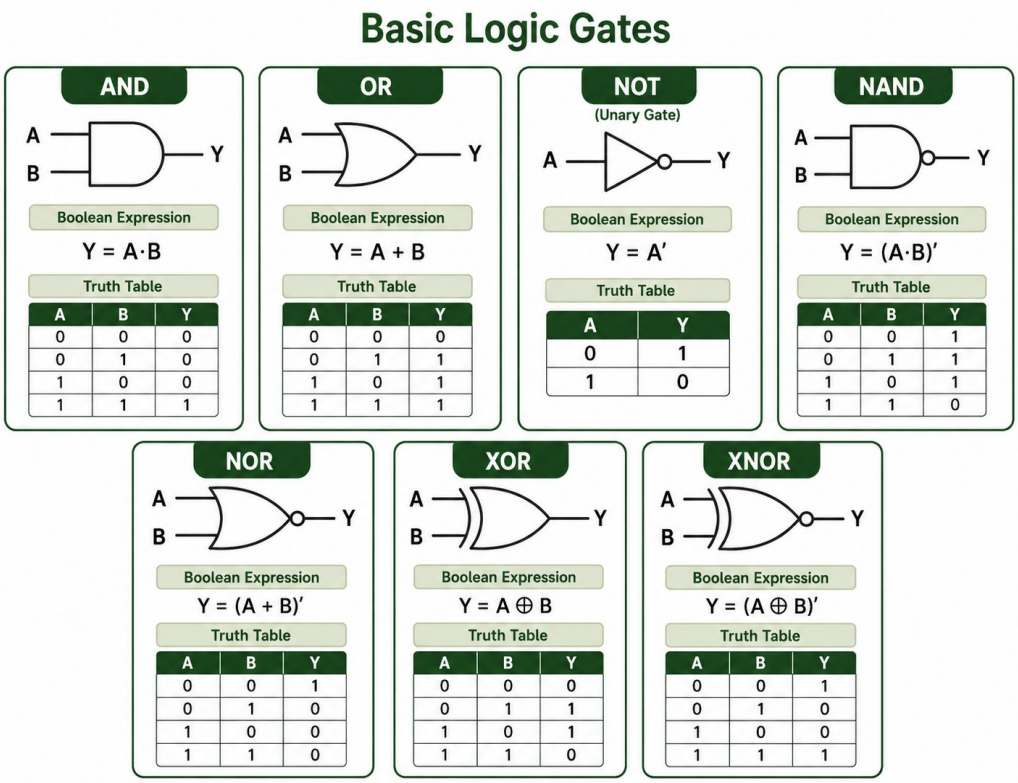


Fig. 8.2 Logic-gate symbols, expressions and truth tables

2 COMBINATIONAL CIRCUITS

2.1 *Definition and characteristics*

Combinational circuit : *a digital circuit whose output at any instant depends only on the present combination of inputs, and not at all on any past input. It has no memory and no feedback — it is built purely from interconnected logic gates.*

Because a combinational circuit has no memory, the same input combination always produces the same output, immediately (after only the gate propagation delay). It is fully described by a truth table or a Boolean expression, and is designed by writing the required output for every input combination, minimising the Boolean expression, and realising it with gates. There is no clock — the output simply follows the inputs.

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2.2 Common combinational circuits

- ***Adders*** : Half-adder (adds two bits → sum and carry) and full-adder (adds three bits incl. carry-in) — the basis of arithmetic in a processor.
- ***Multiplexer (MUX) / Demultiplexer*** : A MUX selects one of several inputs onto a single output line (data selector); a DEMUX routes one input to one of several outputs.
- ***Encoder / Decoder*** : An encoder converts an active input line into a coded output; a decoder converts a code into one active output line (e.g. BCD-to-7-segment for displays).
- ***Comparator*** : Compares two binary numbers and indicates greater/equal/less.

Take the full-adder as a worked illustration of combinational working, since it shows the idea clearly and underlies all computer arithmetic. It has three inputs — the two bits to be added (A, B) and a carry-in (C_in) from the previous stage — and two outputs, the Sum and the Carry-out. The Sum is 1 when an odd number of inputs are 1 (Sum = A ⊕ B ⊕ C_in, two XOR gates), and the Carry-out is 1 when two or more inputs are 1 (Carry = AB + BC_in + AC_in, AND/OR gates). For any given A, B, C_in the outputs are fixed and appear immediately — there is no memory of previous additions. Cascading n full-adders makes an n-bit adder, the arithmetic core of the ALU inside a microprocessor.

These blocks perform arithmetic, data routing, code conversion and selection — the 'processing' part of a digital system — and, crucially, they also feed and read the memory elements of sequential circuits (Section 3), so a real digital system is a partnership of combinational logic (which computes) and sequential elements (which remember).

3 SEQUENTIAL CIRCUITS

3.1 Definition and characteristics

Sequential circuit : *a digital circuit whose output depends on the present inputs AND on the past history of inputs (the stored state). It therefore contains memory elements (flip-flops) and can be regarded as a combinational circuit with feedback from those memory elements.*

The presence of memory is the defining difference. Because a sequential circuit remembers its past, the same present input can give different outputs depending on the stored state — which is exactly what is needed to count, store and sequence operations. Most sequential circuits are ***synchronous***, i.e. all the memory elements change state together at the edges of a common ***clock*** pulse, which keeps the whole system in step; ***asynchronous*** (unclocked) circuits change as soon as an input changes and are faster but harder to design reliably.

3.2 Building blocks — flip-flops, registers, counters

Flip-flop : *the basic 1-bit memory element — a bistable circuit that stores one binary digit until told to change. Types: S-R, J-K (with master-slave), D (data/latch) and T (toggle).*

Flip-flop	*Function*
S-R	Set / Reset; the input combination S=R=1 is forbidden
J-K	like S-R but J=K=1 toggles; master-slave avoids the race problem
D (data)	output follows the D input at the clock edge — a data latch
T (toggle)	T=1 flips the output each clock — used to build counters (÷2)

▣ *Flip-flops and a counter*

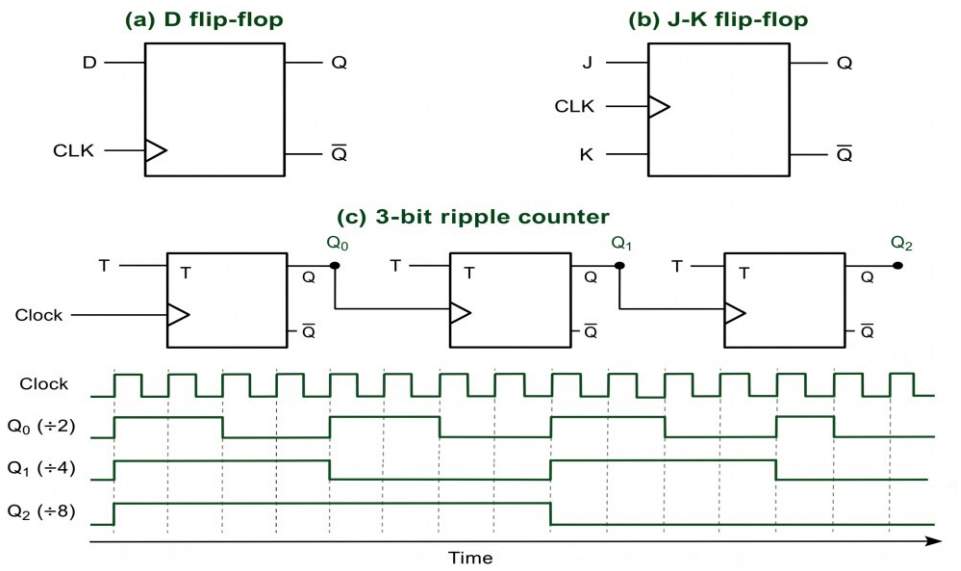


Fig. 8.3 Flip-flops and a ripple counter

- ***Registers*** : A group of flip-flops that stores a multi-bit word; shift registers move data bit-by-bit (serial ↔ parallel conversion, temporary storage).
- ***Counters*** : Cascaded flip-flops that count clock pulses — asynchronous (ripple) or synchronous; used for counting events, frequency division, timing and address generation.

Understand the flip-flop and the clock, because they are the heart of every sequential circuit. A flip-flop has two stable states (0 and 1) and holds whichever it is in until it is told to change — that is the 1-bit memory. In a D flip-flop, for example, whatever is on the D input is captured and stored at the active edge of the clock and then held until the next clock edge. The ***clock*** is a steady train of pulses that acts as the system's heartbeat: by making all the flip-flops update together only at clock edges, it keeps the whole circuit marching in step and avoids race conditions. This is why sequential systems are described by a state table/state diagram (what the next state is, given the present state and input) rather than by a simple truth table.

From these blocks are built registers, counters, memory and the control/sequencing logic of every computer and microprocessor. A register is just several flip-flops loaded together to hold a word; a counter is a chain of flip-flops arranged so that each clock pulse advances a binary count. Sequential circuits are thus what give digital systems the ability to store data and to execute a sequence of operations in time — exactly what a microprocessor does when it steps through a program.

▣ *Sequential circuit — general block diagram*

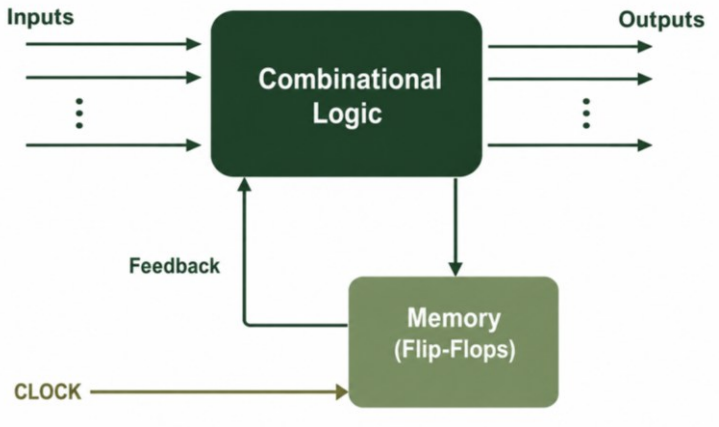


Fig. 8.4 Sequential circuit (combinational logic + memory + feedback)

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4 COMBINATIONAL VS SEQUENTIAL CIRCUITS

PREVIOUS YEAR QUESTIONS

- *Differentiate between the working principles of sequential and combinational systems of digital circuits.* [IFoS 2019 | P2/8(b) | 15M; IFoS 2016 | P2/8(b) | 10M]
- *Differentiate between sequential and combinational circuits with an example.* [OPSC · Forest 2015-16 | P2/7(a) | 20M]
- *Explain the digital circuits of sequential and combinational systems.* [UK·PSC RFO 2012 | Q.8(iv) | 10M]

This differentiation is the single most-repeated digital question in the paper, so it deserves a full, clear treatment. The working principle differs on one fundamental point — memory:

Basis	Combinational circuit	Sequential circuit
Output depends on	present inputs only	present inputs + past state (history)
Memory	none	present (flip-flops)
Feedback	none	present (output fed back)
Clock	not required	usually required (synchronous)
Speed	faster (only gate delay)	slower (clock-paced)
Design tool	truth table / Boolean algebra	state table / state diagram
Examples	adder, MUX, decoder, encoder	flip-flop, register, counter

An example makes the difference vivid. A ***full-adder*** (combinational) always gives the same sum for the same three input bits, no matter what came before — it has no memory. A ***counter*** (sequential) receiving identical clock pulses gives a different output each time (…01, 10, 11, …), because it remembers its previous count. In short: a combinational circuit reacts only to what is present now; a sequential circuit also remembers what happened before — and real digital systems combine both, with combinational logic doing the processing and sequential elements holding the state.

5 MICROPROCESSORS & MICROCONTROLLERS

5.1 What is a microprocessor?

Microprocessor : *a single integrated-circuit chip that contains the central processing unit (CPU) of a computer — it fetches instructions from memory, decodes them and executes them, performing arithmetic, logic, data-transfer and control operations. It is a programmable device: its behaviour is set by the software (program) stored in memory. The Intel 8085 is a classic 8-bit microprocessor.*

A microprocessor by itself is only the CPU; to form a working system it is connected to ***memory*** (ROM for the program, RAM for data) and ***input/output (I/O) ports*** over a set of shared wires called ***buses***. This three-part organisation — CPU + memory + I/O joined by buses — is the foundation on which data-acquisition and control systems (Section 6) are built.

5.2 Architecture of the 8085 microprocessor

The 8085 illustrates the internal architecture of any microprocessor. Its main functional units are:

- ***Arithmetic & Logic Unit (ALU)*** : Performs arithmetic (add, subtract) and logic (AND, OR, XOR, compare) operations on 8-bit data.
- ***Accumulator (A)*** : The primary 8-bit register that holds one operand and receives the ALU result.

- ***General-purpose registers*** : B, C, D, E, H and L (six 8-bit registers, usable in pairs) for temporary data storage; the H-L pair often points to memory.
- ***Program Counter (PC) & Stack Pointer (SP)*** : The 16-bit PC holds the address of the next instruction; the SP points to the stack in memory.
- ***Flag register*** : Status flags (sign, zero, carry, parity, auxiliary carry) that record the result of operations and guide decisions/branching.
- ***Instruction register & decoder, timing & control unit*** : Fetch and interpret each instruction and generate the control signals that run the whole system.
- ***Buses*** : The 16-bit address bus selects a memory/I-O location, the 8-bit (multiplexed) data bus carries the data, and the control bus carries read/write and timing signals.

It is essential to understand ***how the microprocessor actually runs a program***, because this is what 'data acquisition and control' really rests on. The processor repeats a simple three-step cycle over and over: ***fetch → decode → execute***. In the fetch step the program counter puts the address of the next instruction on the address bus; the memory returns that instruction on the data bus into the instruction register, and the PC increments. In the decode step the instruction decoder works out what the instruction means. In the execute step the timing-and-control unit issues the control signals that carry it out — moving data between registers, doing an ALU operation, or reading a byte from an input port. The 16-bit address bus can select any of 2^{16} = 65 536 (64 K) locations, and the 8-bit data bus moves one byte at a time. By stepping through instructions like this millions of times a second, the processor reads sensors, computes and drives outputs — the very actions needed to acquire data and control a process.

▣ 8085 microprocessor — architecture

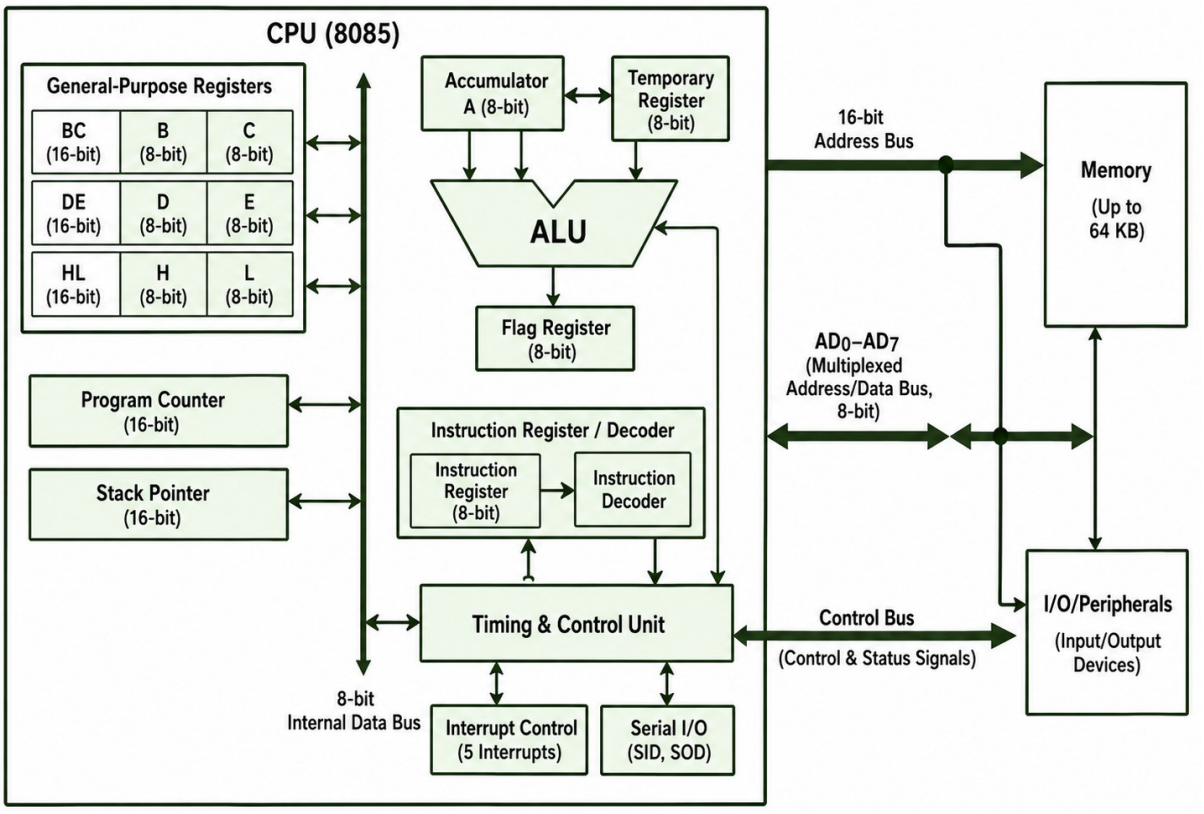


Fig. 8.5 8085 microprocessor architecture (CPU, registers, buses)

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5.3 Microcontroller, and microprocessor vs microcontroller

PREVIOUS YEAR QUESTIONS

- Write in brief: Micro-controlle. [HP·PSC RFO 2021 | Q.8(c) | 10M]

Microcontroller : *a single chip that integrates a CPU together with memory (ROM + RAM), I/O ports, timers/counters, and often ADC and communication interfaces — a complete small computer ('computer on a chip'). A microprocessor, by contrast, is only the CPU and needs external memory and I/O.*

Feature	Microprocessor	Microcontroller
Contents	CPU only	CPU + memory + I/O + timers (+ADC) on one chip
External chips	needs memory & I/O	self-contained
Use	general-purpose computing	dedicated embedded control
Cost / size / power	higher (system)	low, compact, low-power
Example	8085, 8086	8051, AVR, PIC, Arduino

For embedded agricultural instruments — a data logger in a field, a controller in a dryer or a greenhouse — the microcontroller is usually preferred because it is compact, cheap, low-power and self-contained, whereas a microprocessor suits larger general-purpose computing.

A little more on microcontrollers helps, since they now dominate agricultural instrumentation. Because the CPU, program memory (ROM/flash), data memory (RAM), I/O ports, timers/counters and often an on-chip ADC and serial interfaces all sit on ***one chip***, a complete measurement-and-control node can be built with very few external parts, drawing little power (important for battery/solar field devices). Popular families are the 8051, PIC, AVR and ARM; boards such as the Arduino and Raspberry Pi have made them ubiquitous. A single low-cost microcontroller can read several sensors through its ADC, run the control algorithm, log to on-chip or SD memory, and communicate over GSM/LoRa/Wi-Fi — the basis of modern precision agriculture, automatic weather stations and smart irrigation.

6 DATA ACQUISITION & CONTROL SYSTEMS

6.1 What is data acquisition?

PREVIOUS YEAR QUESTIONS

- *State how microprocessors can be utilised in acquisition of data and can subsequently be used in agricultural engineering.* [IFoS 2019 | P2/5(d) | 8M]
- *How are microprocessors used in data acquisition and control of Agricultural Engineering processes?* [IFoS 2016 | P2/8(a) | 10M]

Data acquisition system (DAS) : *a system that senses one or more physical quantities, converts them into digital form and collects (acquires) them into a microprocessor/computer for display, storage, analysis or control. When the processor also drives outputs to regulate the process, it becomes a data acquisition and control system.*

6.2 The microprocessor-based measurement & control chain

A microprocessor-based data-acquisition and control system works as a chain, and understanding each link answers the whole cluster of PYQs on this theme:

- ***Sensor / transducer*** : Converts the physical quantity (temperature, flow, force, pressure, moisture) into an electrical signal (thermocouple, strain gauge, flow meter, load cell).
- ***Signal conditioning*** : Amplifies, filters and linearises the small/noisy sensor signal (the amplifiers, op-amps and filters of Chapter 7) to a level suitable for conversion.
- ***Multiplexer*** : If several sensors are used, an analog MUX time-shares one converter among many channels.
- ***Analog-to-Digital Converter (ADC)*** : Converts the conditioned analog voltage into a digital number the microprocessor can read; its resolution (bits) sets the smallest change it can detect. Common types are flash (fastest, most hardware), successive-approximation (SAR — the usual choice, good speed-cost balance) and dual-slope (slow but very accurate and noise-rejecting, used in digital meters).
- ***Microprocessor*** : Reads the digital data, stores/logs it, performs calculations (scaling, averaging, comparison with set-points) and makes control decisions under program control.
- ***DAC + actuator / output*** : For control, the processor outputs a command through a Digital-to-Analog Converter (DAC) and driver to an actuator (valve, heater, motor, relay); results are also sent to a display, printer or memory.

So the flow is: ***physical quantity → sensor → signal conditioning → (MUX) → ADC → microprocessor → (DAC) → actuator / display / storage***. The processor closes the loop: it compares the measured value with the desired set-point and adjusts the actuator to keep the process on target — real-time, automatic control.

Two links deserve a closer look. The **ADC** is the bridge between the analog world and the digital processor: it samples the conditioned voltage at regular intervals and converts each sample into an n-bit number. Its resolution — the smallest change it can distinguish — is the full-scale range divided by 2^n, so more bits give finer measurement (see the worked example). The sampling must be fast enough to follow the signal. The other key idea is ***control***. In open-loop control the processor simply drives the actuator to a preset value; in closed-loop (feedback) control — the powerful case — it continuously measures the actual output, computes the error against the set-point, and adjusts the actuator (often by a proportional-integral-derivative, PID, algorithm) to drive the error to zero. Because the control law lives in software, the same hardware can run different strategies simply by changing the program, and can supervise many loops at once — for instance holding a dryer's temperature, a greenhouse's humidity and an irrigation flow simultaneously.

▣ ***Microprocessor-based data acquisition & control system***

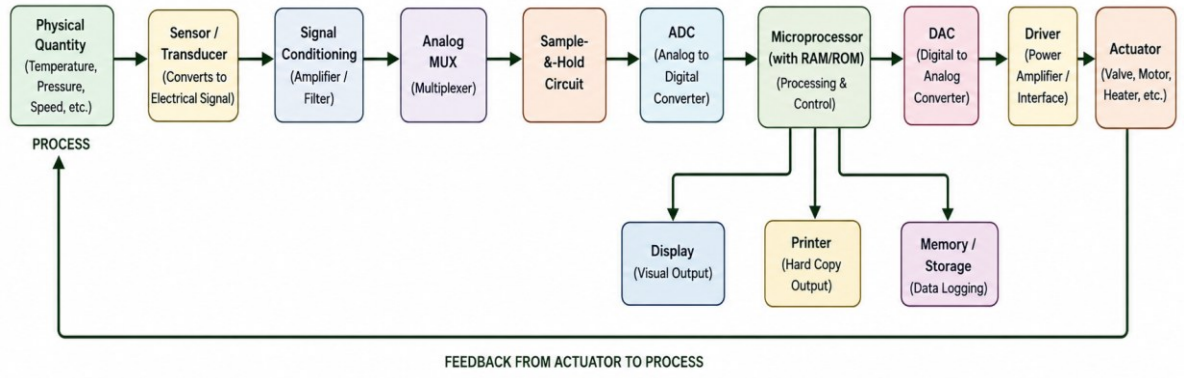


Fig. 8.6 Microprocessor-based data-acquisition & control system

6.3 *Why microprocessors are used — advantages*

Microprocessor-based acquisition and control brings decisive advantages over manual or hard-wired analog methods: high speed and accuracy; the ability to handle many channels and large volumes of data; automatic

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logging, storage and computation; real-time, unattended control with set-points and alarms; programmability and flexibility (behavior changed in software, not by rewiring); remote and networked operation; and low cost and reliability. These make it ideal for agricultural engineering processes.

◆ **WORKED NUMERICAL — ADC *resolution (illustrative)*** [demonstrates DAS quantisation]

Problem. *An 8-bit ADC digitises a 0–5 V sensor output. Find the number of levels and the resolution (smallest detectable change).*

Given:

ADC resolution = 8-bit

Input voltage range = 0–5 V

1. NUMBER OF LEVELS

For an n-bit ADC,

Number of levels = 2^n

For n = 8,

Number of levels = 2^8

Number of levels = 256

Therefore,

Number of levels = 256

2. RESOLUTION / SMALLEST DETECTABLE CHANGE

Resolution is given by:

Resolution = Full-scale voltage range / Number of levels

Resolution = 5 V / 256

Resolution = 0.01953 V

Resolution = 19.53 mV

Therefore,

Resolution ≈ 19.53 mV per step

FINAL ANSWER

Number of levels = 256

Resolution (smallest detectable change) ≈ 19.53 mV per step

7 MICROPROCESSOR PROGRAMMING & AGRI-ENGINEERING APPLICATIONS

7.1 *Programming and development steps*

PREVIOUS YEAR QUESTIONS

- *How is microprocessor programming applied in Agricultural Engineering, and what are the key steps involved, from selecting hardware to testing and documentation?* [OPSC·CSE 2023-24| P2/18(a) | 20M]
- *Write programming of microprocessors and data acquisition and control of agricultural engineering processes.* [OPSC·CSE 2017-18| P2/6(b) | 20M]

Developing a microprocessor-based agricultural instrument follows an orderly sequence, from hardware selection to documentation:

1. ***Define the problem & specifications*** : What to measure/control, ranges, accuracy, number of channels, response time, environment.

2. ***Select the hardware*** : Choose the microprocessor/microcontroller, sensors, signal-conditioning, ADC/DAC, memory and I/O to meet the specification.
3. ***Develop the algorithm & flowchart*** : Work out the logical sequence of steps (read sensor → scale → compare with set-point → act) and draw it as a flowchart.
4. ***Write the program*** : Code the algorithm in assembly (or C), using the instruction set to read the ADC, process data and drive outputs.
5. ***Assemble/compile & load*** : Translate the source program into machine code (assembler/compiler) and load it into memory.
6. ***Test, debug & calibrate*** : Run with known inputs, correct errors, and calibrate readings against standards.
7. ***Document*** : Record the circuit, program listing, flowchart, calibration and user instructions for maintenance and future modification.

Two development ideas underpin the coding steps. An ***algorithm*** is a finite, ordered list of unambiguous steps that solves the problem (e.g. 'read ADC; if temperature > set-point, switch heater off; else on; wait; repeat'); a ***flowchart*** is its diagram, using standard symbols (oval = start/stop, parallelogram = input/output, rectangle = process, diamond = decision) joined by arrows. The program is first written in human-readable ***assembly language*** (mnemonics like MOV, ADD, IN, OUT) or C, and then ***translated*** into the binary machine code the processor actually executes by an assembler or compiler. Careful testing, calibration against known standards, and full documentation make the instrument reliable and maintainable — which is why the examiner lists them as explicit steps.

The programming itself rests on the 8085 instruction set and its addressing modes. The 74 instructions fall into five groups — data transfer (MOV, MVI, LDA, STA, IN, OUT), arithmetic (ADD, ADI, SUB, INR, DCR), logical (ANA, ORA, XRA, CMP), branching (JMP, JZ, JC, CALL, RET) and machine control (HLT, NOP, EI, DI). An instruction names its operand in one of five addressing modes: immediate (MVI A, 32H), direct (LDA 2050H), register (MOV A, B), register-indirect (MOV A, M, addressed through the H-L pair) and implied (CMA, RLC). Each instruction is one, two or three bytes long and takes a fixed number of clock cycles, which is how the programmer budgets response time and writes calibrated delay loops for a chosen sampling interval.

◆ **SAMPLE 8085 PROGRAM** — *on/off temperature control (illustrative) [demonstrates §7.1 steps 3–4]*

```
        MVI  A, 00H     ; initialise
        OUT  02H        ; heater off at start
LOOP:   IN   01H        ; read digitised temperature from ADC at input port 01H
        MOV  B, A       ; save the sensor reading in B
        MVI  A, 80H     ; load the stored set-point into A
        CMP  B          ; compare set-point with reading (carry set if reading > set-point)
        JC   OFF        ; reading above set-point → switch heater off
        MVI  A, 01H     ; else heater ON
        OUT  02H        ; write command to control port 02H
        CALL DELAY      ; wait one sampling interval
        JMP  LOOP       ; repeat continuously
OFF:    MVI  A, 00H     ; heater OFF
        OUT  02H
        CALL DELAY
        JMP  LOOP
```

The loop is the whole of on/off closed-loop control in a dozen instructions: read the sensor, compare with the set-point, drive the output, wait, repeat. The DELAY subroutine sets the sampling interval, and replacing the

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single comparison with a proportional or PID calculation converts the same hardware to continuous control – the flexibility that makes software-based control attractive.

7.2 *Applications in agricultural engineering*

PREVIOUS YEAR QUESTIONS

- *Explain the application of microprocessor for measurement of force.* [UK·PSC RFO 2021| Q.8(ii) | 10M; UK·PSC ACF 2019| Q.8(ii) | 10M]
- *Explain the application of microprocessor in the measurement of flow-rate and temperature.* [UK·PSC RFO 2012| Q.8(iv) | 10M]
- *Explain a microprocessor-based operation to study some engineering properties of a food product.* [OPSC· CSE 2020-21| P2/8(a) | 20M; OPSC· CSE 2015-16| P2/6(c) | 20M]
- *Short note: application of microprocessors in data acquisition in deep forests.* [UK·PSC RFO 2015| Q.8(ii) | 10M]

- ***Force measurement*** : A load cell/strain gauge (in a Wheatstone bridge) senses force; the small bridge output is amplified, digitised by the ADC and read by the microprocessor, which scales it to force units and displays/logs it — used in tensile testers, weighing and draft measurement of implements.

  Force measurement makes a good detailed example of the whole chain in action. The primary sensor is a ***strain gauge*** bonded to an elastic element (a load cell): when force deforms the element, the gauge's length — and hence its electrical resistance — changes very slightly. To turn this tiny resistance change into a voltage, four gauges are connected in a ***Wheatstone bridge***, which produces an output voltage proportional to the applied force but only a few millivolts in size. This weak signal is boosted by an ***instrumentation amplifier*** then fed to the **ADC**, which converts it to a digital number. The ***microprocessor*** reads that number, multiplies it by a stored calibration factor to give the force in newtons or kilograms, and displays, records or transmits it — and, if the force must be controlled, compares it with a set-point and drives an actuator. The same architecture, with only the sensor changed, measures pressure, weight, torque or draft.

- ***Flow-rate & temperature*** : A flow sensor (turbine/electromagnetic/orifice-with-DP) and a thermocouple/RTD feed the ADC; the processor computes flow rate and temperature, logs them and can control a pump or heater — used in irrigation, dairies and dryers.

  Flow-rate and temperature are measured on the same chain, differing only in the sensor and the software scaling. For temperature, a ***thermocouple*** gives a few millivolts of Seebeck emf (needing cold-junction compensation) while an **RTD** or thermistor gives a resistance change read through a bridge; the signal is amplified, digitised, and the processor applies a stored calibration equation to display °C. For flow, a turbine or paddle-wheel sensor gives a ***pulse train*** whose frequency is proportional to flow — the processor simply counts pulses on a timer/counter input, so no ADC is needed, and totalises them to give volume delivered. An electromagnetic meter or an orifice plate with a differential-pressure transmitter instead gives an analog voltage; for the orifice, flow varies as the square root of the pressure drop, so the processor performs the ***square-root extraction*** in software. Having both values, it can log them, raise alarms and close the loop — throttling a pump to hold irrigation discharge, or switching a burner to hold a grain dryer's plenum temperature.

- ***Engineering properties of food*** : A microprocessor-based rig applies a known load/temperature/moisture and records the response (force–deformation for texture/hardness, thermal or electrical response), computing properties such as firmness, specific heat or moisture rapidly and repeatably.

A microprocessor-based rig measures engineering properties of a food product by applying a controlled input and sampling the response fast enough to capture the entire curve, which manual reading cannot do. For mechanical/textural properties, a motorised probe compresses or shears the sample while a ***load cell*** senses force and an LVDT or shaft encoder senses deformation; the processor samples both channels simultaneously through the ADC and builds the ***force–deformation curve***, from which it computes hardness (peak force), stiffness (initial slope), rupture point and toughness (area under the curve) — the basis of ***texture-profile analysis*** of fruits, grains and processed foods. For thermal properties, a line heat source or guarded hot plate heats the sample while thermocouples are logged against time, and the processor fits the temperature-rise data to obtain ***thermal conductivity***, specific heat and diffusivity. Moisture content is obtained from a capacitance or resistance probe with a stored calibration, and colour from a photodiode-based colorimeter. Because the acquisition, computation, storage and printing of results are all under program control, the measurement is rapid, repeatable and operator-independent, and a large number of samples can be tested to a fixed protocol.

- ***Remote / deep-forest data acquisition*** : A low-power microcontroller data-logger with sensors records temperature, humidity, rainfall, soil moisture etc. at unattended remote/forest sites, storing data and transmitting it (GSM/radio/satellite) — enabling monitoring where no operator can be present.

▣ *Microprocessor-based force measurement*

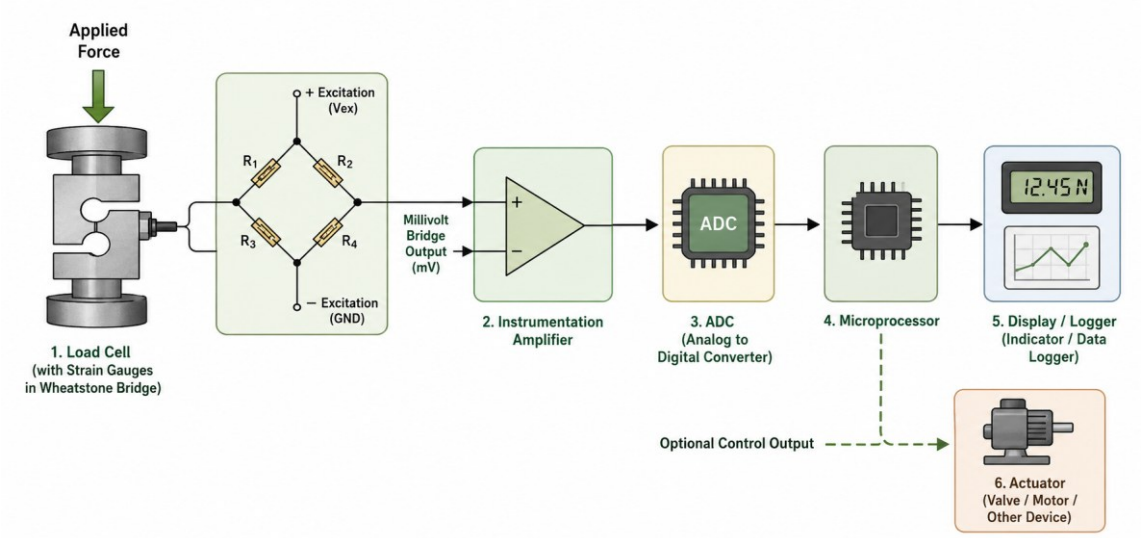


Fig. 8.7 Microprocessor-based force (load-cell) measurement

The deep-forest / remote application is worth expanding, as it is directly asked. In inaccessible sites there is no operator to take readings, so a self-contained, battery- or solar-powered microcontroller data-logger is installed with the required sensors (temperature, humidity, rainfall, soil moisture, water level). It wakes at set intervals, reads each sensor through its ADC, time-stamps and stores the data in non-volatile memory, and either stores it for later collection or transmits it over GSM/radio/satellite to a central station. Low power consumption, rugged weatherproof packaging and reliable unattended operation are the key design requirements — letting scientists monitor remote forest and catchment conditions continuously.

Across all of these the microprocessor replaces manual reading with fast, accurate, automatic measurement, logging and control — improving precision, saving labour and enabling unattended and remote operation in agricultural and forestry processes.

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7.3 PLC and PAC; microprocessor in industrial control

PREVIOUS YEAR QUESTIONS

Differentiate: Programmable Logic Controller and Programmable Automation Controller.

[HP·PSC RFO 2021 | Q.8(c) | 10M]

PLC (Programmable Logic Controller) : *a ruggedised industrial computer built around a microprocessor, designed to control machinery and processes by reading sensor inputs and driving outputs according to a stored program (usually ladder logic). It is robust, easy to program and reliable in harsh environments.*

PAC (Programmable Automation Controller) : *a more powerful, modern controller that combines PLC ruggedness with PC-like capability — handling complex logic, analog and motion control, advanced maths and data handling, multiple programming languages and better networking, over a common software platform.*

Feature	PLC	PAC
Task	discrete logic / on-off control	complex, mixed logic + analog + motion + data
Programming	mainly ladder logic	multiple languages, unified platform
Processing / memory	modest	high (PC-class)
Networking / data	basic	advanced (databases, enterprise integration)
Use	simple machine control	complex, integrated automation

8 FORMULA/FACT SHEET · SUMMARY · LAST-NIGHT REVISION

Fact Sheet

Combinational: output = f(present inputs) — no memory ; Sequential: output = f(inputs, past state) — has memory

Universal gates: NAND, NOR (any function realisable) ; De Morgan: $(A \cdot B)' = A' + B'$; $(A + B)' = A' \cdot B'$

ADC levels = 2^n ; resolution = full-scale voltage / 2^n (n = number of bits)

DAS chain: sensor → signal conditioning → (MUX) → ADC → microprocessor → (DAC) → actuator/display/storage

8085: 8-bit data bus, 16-bit address bus (64 KB), accumulator + B,C,D,E,H,L registers, 5 flags

Microprocessor = CPU only ; Microcontroller = CPU + memory + I/O + timers (+ADC) on one chip

Number systems: $(1011)_2 = 11_{10}$; $200_{10} = C8_{16}$; BCD = 4 bits per decimal digit

8085 addressing modes: immediate, direct, register, register-indirect, implied

Summary

Digital circuits work with two-state (binary) signals, giving noise-immunity, accuracy and easy storage/processing; logic gates (AND, OR, NOT and the derived NAND, NOR, XOR, XNOR — with NAND/NOR universal) are the building blocks. A combinational circuit (adder, MUX, decoder) has no memory — its output depends only on present inputs; a sequential circuit (flip-flop, counter, register) has memory and feedback, so

its output depends on present inputs and past state, usually paced by a clock — the key differentiation. A microprocessor is the CPU on a chip (the 8085: ALU, accumulator, B-C-D-E-H-L registers, PC/SP, flags, timing-control, and 8-bit data / 16-bit address buses), which with external memory and I/O forms a system; a microcontroller integrates CPU, memory, I/O and timers on one chip for embedded control. In data acquisition and control, the microprocessor sits at the centre of the chain sensor → signal conditioning → ADC → microprocessor → DAC → actuator, reading physical quantities (force via load cell, flow, temperature, food properties), logging them and controlling the process in real time — used in field data-loggers, dryers, irrigation and remote/forest monitoring. Development runs from problem definition and hardware selection through algorithm/flowchart, coding, assembly, testing/calibration to documentation. PLCs (ladder-logic industrial controllers) and the more powerful PACs extend this to rugged factory/farm automation.

Last-Night Revision

- Digital = two states (0/1) → noise-immune, accurate, storable, programmable.
- Gates: AND (all-1), OR (any-1), NOT (invert), NAND/NOR (universal), XOR (unequal), XNOR (equal).
- Combinational = present inputs only, NO memory (adder, MUX, decoder). Sequential = inputs + past state, HAS memory + feedback + clock (flip-flop, counter, register).
- Example: full-adder (combinational) same output for same inputs; counter (sequential) different output each pulse.
- Microprocessor = CPU on a chip (8085: ALU, accumulator, registers, PC/SP, flags; 8-bit data, 16-bit address). Microcontroller = CPU+memory+I/O+timers on one chip (embedded).
- DAS chain: sensor → signal conditioning → ADC → microprocessor → DAC → actuator/display. ADC resolution = FS/2^n.
- Applications: force (load cell), flow & temperature, food properties, remote/forest data logging — fast, accurate, automatic, unattended.
- Programming steps: problem → hardware → algorithm/flowchart → code → assemble → test/calibrate → document.
- 8085 instruction set: 74 instructions in 5 groups (data transfer, arithmetic, logical, branch, machine control); 5 addressing modes (immediate, direct, register, register-indirect, implied).
- PLC = rugged ladder-logic controller; PAC = PLC + PC-class power (complex logic, analog, motion, networking).

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CHAPTER

9

MEASUREMENT SYSTEMS IN AGRICULTURAL ENGINEERING

Instrument characteristics · Transducers · Temperature · Strain, force & torque · Flow · Pressure

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 4 (Instrumentation & Computer Applications). Chapter 9: measurement systems for level, flow, strain, force, torque, power, pressure, vacuum and temperature; transducers, sensors and their characteristics; the generalized measurement system, instrument characteristics and errors.

Chapter Outline

1. **The Generalized Measurement System & Types of Instruments**
2. **Characteristics of Instruments & Errors**
3. **Transducers & Sensors**
4. **Temperature Measurement**
5. **Strain, Force & Torque Measurement**
6. **Flow Measurement**
7. **Pressure & Vacuum Measurement**
8. **Level, Speed, Vibration & Electrical Measurement**
9. **Fact Sheet · Summary · Last-Night Revision**

1 THE GENERALIZED MEASUREMENT SYSTEM & TYPES OF INSTRUMENTS

1.1 Measurement in agricultural engineering

Measurement : *the process of determining the magnitude of an unknown quantity by comparing it with a known standard of the same kind. In agricultural engineering, measurement of temperature, pressure, flow, force, strain, torque, power and level underpins process monitoring, automatic control, machinery testing, research and quality assurance.*

1.2 The generalized measurement system and its functional elements

PREVIOUS YEAR QUESTIONS

- *Draw a figure of generalized measurement system and write about its functional elements.*
  [IFOS 2021 | P2/7(c) | 15M]
- *Explain the generalized/basic measuring instrumentation system with a block diagram.*
  [OPSC·CSE 2017-18 | P2/6(a) | 20M; HP·PSC 2021 | Q.8 (a) | 10M]

Whatever the quantity being measured, a measurement system can be described by a chain of functional elements — defined by what they do, not how they are built:

1. ***Primary sensing element*** : First contacts the quantity (the measurand) and detects it — a sensor/transducer that converts the physical quantity into an analogous (usually electrical) signal (thermocouple, strain gauge, Bourdon tube).
2. ***Variable conversion element*** : Converts the sensor output into a more convenient form while preserving the information (mechanical displacement → voltage, or an ADC). Some systems need none, others several.
3. ***Variable manipulation element*** : Changes the magnitude/level of the signal without changing its nature (an amplifier raising a millivolt signal to a usable level).
4. ***Data transmission element*** : Carries the signal from one element to another (leads, links, telemetry) when they are physically separated.
5. ***Data presentation element*** : Communicates the result by indicating, recording or displaying it (pointer-and-scale, chart recorder, digital display) or storing it.
6. **Control (feedback) element** : present only in closed-loop systems: it compares the measured value with the desired value and issues a corrective signal to a controller and final control element (valve, heater, drive) so the deviation is reduced. Adding it converts the open-loop measuring chain into a closed-loop measurement-and-control system, as in a thermostatically controlled grain dryer or a pasteuriser holding-temperature loop.

Signal conditioning : *the combined operations of conversion, manipulation and transmission (amplification, filtering, linearisation, A/D conversion) that make the raw sensor signal suitable for presentation or for a data-acquisition system.*

Example (Bourdon pressure gauge): the Bourdon tube is the primary sensing element (pressure → tip movement); the gear-and-linkage is the conversion/manipulation element (movement → pointer rotation); the calibrated dial-and-pointer is the data-presentation element.

Methods of measurement. Whatever the system, the measurand is obtained in one of three ways:

- **Direct method** : The quantity is compared straight against a standard of the same kind and the result read at once (measuring length with a steel tape, mass on a beam balance). Simple, but limited in accuracy by human judgement.

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- **Indirect method** : The quantity is inferred from a measured related quantity through a known relation (discharge from the pressure drop across an orifice plate, torque from the strain in a shaft). Most engineering instruments work this way.
- **Comparison / null method** : The unknown is balanced against a known adjustable standard until the detector reads zero, and the unknown is then equal to the standard (Wheatstone bridge, potentiometer, null-balance recorder). Since the detector need only sense zero, this method is the most accurate — the deflection method, by contrast, relies on the detector's own calibration.

▣ *Generalized measurement system*

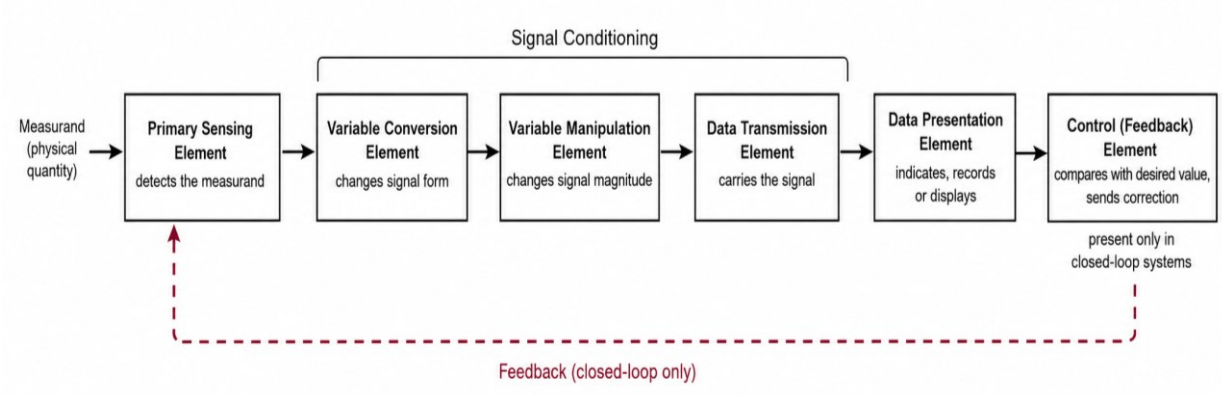


Fig. 9.1Generalized measurement system — functional elements

1.3 *Classification of instruments*

PREVIOUS YEAR QUESTIONS

- *Explain the classification of analog instruments: (i) Indicating (ii) Recording.* [IFOS 2022 | p2/5(d) | 8M]
- *What do you mean by absolute and secondary instruments?* [OPSC·CSE 2015-16 | p2/7(c) | 20M]

Basis	*Types*
Standard needed	Absolute (magnitude via physical constants, e.g. tangent galvanometer) vs Secondary (direct-reading, calibrated)
Signal	Analog (continuous) vs Digital (discrete numeric)
Output function	Indicating (instantaneous value) · Recording (continuous chart record) · Integrating (totalises over time, e.g. energy meter)
Operation	Deflection type vs Null (balance) type — null more accurate

Instruments are first classed by whether they need a standard to be read. The distinction is one of calibration: an absolute instrument needs none, a secondary instrument is useless without it.

- **Absolute (primary) instruments** : Give the magnitude of the measurand in terms of the instrument's own physical constants and dimensions, through a deduced relation, without any comparison with another instrument. No calibration and no graduated scale are required; the reading is computed. In a tangent galvanometer the current follows $I = (2rH_e/\mu_0 N)\cdot\tan\theta$, so it is obtained from the coil radius r, number of turns N, the horizontal component of the earth's field H_e and the observed deflection θ. Other examples: Rayleigh current balance, Kelvin's absolute electrometer, mercury column manometer, dead-weight pressure tester. They are elaborate, slow, need a skilled observer and controlled conditions, so their use is

confined to standards and calibration laboratories, where they establish or verify the standards themselves.

- **Secondary instruments** : The deflection of the moving system is read off directly on a scale that has already been graduated by calibrating the instrument against an absolute instrument or a certified standard. The value is obtained by inspection, with no computation. They are simple, quick, portable and suited to routine field and laboratory work, but their accuracy rests entirely on the calibration held: if calibration drifts or is lost the readings are meaningless, so periodic re-calibration is essential. Examples: PMMC and moving-iron ammeters and voltmeters, Bourdon pressure gauge, thermocouple and RTD thermometers, rotameter, platform weighing scale, grain-moisture meter. Almost every instrument used in agricultural engineering practice is of this type.

  The two are therefore complementary rather than competing: absolute instruments define the unit, secondary instruments apply it. Calibration of a secondary instrument must trace back through an unbroken chain of comparisons to an absolute instrument or a national standard, which is what makes its reading defensible. Secondary instruments are further classed by output function as indicating, recording or integrating types.

  Analog instruments give a continuous output that varies smoothly with the measurand. On the basis of the function performed by the data-presentation element they are grouped as indicating, recording and integrating types.

i. **Indicating instruments** : Show the instantaneous value of the measurand by a pointer moving over a calibrated scale (or a light-spot on a scale). Three torques must act: a deflecting torque produced by the measurand which moves the moving system; a controlling torque (spring or gravity) which opposes deflection so the pointer rests where the two balance, giving a deflection proportional to the input and returning the pointer to zero on removal; and a damping torque (air-friction, fluid-friction or eddy-current) which absorbs oscillation energy so the pointer settles quickly without hunting. Examples: PMMC and moving-iron ammeters and voltmeters, Bourdon pressure gauge, dial thermometer, rotameter, spring balance. They keep no record — the reading must be observed at the moment it occurs.

ii. **Recording instruments** : Produce a continuous written record of the measurand against time. The deflecting system carries a pen or stylus that writes on a chart driven at constant speed by a clock or synchronous motor, so pen displacement gives magnitude and chart travel gives the time base. Strip-chart recorders (single- or multi-channel, ink-pen, thermal or electric-stylus writing) are the common form; circular-chart recorders give a 24-hour or 7-day record; X–Y recorders plot one variable against another instead of against time. Because the moving system must carry the pen against paper friction its inertia is higher, so recorders respond more slowly and are less accurate than the corresponding indicating instrument. Used wherever a quantity must be monitored unattended over long periods — cold-store and grain-dryer temperature and humidity, pasteuriser holding temperature, drying-air flow.

iii. **Integrating instruments** : Totalise the measurand over time rather than showing its value, the reading being the product of the quantity and time (energy meter, water meter, fuel totaliser).

In short: an indicating instrument answers what the value is now, a recording instrument preserves how it varied, and an integrating instrument gives how much accumulated. Recorders are preferred for process monitoring and fault diagnosis because trends and transients are retained; indicators are preferred for quick, accurate spot readings.

1.4 *Instrumentation systems in food processing; analog DAS*

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PREVIOUS YEAR QUESTIONS

- *Write the types of instrumentation systems used in food processing. Explain the elements of an analog data-acquisition system.* [IFOS 2020 | p2/5(e) | 8M]

Instrumentation systems in food processing are classed as indicating, recording and controlling systems; analog vs digital; and open-loop vs closed-loop (feedback control). An analog data-acquisition system comprises: transducers (sense the quantities) → signal conditioners (amplify/filter) → analog multiplexer (time-shares channels) → display/recording devices → transmission links.

2 CHARACTERISTICS OF INSTRUMENTS & ERRORS

An instrument's performance is described by its static characteristics (steady/slowly-varying inputs) and dynamic characteristics (rapidly-varying inputs).

2.1 *Static characteristics*

PREVIOUS YEAR QUESTIONS

- *Explain five important static characteristic parameters of a simplified measuring system.* [IFOS 2017 | p2/7(d) | 10M]
- *Write short note on precision, resolution and threshold of an instrument.* [IFOS 2024 | p2/6(c) | 8M]
- *Define precision, accuracy and drift with examples.* [IFOS 2017 | p2/8(a) | 10M; OPSC-CSE 2022-23 | Q.11(a) | 5M]

Accuracy & Precision : *Accuracy — the closeness of a measured value to the true value (stated as ± % of full scale). Precision — the closeness of repeated measurements to one another (reproducibility), regardless of nearness to the true value.*

MODEL Q Accuracy vs precision: if a rifle's shots cluster tightly but off the bullseye it is precise but not accurate; if they scatter around the bullseye, accurate but not precise. True value vs accuracy: the true value is the actual magnitude; accuracy is how close the reading comes to it.***

Accuracy : The closeness of a reading to the true value, always quoted as a tolerance: ± % of full-scale deflection (FSD), ± % of the true reading, or ± % of span. The basis matters. A 0–100 °C thermometer specified as ±1 % FSD may be in error by ±1 °C anywhere on the scale, so at a reading of 10 °C the error is 10 % of the reading; an instrument quoted on FSD must therefore be chosen so that the expected reading falls in the upper two-thirds of its range. Related terms: static error = measured value − true value, and static correction = − static error, the quantity added to a reading to obtain the true value.

Precision : The closeness of repeated readings taken under unchanged conditions, expressed as ± a value or as the standard deviation of the repeats. Repeatability refers to short-term agreement with the same observer and conditions; reproducibility to agreement over long periods or across observers and conditions. Precision is necessary but not sufficient for accuracy: a platform scale reading 12.20, 12.21, 12.20 kg against a 12.00 kg standard is precise to ±0.01 kg yet inaccurate by +0.20 kg. That bias is a systematic error and is removed by calibration, whereas scatter is random error and is reduced only by averaging repeated readings.

- ***Sensitivity*** : Ratio of change in output to change in input (slope of the calibration curve). the ratio of change in output to change in input, S = Δy/Δx, i.e. the slope of the calibration curve; its units are output units per input unit (a K-type thermocouple gives about 41 µV/°C, a load cell 2 mV/V at full load). Its reciprocal, 1/S, is the deflection factor or scale factor. For a linear instrument S is a constant; for a non-

linear one it varies along the scale and must be quoted at a stated operating point. High sensitivity is not automatically desirable — it narrows the usable range and amplifies noise and drift along with the signal.

- ***Resolution and Threshold*** : The minimum input needed to produce a detectable output, starting from zero. Resolution is the smallest change in input that produces a discernible change in output at any point in the range, stated as an absolute value or as a percentage of full scale. In a digital instrument it is one count of the least significant digit, so a 3½-digit meter on a 0–200 °C range resolves 0.1 °C; in an analog instrument it is taken as about half the smallest scale division. Threshold is the same idea measured from zero — the minimum input needed before the instrument gives any detectable output — and arises from friction, stiction and backlash in the moving system. Both limit precision rather than accuracy.
- ***Linearity, hysteresis, dead zone*** : Closeness of calibration to a straight line; different readings for increasing vs decreasing input; the input range giving no output.

  linearity is the maximum deviation of the calibration curve from the best-fit straight line, quoted as ± % of full scale; a linear instrument is preferred because output is proportional to input and needs no correction chart. Hysteresis is the difference in output for the same input depending on whether the input is being increased or decreased, produced by internal friction and elastic or magnetic lag; it is quoted as the maximum such difference as a percentage of full scale and appears as a closed loop when the instrument is cycled up and down its range. Dead zone (dead band) is the range of input over which the output does not change at all — stiction in a Bourdon gauge linkage is a common cause — and dead time is the delay between application of the input and the start of any response.
- ***Drift, span, readability*** : Gradual change of output with time at constant input (temperature/ageing); span = max − min of range; readability = ease of reading the scale.

  Drift — a gradual change in output with time although the input is held constant, caused by ageing of components, ambient temperature change or supply variation. Zero drift shifts the whole scale by a constant amount (a strain-gauge bridge whose zero wanders as the specimen warms); sensitivity or span drift changes the slope of the calibration curve; zonal drift affects only part of the scale. It is countered by temperature compensation, a stabilised supply, warm-up before use and periodic re-calibration.

Pair	Distinction
Accuracy vs Precision	closeness to true value vs closeness of repeats
True value vs Accuracy	actual magnitude vs closeness of reading to it
Readability vs Span	ease of reading the scale vs the full measurable range
Resolution vs Threshold	smallest detectable change anywhere vs from zero

2.2 *Errors in measurement*

PREVIOUS YEAR QUESTIONS

What are the types of error? [OPSC·CSE 2015-16 | p2/7(c) | 20M]

Error = measured value − true value (absolute error); relative error = absolute error/true value. Types: (1) Gross errors — human mistakes (misreading, wrong recording); (2) Systematic errors — consistent bias from the instrument (instrumental), surroundings (environmental) or observer (observational, e.g. parallax); (3) Random (residual) errors — small unpredictable scatter, treated statistically. Systematic errors reduce accuracy; random errors reduce precision.

2.3 *Dynamic characteristics*

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PREVIOUS YEAR QUESTIONS

Differentiate: Static and Dynamic characteristics; Response time and Rise time.
[HP·PSC 2021 | Q8(b) | 10M]

For rapidly-changing inputs the instrument cannot follow instantly; its dynamic characteristics describe the response: speed of response, measuring lag (delay), dynamic error and fidelity. Response (measuring) time — time for the output to reach and stay within a small band of its final value after a step input. Rise time — time for the output to rise from 10 % to 90 % of its final value (initial speed). Also settling time, overshoot and bandwidth.

Static vs dynamic characteristics : Static characteristics apply when the input is constant or changes so slowly that time plays no part; they are obtained by static calibration, holding the input steady at successive values against a standard and noting the output. Dynamic characteristics apply when the input changes rapidly, and are obtained by applying a known test input — step, ramp or sinusoidal — and recording the output against time. Static parameters are accuracy, precision, sensitivity, resolution, threshold, linearity, hysteresis, dead zone and drift; dynamic parameters are speed of response, measuring lag, dynamic error, fidelity, rise time, settling time, overshoot and bandwidth. The difference is physical, not merely definitional: dynamic behaviour arises from the inertia, damping and stiffness (or thermal and fluid capacitance) of the moving system, which store and release energy and so make the output lag the input. An instrument may be excellent statically and poor dynamically — a mercury-in-glass thermometer is accurate for a steady bath temperature yet useless for tracking a fast temperature transient.

Response time vs rise time : Both are measured from the same step-input response curve, but over different parts of it. Response (measuring) time is the total time taken for the output to reach and thereafter remain within a specified narrow band, usually ±2 % or ±5 %, of its final steady value; it therefore includes any overshoot and settling and describes the instrument's overall speed. Rise time is the time for the output to climb from 10 % to 90 % of its final value; it looks only at the initial rapid climb and says nothing about settling, so it measures the steepness of response. For a first-order instrument of time constant τ the output reaches 63.2 % of its final value in one τ, giving rise time $\approx 2.2\,\tau$ and response time $\approx 4\,\tau$ for a ±2 % band — hence a small τ means a fast instrument. Rise time is always the smaller of the two, and in an underdamped instrument a short rise time can coexist with a long response time because of prolonged oscillation.

2.4 *Response of a first-order instrument (derivation)*

PREVIOUS YEAR QUESTIONS

Derive an expression for the output of a first-order instrument. [IFOS 2017 | P2/7(d) | 10M]

Governing equation: $\tau\,(dy/dt) + y = K\cdot x$

y = output; x = input; K = static sensitivity; τ = time constant.

Step response ($x = x_0$): $y(t) = K\cdot x_0\,(1 - e^{(-t/\tau)})$

For a step input the output rises exponentially toward its final value $K\cdot x_0$; after one time constant $t = \tau$ it reaches 63.2 %, and after ~4–5 τ it is essentially complete. A small time constant τ means a fast instrument.

Physical origin of the first-order equation : Any instrument having a single energy-storage element and a single dissipative element behaves as a first-order system. Take a mercury-in-glass thermometer plunged into a bath at temperature T_e. Heat entering the bulb by convection in time dt equals the heat stored by the mercury: $hA(T_e - T)\,dt = mc\,dT$, where h is the film coefficient, A the bulb surface area, m the mass and c the specific heat. Rearranging, $(mc/hA)(dT/dt) + T = T_e$, which is the standard form $\tau\,(dy/dt) + y = K\cdot x$ with $y = T$, $x = T_e$, static

sensitivity K = 1 and time constant τ = mc/hA seconds. The electrical analogue is an RC low-pass circuit, RC $(dv_o/dt) + v_o = v_i$, for which τ = RC; a bare thermocouple, a mercury thermometer, a first-order pressure transducer and a single-tank level system all reduce to the same equation.

Solution for a step input :

1. Input jumps from zero to a constant x_o at t = 0; instrument initially at rest, so y = 0 at t = 0.
2. Governing equation: $\tau (dy/dt) + y = Kx_o$, i.e. $\tau (dy/dt) = Kx_o - y$.
3. Separate the variables: $dy/(Kx_o - y) = dt/\tau$.
4. Integrate both sides: $-\ln(Kx_o - y) = t/\tau + C$.
5. Apply the initial condition y = 0 at t = 0: $C = -\ln(Kx_o)$, so $\ln[(Kx_o - y)/Kx_o] = -t/\tau$.
6. Response: $y(t) = Kx_o (1 - e^{-t/\tau})$.
7. Alternative route: complementary function $y^c = A\, e^{-t/\tau}$ plus particular integral $y^p = Kx_o$, with A fixed by the initial condition.
8. Steady output: $y^{\infty} = Kx_o$.
9. Measurement lag (dynamic error): $e(t) = y^{\infty} - y = Kx_o\, e^{-t/\tau}$, which decays exponentially and never becomes exactly zero.

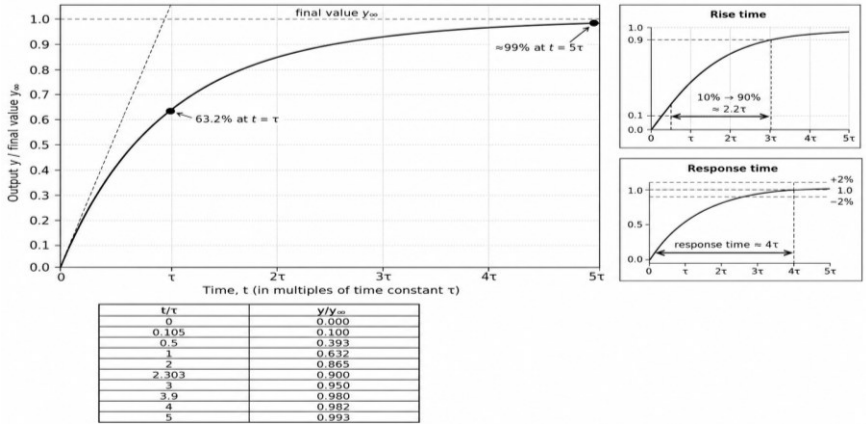
Meaning of the time constant : Putting t = τ gives $y/y^{\infty} = 1 - e^{(-1)} = 0.632$, so τ is the time to complete 63.2 % of the change, whatever the size of the step. Differentiating at the origin, $(dy/dt)_{t=o} = Kx_o/\tau$, so if the instrument continued at its initial rate it would reach the final value in exactly τ — τ is the subtangent of the response curve at t = 0. Successive values are: t = τ ⟶ 63.2 %, 2τ ⟶ 86.5 %, 3τ ⟶ 95.0 %, 4τ ⟶ 98.2 %, 5τ ⟶ 99.3 %. Hence rise time (10 % to 90 %) = (2.303 − 0.105)τ ≈ 2.2 τ, and response time to settle within a ±2 % band ≈ 3.9 τ ≈ 4 τ. A small τ means a fast instrument, and since τ = mc/hA for the thermometer it is reduced by a smaller bulb (**less mc)** or by stirring the fluid (larger h).

Response to a ramp input : For an input rising at a constant rate, x = Rt, the solution of $\tau (dy/dt) + y = KRt$ with y = 0 at t = 0 is $y(t) = KR(t - \tau) + KR\tau\, e^{(-t/\tau)}$. Once the transient term has died away the output becomes $y \approx KR(t - \tau)$: the instrument tracks the ramp correctly in slope but permanently behind it, lagging the true value by a time τ and reading low by a steady-state dynamic error of KRτ. The error is therefore proportional both to the rate of change of the measurand and to the time constant, which is why a slow thermometer under-reads a steadily rising temperature.

Response to a sinusoidal input : For $x = x_o \sin \omega t$ the steady-state output is $y = [Kx_o/\sqrt{(1 + (\omega\tau)^2)}] \sin(\omega t - \phi)$ with $\phi = \tan^{-1}(\omega\tau)$. The amplitude ratio falls and the phase lag grows as frequency rises, so faithful reproduction (good fidelity) requires $\omega\tau \ll 1$; the frequency at which the amplitude ratio falls to $1/\sqrt{2}$ of its static value, $\omega = 1/\tau$, is the bandwidth of the instrument.

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First-order step response



t/τ	y/y∞
0	0.000
0.105	0.100
0.5	0.393
1	0.632
2	0.865
2.303	0.900
3	0.950
3.9	0.980
4	0.982
5	0.993

Fig. 9.2 First-order instrument step response

ss

2.5 Analog vs digital signals; noise

PREVIOUS YEAR QUESTIONS

- *Differentiate: Analog signal and Digital signal.* [IFOS 2023 | P2/5(d) | 8M: IFOS 2016 | P2/5(a) | 8M]
- *Write in brief: Noise.* [HP·PSC | Q.8(c) | 10M]

Feature	Analog signal	Digital signal
Nature	varies continuously	discrete levels (0,1)
Values	infinite	two states
Noise	more prone	noise-immune
Example	thermocouple emf	counter output
Reading	read by interpolating between scale divisions; parallax and observer judgement enter	direct numeric readout; no interpolation or parallax error
Accuracy & resolution	limited by the scale and the observer, typically ±0.5–1 % of full scale	set by the word length of the converter — a 12-bit ADC resolves 1 part in 4096, i.e. 0.024 %
Transmission	attenuates and picks up interference with cable length, so error grows with distance	can be regenerated and re-clocked, so long-distance and telemetry links are effectively lossless
Drift & ageing	zero and span drift with temperature and component ageing	the number is unaffected once converted; only the analog front end can drift
Processing & storage	needs analog conditioning; record kept on a chart	fed straight to a computer or PLC; stored, averaged and logged in memory
Hardware	bridge, amplifier, filter, pointer or chart recorder	sample-and-hold, ADC, microprocessor, digital display
Cost & power	simple, cheap, low power consumption	more components and higher power, though cost is falling

Noise : *any unwanted signal superimposed on the wanted measurement signal (thermal agitation, electromagnetic interference, ground loops, vibration) that reduces accuracy and resolution.*

Minimised by shielding, grounding, filtering, twisted/differential wiring and high-CMRR amplifiers; the signal-to-noise ratio (SNR) measures signal quality.

Conversion, sampling and quantisation : Every primary transducer is inherently analog, since the physical quantity it senses varies continuously; a digital instrument is therefore an analog front end (transducer, amplifier, filter) followed by a sample-and-hold circuit and an analog-to-digital converter. The ADC samples the signal at a fixed rate and assigns each sample to the nearest of 2^n levels, n being the word length, so two errors are introduced that have no analog counterpart. Quantisation error is the rounding to the nearest level, at most half a level or ±½ LSB, which fixes the resolution: 0.024 % of span for 12 bits. Aliasing occurs if the sampling rate is too low — by the sampling (Nyquist) theorem the rate must exceed twice the highest frequency present in the signal, failing which a high-frequency component is recorded as a spurious low-frequency one. A low-pass anti-aliasing filter ahead of the ADC prevents it. A DAC performs the reverse conversion where an analog output is needed to drive a valve or recorder.

Classification of noise : Internal (inherent) noise is generated within the instrument itself and cannot be eliminated, only minimised: thermal or Johnson noise from the random motion of charge carriers in every resistance (proportional to $\sqrt{}$(resistance $\times$ bandwidth × absolute temperature)), shot noise in semiconductor junctions and flicker noise at low frequencies. Together these set the noise floor and hence the smallest signal an instrument can usefully resolve. External noise, better called interference, is coupled in from the surroundings: 50 Hz mains hum, capacitive (electrostatic) and inductive (electromagnetic) pick-up from nearby cables and motors, radio-frequency interference, switching transients, ground loops between earth points at different potentials, and triboelectric or vibration-induced signals in cables. Interference is avoidable by wiring practice and layout, which is why the two classes are treated separately.

Signal-to-noise ratio : SNR is the ratio of signal power to noise power, expressed in decibels as $10 \log_{10}(P_s/P_n)$ or, in terms of voltages, $20 \log_{10}(V_s/V_n)$; the larger the value the cleaner the measurement. It matters most where the transducer output is small: a strain-gauge bridge delivers only a few millivolts, comparable with the interference picked up along a long cable run, so the amplifier must be placed at the transducer rather than at the far end of the cable. Note also the difference in remedy — random noise is reduced by narrowing the bandwidth, filtering or averaging repeated readings (averaging n readings improves SNR by $\sqrt{}$n), whereas deterministic interference is best eliminated at source by shielding, single-point earthing, twisted-pair or coaxial cable, differential measurement with a high common-mode rejection ratio, and physical separation from power circuits.

3 TRANSDUCERS & SENSORS

3.1 *Sensor and transducer*

PREVIOUS YEAR QUESTIONS

- *What is the basic difference between sensors and transducers?* [IFOS 2019 | P2/8(a) | 15M]
- *What is a transducer? Distinguish between active and passive transducers.* [OPSC·Forest 2019-20 | Q.7(a) | 20M; OPSC·CSE 2018-19 | Q.8(b) | 20M]

Sensor & transducer : *a sensor detects/responds to the physical quantity (measurand) and gives a related output — it is the sensing element. A transducer converts one form of energy into another; in measurement it converts the physical quantity into an electrical quantity (sensor + conversion). The*

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terms are often used interchangeably.

Structure and examples : a transducer consists of a sensing element that responds to the measurand and a transduction element that converts that response into an electrical output, so the sensor is one part of the transducer. A bare thermocouple junction or a strain gauge is a sensor; the same thermocouple with cold-junction compensation and an amplifier, or that gauge bonded into a load cell, is a transducer. A sensor's output need not be electrical — a bimetallic strip gives a mechanical deflection — whereas an instrumentation transducer almost always gives an electrical output, because it is easily amplified, transmitted, recorded and fed to a computer, and draws little energy from the measurand. Related terms: an inverse transducer or actuator works the other way, converting an electrical signal into physical action (solenoid valve, control-valve positioner); a transmitter is a transducer with built-in conditioning that delivers a standard 4–20 mA or 0–10 V signal to a control room.

3.2 *Classification of transducers*

Active vs passive transducers : *Active (self-generating) transducers produce their own output emf/current without external power (thermocouple, piezoelectric, photovoltaic/solar cell, tacho-generator). Passive transducers need external excitation and vary a parameter — resistance, inductance or capacitance (strain gauge, RTD, thermistor — R; LVDT — L; capacitive — C).*

Feature	*Active transducer*	*Passive transducer*
Power	self-generating (none needed)	needs external excitation
Output	emf / current	change in R, L or C
Energy source	output energy comes from the measurand itself	output energy comes from the excitation supply; the measurand only modulates it
Signal level	usually very small and fixed by the material (a K-type thermocouple gives ≈41 µV/°C), so amplification is essential	level can be raised by increasing the excitation voltage, so a usable output is easier to obtain
Circuit needed	amplifier, plus cold-junction or charge-amplifier arrangements	bridge, potentiometer or oscillator circuit to convert the R, L or C change into a voltage
Loading effect	draws energy from the measurand, so it can disturb what it measures	draws energy from the supply, so loading of the measurand is negligible
Stability	no supply to drift, but output depends on material properties and temperature	zero and span drift with any variation in excitation voltage, so a stabilised supply is needed
Examples	thermocouple, piezoelectric, solar cell, tacho-generator	strain gauge, RTD, thermistor, LVDT, capacitive

Transducers are also classified by principle (resistive, inductive, capacitive, thermoelectric, piezoelectric, photoelectric), by output (analog/digital), as primary vs secondary, and by the quantity measured.

Bases of classification — by principle of transduction: resistive (strain gauge, RTD, thermistor, potentiometer), inductive (LVDT, variable-reluctance), capacitive (grain-moisture and level probes), thermoelectric (thermocouple), piezoelectric (accelerometer, dynamic force), photoelectric (photodiode, LDR) and magnetostrictive. By primary or secondary function: a primary transducer receives the measurand directly and converts it into a mechanical signal (a Bourdon tube deflecting under pressure), while a secondary transducer converts that mechanical signal into an electrical one (an LVDT reading the tube's tip movement) — the two in series form the complete transducer. By nature of output: analog transducers give a continuous output

(potentiometer, thermocouple, LVDT), whereas digital transducers give a pulse train or coded output that needs no ADC (shaft encoder, turbine flowmeter, opto-interrupter grain counter). By quantity measured: displacement, force, torque, pressure, flow, temperature, moisture and level transducers.

3.3 *Requirements of a good transducer*

PREVIOUS YEAR QUESTIONS

- *What is a transducer? Classify and explain the basic requirements of a transducer.*
  [OPSC·Forest 2015-16 | P2/8(c) | 20M]

A good transducer should have high accuracy, good linearity and high sensitivity; fast dynamic response with low lag; minimum hysteresis and drift; good repeatability and stability; low noise and no loading effect (it should not disturb the quantity measured); a wide operating range; ruggedness and environmental resistance; and be small, reliable and low-cost.

Performance requirements : Accuracy and repeatability decide whether the reading can be trusted at all, and both must hold over the whole operating range, not merely at the calibration point. Linearity is wanted because output then bears a constant ratio to input, so the scale is uniform and no correction chart is needed; a thermistor is very sensitive but strongly non-linear, which is why an RTD is preferred where the reading is used directly. High sensitivity gives a large output for a small input and so eases amplification, but it must not be bought at the cost of a narrow range or amplified noise. Resolution and threshold must be finer than the smallest change of interest.

Dynamic requirements : The transducer must follow a changing measurand, so a small time constant, low measuring lag and good fidelity are needed; a heavy sheathed thermocouple cannot record the temperature transient inside a grain dryer. Minimum hysteresis and dead zone ensure the same reading whether the input is rising or falling, and low drift ensures the calibration holds through the working day.

Environmental and loading requirements : There should be no loading effect: the transducer must draw negligible energy from the measurand, since a large probe cools the sample it measures and a low-impedance voltmeter alters the circuit it reads. It must also be insensitive to interfering inputs such as ambient temperature, humidity and supply variation, or be compensated for them. Ruggedness usually decides the choice in agricultural service — sealing against dust, washdown water, ammonia in poultry sheds, and resistance to vibration and shock on a tractor or harvester matter more than laboratory-grade accuracy.

Practical requirements : Small size and low mass (which also improve dynamic response), an electrical output of convenient level for transmission and computer interfacing, stability of calibration so that re-calibration is infrequent, freedom from noise pick-up, good overload capacity, long life with low maintenance, ready availability of spares, and low cost. A transducer that meets every technical requirement but cannot be afforded or serviced in the field is of no practical use.

3.4 *Signal conditioning*

PREVIOUS YEAR QUESTIONS

- *Write the working principle of: Signal conditioning.* [IFOS 2017 | P2/6(b)(iv) | 10M]

Signal conditioning : *processing applied to a transducer's raw output to make it suitable for display, recording or data acquisition: amplification (raise weak mV/µV signals), filtering (remove noise),*

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linearisation, level shifting, impedance matching/isolation and A/D conversion — using the amplifiers, op-amps and filters of Chapter 7.

3.5 Common transducer principles

PREVIOUS YEAR QUESTIONS

- *Working principle of: Piezoelectric transducer, Semiconductor resistance sensor, Solar cell, Vibration meter.* [IFOS 2017 | P2/6(b) | 10M; IFOS 2025 | P2/6(c) | 8M]

- ***Piezoelectric transducer*** : Certain crystals (quartz, barium titanate) generate a charge/voltage proportional to applied mechanical stress (and vice-versa). Active; for dynamic pressure, force, acceleration and vibration. (Input: force/pressure; output: charge/voltage.)
- ***Semiconductor resistance sensors*** : Semiconductor resistance changes markedly with temperature (thermistor), light (LDR) or strain (semiconductor strain gauge); high sensitivity but non-linear.
- ***Solar cell (photovoltaic)*** : Converts light directly into an emf; an active photoelectric transducer. (Input: light; output: voltage.)
- ***Vibration meter*** : Measures amplitude/velocity/acceleration and frequency of vibration, usually with a seismic/piezoelectric accelerometer; for machinery condition monitoring.

3.6 Sensors in precision agriculture

PREVIOUS YEAR QUESTIONS

- *What sensors and transducers are used in agricultural instrumentation and how do they contribute to precision agriculture (soil, weather, crops)?* [OPSC·CSE 2023-24 | P2/18(b) | 20M; OPSC·CSE 2017-18 | P2/5(d) | 20M]
- *Explain the applications of primary sensors and transducers in agricultural processing.* [OPSC·CSE 2017-18 | P2/5(d) | 20M]

- ***Soil*** : Moisture (capacitance/TDR), temperature, pH, electrical conductivity (salinity/nutrients), and N-P-K nutrient sensors.
- ***Weather*** : Temperature, humidity, rainfall (tipping-bucket), wind speed (anemometer), solar-radiation (pyranometer) sensors in automatic weather stations.
- ***Crop*** : Canopy, NDVI/multispectral and chlorophyll sensors for crop vigour; yield-monitor sensors on harvesters.

Combined with GPS and GIS these feed variable-rate application, yield mapping and decision-support systems, so water, seed, fertiliser and pesticide are applied only where and in the amount needed — saving inputs, raising yield and reducing environmental impact.

How they work : capacitance and TDR probes read the dielectric constant of soil, which rises with water content; electrical conductivity indicates salinity and texture; NDVI is computed from the ratio of near-infrared to red reflectance, high in vigorous canopy; a pyranometer uses a thermopile under a glass dome; yield monitors use a load cell or impact plate with a moisture sensor to correct to standard moisture.

How they contribute : the sensors close a loop: sense → geo-reference by GPS → map in GIS → prepare a prescription map → apply variably → verify by yield map. Readings reach the controller through dataloggers or IoT nodes on LoRa or GSM links, with drone and satellite imagery adding a remote-sensing tier above the

ground sensors. Outputs drive variable-rate controllers, section control on planters and sprayers, auto-steer guidance and draft-depth control. Typical uses: soil-moisture-triggered drip irrigation, evapotranspiration-based scheduling from an automatic weather station, NDVI-guided nitrogen top-dressing, and grain-moisture sensors modulating dryer burners — each cutting input use while protecting yield.

3.7 Instruments for common measurements

PREVIOUS YEAR QUESTIONS

- *Name the measuring instruments for current, voltage, power, pressure, temperature, humidity, strain, force, torque and energy.* [OPSC·CSE 2017-18 | P2/8(c) | 20M]

Quantity	Instrument	Quantity	Instrument
Current	Ammeter	Temperature	Thermocouple/RTD/thermistor
Voltage	Voltmeter	Humidity	Hygrometer/psychrometer
Power	Wattmeter	Strain	Strain gauge
Energy	Energy meter	Force	Load cell
Pressure	Bourdon/manometer	Torque	Dynamometer/torque meter
Flow	Venturi/rotameter	Level	Float/capacitive gauge

4 TEMPERATURE MEASUREMENT

4.1 Methods of temperature measurement

PREVIOUS YEAR QUESTIONS

- *Explain the different instruments/sensors used for measurement of temperature.* [IFOS 2023 | P2/8(a) | 10M; MH·PSC 2024 | Q.7(b) |15M; OPSC· CSE 2016-17 |Q.8(b) | 20M; OPSC·Forest 2015-16 | Q.7(b) | 20M]

Temperature is measured by a temperature-dependent property: expansion (liquid-in-glass, bimetallic, filled-system); electrical resistance (RTD, thermistor); thermoelectric (thermocouple); radiation (pyrometer, non-contact); and semiconductor (IC/transistor sensors). Grouped as contact vs non-contact.

4.2 The thermocouple

PREVIOUS YEAR QUESTIONS

- *Principle of operation of thermocouple. Draw the common forms of construction and explain.* [IFOS 2022 | P2/8(a) | 15M]
- *What is Seebeck effect? Explain Seebeck, Peltier and Thomson effects; how applied in a thermocouple; types.* [IFOS 2018 | P2/6(c) | 15M; IFOS 2019 | P2/8(c) | M; OPSC·CSE 2024-25 | Q.11 | 15M; OPSC·Forest 2023-24 | Q.7(a) | 20M]

Seebeck effect : *when two dissimilar metals are joined to form a closed circuit with the two junctions at different temperatures, a net thermo-emf is generated and current flows; the emf is approximately proportional to the temperature difference — the working principle of the thermocouple.*

$$\text{Thermo-emf } E \approx \alpha \cdot (T_1 - T_2)$$

α = Seebeck coefficient (μV/°C); T_1, T_2 = hot & cold junction temperatures.

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- ***Peltier effect*** : The reverse: passing current through a junction of two dissimilar metals absorbs or liberates heat at the junction (reversible) — the basis of thermoelectric cooling.
- ***Thomson effect*** : An emf/heat effect along a single conductor carrying current with a temperature gradient.

Laws of thermocouples : *(1) Law of intermediate metals — a third metal does not change the emf if its two junctions are at the same temperature (lets us connect meters/copper leads). (2) Law of intermediate temperatures — $emf(T_1,T_3) = emf(T_1,T_2) + emf(T_2,T_3)$, the basis of cold-junction compensation.*

Construction & common forms: two thermocouple wires welded/beaded at the measuring (hot) junction, with a reference (cold) junction at a known temperature; the junction may be exposed (fast), grounded or ungrounded in a protective sheath/thermowell with mineral insulation; cold-junction compensation corrects for the reference temperature.

Type	Materials	Range / use
K	Chromel–Alumel	−200 to 1260 °C, general
J	Iron–Constantan	up to 760 °C
T	Copper–Constantan	low temperature
E	Chromel–Constantan	high sensitivity
R/S/B	Platinum–Rhodium	up to ~1700 °C, high temperature

Thermopile : *a number of thermocouples connected in series so their emfs add, giving a larger, more sensitive output; used in radiation pyrometers and low-level radiant-heat detection.*

▣ *Thermocouple — circuit, forms and emf curves*

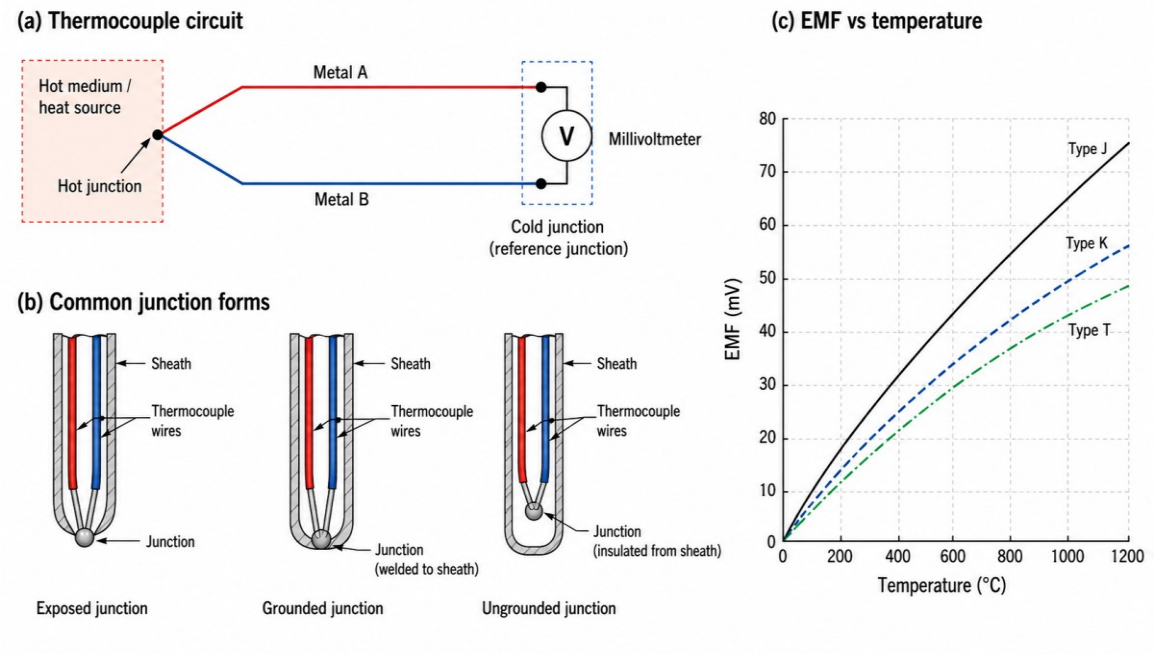


Fig. 9.3 Thermocouple circuit, construction forms and emf curves

Thermocouples are self-powered (active), rugged, cheap, fast and wide-range — hence they dominate industrial and agricultural temperature measurement.

4.3 Resistance thermometer (RTD)

PREVIOUS YEAR QUESTIONS

- *Principle of operation of resistance thermometer.* [IFOS 2024 | P2/5(d)(iv) | 8M]

$$R_t = R_0 (1 + \alpha \cdot t)$$

metal resistance rises nearly linearly with temperature; Platinum (Pt-100) is the standard, –200 to 850 °C.

The RTD is a passive transducer (needs excitation), very accurate, stable and repeatable, measured in a Wheatstone bridge. (Input: temperature; output: resistance.)

4.4 Thermistor

$$R_T = R_0 \cdot \exp[\beta(1/T - 1/T_0)]$$

a semiconductor whose resistance falls steeply with temperature (NTC); very sensitive but non-linear.

◆ **WORKED NUMERICAL — Thermistor temperature** [IFoS 2021 · P2/8(c) · 10M]

Problem. *β = 3140 K; R_0 = 1050 Ω at 27 °C; measured resistance = 2330 Ω. Find the temperature.*

Given:

$\beta = 3140$ K

$R_0 = 1050$ Ω at 27°C

$R = 2330$ Ω

For an NTC thermistor, the β-equation is:

$$\mathbf{1/T = 1/T_0 + (1/\beta)\ln(R/R_0)}$$

Where,

$$T_0 = 27 + 273.15 = 300.15 \text{ K}$$

Substituting the values:

$$1/T = 1/300.15 + (1/3140)\ln(2330/1050)$$

$$1/T = 0.0033317 + (1/3140) \times 0.7977$$

$$1/T = 0.0035857$$

Therefore,

$$T = 278.9 \text{ K}$$

Converting Kelvin into degree Celsius:

$$T = 278.9 - 273.15$$

$$\mathbf{T \approx 5.75°C}$$

Answer: The temperature is approximately 5.8°C.

Check. resistance rose (1050→2330 Ω); for an NTC thermistor higher R means lower T, so a result below 27 °C is consistent.

4.5 Pyrometer

PREVIOUS YEAR QUESTIONS

- *Working principle of: Pyrometer.* [IFOS 2017 | P2/6(b)(ii) | 10M]

A pyrometer measures high temperatures without contact, from the thermal radiation emitted by a hot body. Total-radiation pyrometer — focuses radiation onto a thermopile (output $\propto T^4$, Stefan–Boltzmann). Optical (disappearing-filament) pyrometer — matches the brightness of a heated filament to the target and reads temperature from the filament current. Ideal for furnaces, kilns and molten metal.

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4.6 Comparison of temperature sensors

PREVIOUS YEAR QUESTIONS

Compare RTD, transistors and thermocouples for temperature measurement.

[OPSC·CSE 2022-23 | P2/11(c) | 5M]

Feature	Thermocouple	RTD (Pt)	Thermistor
Range	widest (−200→1700 °C)	−200→850 °C	limited
Linearity	fair	good	poor
Sensitivity	low	medium	high
Self-powered	yes	no	no
Cost / use	low, wide	high, precision	low, sensitive/narrow

4.7 Worked numericals

◆ **WORKED NUMERICAL — *Seebeck emf*** [IFoS 2019 · P2/8(c) · 10M]

Problem. *Find the Seebeck emf (mV) for a material with α = 60 μV/°C if the junction temperatures are 30 °C and 100 °C.*

Solution:

The Seebeck emf is given by:

$$\mathbf{E = \alpha \times \Delta T}$$

Where:

$\alpha = 60\ \mu V/°C$

$T_1 = 30\ °C$

$T_2 = 100\ °C$

Temperature difference:

$$\mathbf{\Delta T = T_2 - T_1}$$

$\Delta T = 100 - 30 = 70\ °C$

Therefore,

$E = 60 \times 70\ \mu V$

$E = 4200\ \mu V$

Since,

$1000\ \mu V = 1\ mV$

Therefore,

$E = 4.2\ mV$

Answer: Seebeck emf = 4.2 mV

◆ **WORKED NUMERICAL — *Initial steam to heat cream*** [IFoS 2023 · P2/8(a)(ii) · 5M]

Problem. *Estimate the steam requirement in the initial stage of heating 120 L cream (initial 18 °C) in a jacketed pan; steam at 2 kg/cm² abs (sat. 119.6 °C, λ = 526 kcal/kg); area 1 m²; U = 250 kcal/m²·h·°C.*

Solution:

For the initial stage of heating, the rate of heat transfer is:

$$\mathbf{Q = U \times A \times \Delta T}$$

Where:

$U = 250\ kcal/m^2 \cdot h \cdot °C$

$A = 1\ m^2$

Steam temperature, $T_s = 119.6\ °C$

Initial cream temperature, $T_i = 18\ °C$

Temperature difference:

$$\Delta T = T_s - T_i$$

$$\Delta T = 119.6 - 18 = 101.6\ °C$$

Therefore,

$$Q = 250 \times 1 \times 101.6$$

$$Q = 25{,}400\ \text{kcal/h}$$

Steam requirement is:

$$m_s = Q / \lambda$$

Given latent heat of steam:

$$\lambda = 526\ \text{kcal/kg}$$

Therefore,

$$m_s = 25{,}400 / 526$$

$$m_s = 48.29\ \text{kg/h}$$

Answer: Initial steam requirement ≈ 48.3 kg/h

Note: The 120 L quantity of cream is not required for calculating the instantaneous steam requirement at the initial stage; it would be needed for calculating the total heating time or total steam consumption.

5 STRAIN, FORCE & TORQUE MEASUREMENT

5.1 *Stress, strain and the stress–strain curve*

PREVIOUS YEAR QUESTIONS

- *What is meant by strain? Draw the typical stress–strain curve (linear, necking, break). What is the principle of a metal strain-gauge?* [IFOS 2019 | P2/5(e) | 8M]
- *Differentiate: Stress and Strain; Force and Torque.* [IFOS 2023 | P2/5(d) | 8M]

Stress, strain, force, torque : *Stress = internal resisting force per unit area ($\sigma = F/A$, N/m^2). Strain = deformation per unit original dimension ($\varepsilon = \Delta L/L$, dimensionless). Force = a push/pull (N). Torque = a turning moment = force × perpendicular distance (N·m).*

▣ *Stress–strain curve*

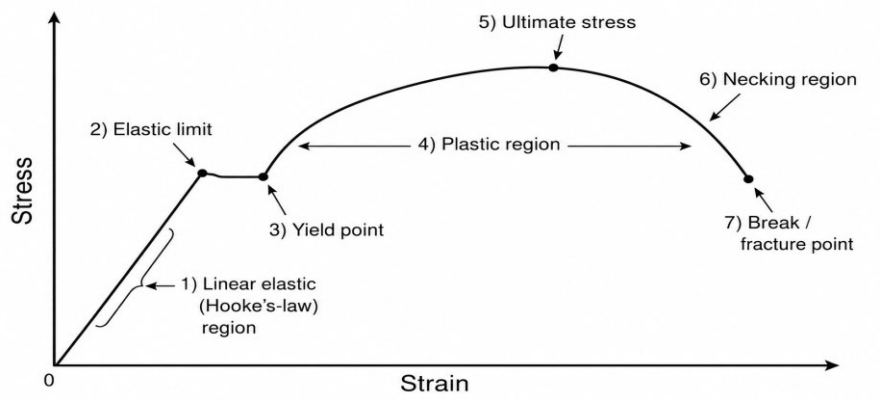


Fig. 9.4 Stress–strain curve

5.2 *The strain gauge*

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PREVIOUS YEAR QUESTIONS

- *Describe the working of electrical resistance strain gauges.* [UK·PSC 2025 | Q.8(iii) | 10M]
- *Name the types of strain-measuring equipment and describe the techniques using strain gauges.* [IFOS 2016 | P2/7(b) | 10M]

Metal resistance strain gauge : *a fine wire/foil grid bonded to a component's surface. When the component is strained, the grid stretches (length up, cross-section down), so its resistance changes in proportion to the strain.*

$$\Delta R/R = G \cdot \varepsilon$$

G = gauge factor (≈ 2 for metal, up to ~100 for semiconductor); ε = strain. (1000 με → ~0.2 % ΔR.)

Because ΔR is tiny, the gauge is connected in a Wheatstone bridge (quarter/half/full); a dummy gauge gives temperature compensation. Strain techniques are mechanical, optical, pneumatic and electrical, the bonded electrical-resistance strain gauge being the commonest; types are unbonded, bonded (wire/foil) and semiconductor.

▣ *Strain gauge and Wheatstone bridge*

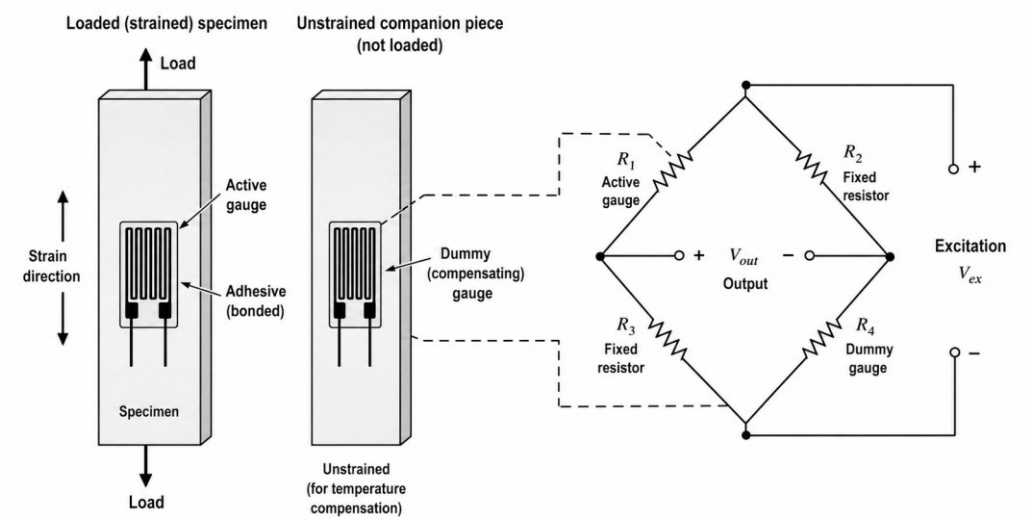


Fig. 9.5 Strain gauge with Wheatstone-bridge circuit

5.3 *Force measurement*

PREVIOUS YEAR QUESTIONS

- *Describe the basic methods of force measurement.* [IFOS 2016 | P2/6(c) | 10M]
- *Working principles of hydraulic load cell and pneumatic load cell in force measurement.* [IFOS 2023 | P2/8(c) | 10M]

MODEL Q Basic methods of force measurement: (1) balancing against a known gravitational force (weights on a balance/lever); (2) measuring the acceleration of a known mass (F = ma); (3) balancing against an electromagnetic force; (4) elastic deformation of a member and measuring its strain/deflection (proving ring, strain-gauge load cell); (5) converting force to fluid pressure (hydraulic/pneumatic load cells).***

- ***Strain-gauge load cell*** L: Force strains an elastic element carrying strain gauges; the bridge output gives the force.

- ***Hydraulic load cell*** : Force acts on a piston/diaphragm over an oil-filled chamber, raising the oil pressure; the pressure (read on a Bourdon gauge) gives F = p × A. Rugged, no external power.
- ***Pneumatic load cell*** : The force is balanced by air pressure on a diaphragm through a nozzle-flapper feedback; the balancing air pressure indicates the force.

5.4 Torque measurement

PREVIOUS YEAR QUESTIONS

- *Describe different types of torque sensors and their working. How is PTO-pulley torque measured?*

[IFOS 2017 | P2/6(c) | 10M]

- *Working principle of strain-gauge torque meters / torque transducers — show the strain-gauge position on the shaft and the circuit.* [IFOS 2020 | P2/8(a) | 15M; OPSC·CSE 2018-19 | Q.6(b) | 20M]

- ***Strain-gauge torque transducer*** : Four strain gauges bonded on the shaft at ±45° helices (directions of maximum tensile/compressive strain under torsion) in a full Wheatstone bridge; output ∝ torque, while ±45° cancels bending/axial effects. Signals taken off by slip rings or telemetry.
- ***Torsion-bar / optical*** : Measures the angle of twist of a calibrated shaft (θ ∝ torque).
- ***PTO torque*** : Tractor power-take-off torque measured with a strain-gauge torque sensor on the PTO shaft (slip-ring/telemetry) or a PTO dynamometer; with speed gives PTO power.

▣ Strain-gauge torque transducer on a shaft

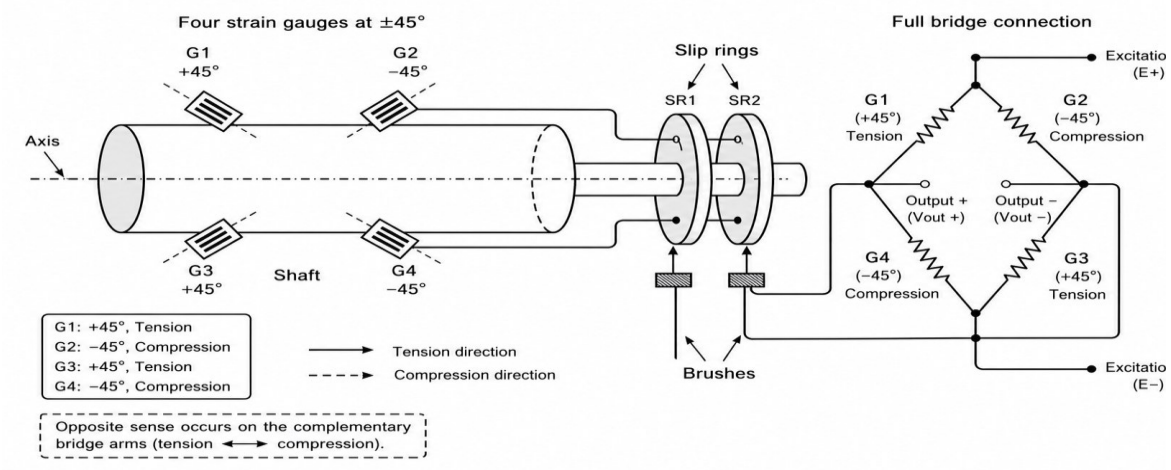


Fig.: Strain-gauge torque transducer (±45° gauges, full bridge)

5.5 Dynamometers

PREVIOUS YEAR QUESTIONS

- *Write in brief: (i) Transmission (ii) Driving (iii) Absorption dynamometer.*

[IFOS 2021 | P2/8(b) | 15M]

- *Principle, working and uses of strain-gauge dynamometer and torsion dynamometer.*

[OPSC·CSE 2020-21 | Q.8(c) | 20M]

- *Functioning of the strain-gauge-type drawbar dynamometer.*

[OPSC·Forest 2019-20 | Q.5(b) | 20M; OPSC·CSE 2018-19 | Q.5(c) | 20M]

Dynamometer : *an instrument to measure force, torque or power. Absorption dynamometer — absorbs*

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and dissipates the power measured (prony brake, rope brake, hydraulic/water brake, eddy-current); measures output power (BHP). Transmission dynamometer — measures torque/power in a shaft/belt without absorbing it. Driving dynamometer — drives the machine and measures the power supplied.

- ***Strain-gauge / torsion dynamometer*** : Strain gauges on an elastic element (or shaft twist) give force/torque electrically.
- ***Drawbar (draft) dynamometer*** : A strain-gauge (or hydraulic) transducer inserted in the drawbar between tractor and implement measures the draft (pull) force for field testing.

5.6 *Draft, drawbar power and BHP measurement*

PREVIOUS YEAR QUESTIONS

- *Method of measurement/calibration of draft of an animal-drawn plough and a tractor-drawn trailed disc harrow.* [IFOS 2016 | P2/5(b) | 8M]
- *How are BHP of an engine (hydraulic brake dynamometer) and calibration of a hydraulic tension dynamometer done?* [IFOS 2016 | P2/5(c) | 8M]

Draft measurement — a dynamometer (hydraulic or strain-gauge load cell) is connected between the prime mover (animal/tractor) and the implement (plough, disc harrow); it reads the horizontal pull (draft force) as the implement works. With the forward speed, drawbar power = draft × speed. BHP by hydraulic (brake) dynamometer — the engine drives a water brake; the brake casing tends to rotate and is restrained by a load arm and weight (or load cell), giving the torque; with the speed, the brake power is found.

Power $P = 2\pi NT/60$ (W) (N = rev/min, T = torque N·m) ; Drawbar power = draft × speed

◆ **WORKED NUMERICAL — *Power measurement (illustrative)*** [demonstrates the power formulas]

Problem. *An engine develops 100 N·m torque at 1500 rpm; a tractor pulls a disc harrow at 8 kN draft and 5 km/h.*

Given:

Engine torque, T = 100 N·m
Engine speed, N = 1500 rpm
Draft, D = 8 kN
Forward speed, v = 5 km/h

1. Engine Power

Power developed by the engine:

$$P = (2\pi NT) / 60$$

Substituting the values:

$$P = (2 \times 3.1416 \times 1500 \times 100) / 60$$

$$P = 15{,}708 \text{ W}$$

Therefore,

Engine power = 15.71 kW

2. Drawbar Power

First, convert speed into m/s:

$$v = 5 / 3.6 = 1.389 \text{ m/s}$$

Draft:

$$D = 8 \text{ kN} = 8000 \text{ N}$$

Drawbar power:

$$Pdb = D \times v$$

Pdb = 8000 × 1.389

Pdb = 11,112 W

Therefore,

Drawbar power = 11.11 kW

3. Power Utilization Efficiency

Efficiency = (Drawbar power / Engine power) × 100

Efficiency = (11.11 / 15.71) × 100

Efficiency ≈ 70.7%

Answer:

Engine power = 15.71 kW

Drawbar power = 11.11 kW

Power utilization efficiency ≈ 70.7%

Calibration of a hydraulic tension dynamometer is done by applying known weights/forces and recording the readings to build the calibration curve.

6 FLOW MEASUREMENT

6.1 *Classification of flow meters*

PREVIOUS YEAR QUESTIONS

- *Classify flow meters.* [IFOS 2017 | P2/6(a) | 10M]
- *What are the different instruments for measurement of flow? Explain them in brief.* [UK·PSC 2025| Q.8(ii) | 10M]

Flow meters are classified by principle: differential-pressure (head) type — venturimeter, orifice meter, flow nozzle, pitot tube; variable-area type — rotameter; velocity type — hot-wire anemometer, turbine, electromagnetic, ultrasonic; positive-displacement type; and mass-flow (Coriolis, thermal). Also grouped as quantity meters (total volume) vs rate meters (instantaneous rate).

6.2 *Differential-pressure meters — venturimeter and orifice meter*

PREVIOUS YEAR QUESTIONS

- *Explain with neat figures: (i) Orifice meter (ii) Venturimeter.* [IFOS 2023 | P2/8(b) | 10M; IFOS 2025 | P2/6(c)(iii) | M]
- *State the principle of flow measurement using a venturi tube.* [OPSC·CSE 2022-23| P2/11(b) | 5M]

Principle (Bernoulli + continuity) : *a restriction increases fluid velocity and lowers the pressure there; the pressure difference between upstream and the restriction measures the flow, with* $Q \propto \sqrt{(\Delta p)}$.

$$Q = C_d \cdot A_2 \cdot \sqrt{[2g \cdot h / (1 - (A_2/A_1)^2)]}$$

C_d = discharge coefficient; A_1, A_2 = pipe & throat areas; h = head difference.

- ***Venturimeter*** : A smooth converging cone → throat → gently diverging cone; pressure difference between inlet and throat gives the flow. Accurate, low permanent pressure loss (recovers pressure), but bulky and costly.
- ***Orifice meter*** : A thin plate with a central hole; the pressure drop across it gives the flow. Simple and cheap but high permanent pressure loss and lower accuracy.

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▣ *Venturimeter and orifice meter*

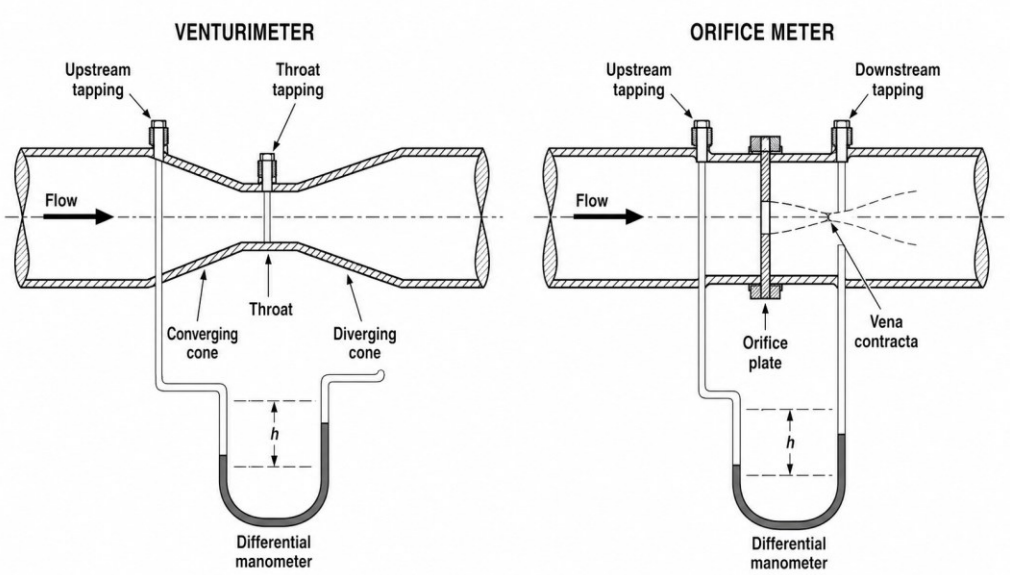


Fig. 9.7 Venturimeter and orifice meter

◆ WORKED NUMERICAL — *Venturimeter flow (illustrative)* [demonstrates the flow formula]

Problem. *A venturimeter has pipe diameter 10 cm, throat 5 cm, C_d = 0.98, and shows a head difference h = 0.20 m. Find the flow rate.*

Given:

Pipe diameter, $D_1 = 10\ \text{cm} = 0.10\ \text{m}$

Throat diameter, $D_2 = 5\ \text{cm} = 0.05\ \text{m}$

Coefficient of discharge, $C_d = 0.98$

Head difference, $h = 0.20\ \text{m}$

Acceleration due to gravity, $g = 9.81\ \text{m/s}^2$

Area of pipe:

$$A_1 = (\pi/4)D_1^2$$

$$A_1 = (\pi/4)(0.10)^2 = 0.007854\ \text{m}^2$$

Area of throat:

$$A_2 = (\pi/4)D_2^2$$

$$A_2 = (\pi/4)(0.05)^2 = 0.001963\ \text{m}^2$$

For a venturimeter:

$$Q = C_d \times [A_1A_2 / \sqrt{(A_1^2 - A_2^2)}] \times \sqrt{(2gh)}$$

Substituting the values:

$$Q = 0.98 \times [(0.007854 \times 0.001963) / \sqrt{((0.007854)^2 - (0.001963)^2)}] \times \sqrt{(2 \times 9.81 \times 0.20)}$$

$$Q \approx 0.00394\ \text{m}^3/\text{s}$$

Therefore,

$$\text{Flow rate, } Q \approx 3.94 \times 10^{-3}\ \text{m}^3/\text{s}$$

or

$$Q \approx 3.94\ \text{L/s}$$

Answer: Flow rate ≈ 0.00394 m^3/s or 3.94 L/s

6.3 Variable-area meter – the rotameter

PREVIOUS YEAR QUESTIONS

- *For what purpose is a rotameter used in fluid flow? How does it operate?* [IFOS 2019 | P2/8(a) | 15M]

Rotameter : *a tapered vertical tube (wide at the top) containing a float. The upward flow lifts the float until the annular area between float and tube balances the float's weight against drag and buoyancy; the float height reads the flow rate directly on the graduated tube. It works at constant pressure drop with variable area (the opposite of a venturi). Simple, direct-reading, cheap; for gas and liquid rate.*

6.4 Velocity meter – the hot-wire anemometer

PREVIOUS YEAR QUESTIONS

- *Explain the functioning of a hot-wire anemometer.*

[IFOS 2017 | P2/6(a) | 10M; IFOS 2024 | P2/5(d)(iii) | M; HP· PSC 2021 | Q.8(c) | M]

Hot-wire anemometer : *a fine electrically-heated wire (platinum/tungsten) placed in the flow; the moving fluid carries heat away and cools the wire, changing its resistance – the cooling depends on the flow velocity. Operated in constant-current or constant-temperature mode; fast response; for air velocity and turbulence. (Input: velocity; output: resistance/current.)*

▣ Hot-wire anemometer

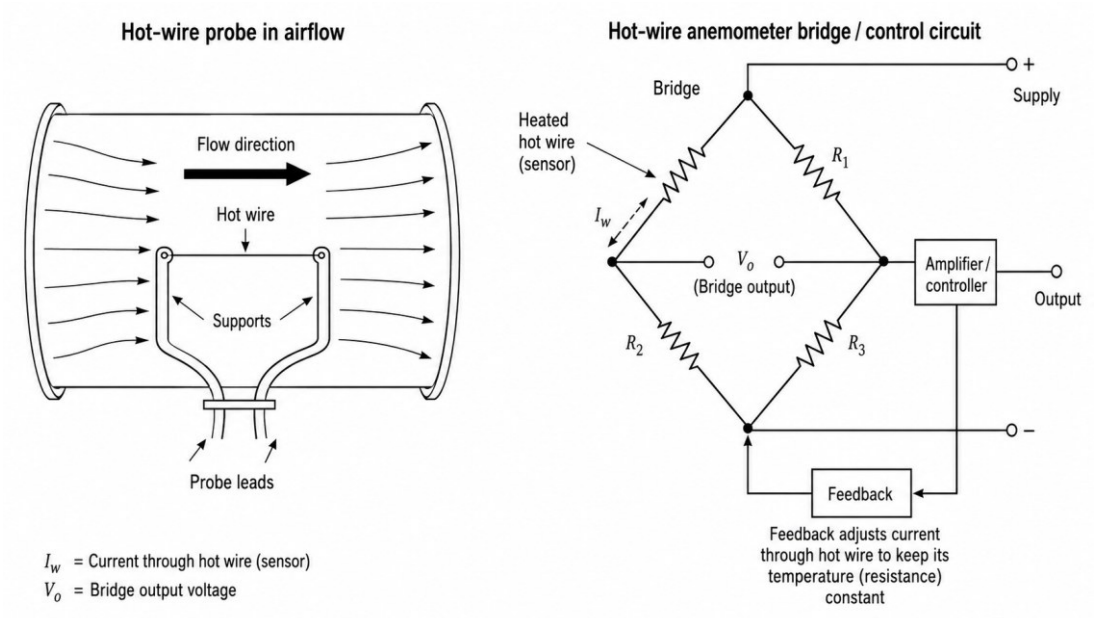


Fig. 9.8 Hot-wire

7 PRESSURE & VACUUM MEASUREMENT

7.1 Pressure terms

Pressure is measured as absolute (from perfect vacuum), gauge (above atmospheric), differential (between two points) or vacuum (below atmospheric). Devices: liquid-column (manometers), elastic (Bourdon, diaphragm, bellows) and electrical (pressure transducers).

7.2 Manometers

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PREVIOUS YEAR QUESTIONS

- *Discuss the use of U-tube manometer. What are the desirable characteristics of manometric fluid?* [IFOS 2024 | P2/8(a) | 8M]
- *With a neat sketch, explain the cistern-type manometer for measuring static pressure.* [IFOS 2025 | P2/7(d) | 7M]

Manometer : *measures pressure by balancing it against a liquid column: $p = \rho \cdot g \cdot h$. U-tube manometer — pressure/difference read from the difference in liquid levels of the two limbs. Cistern (well-type) — one limb replaced by a large cistern whose level barely moves, so only the single narrow limb is read against one scale (convenient for static pressure).*

Desirable characteristics of a manometric fluid : *suitable density (light oil for small pressures, mercury for large); low vapour pressure (non-volatile); low surface tension (no capillary error); non-corrosive and chemically stable; immiscible with and distinguishable from the process fluid (good colour/visibility); and low thermal expansion.*

U-tube and cistern manometers

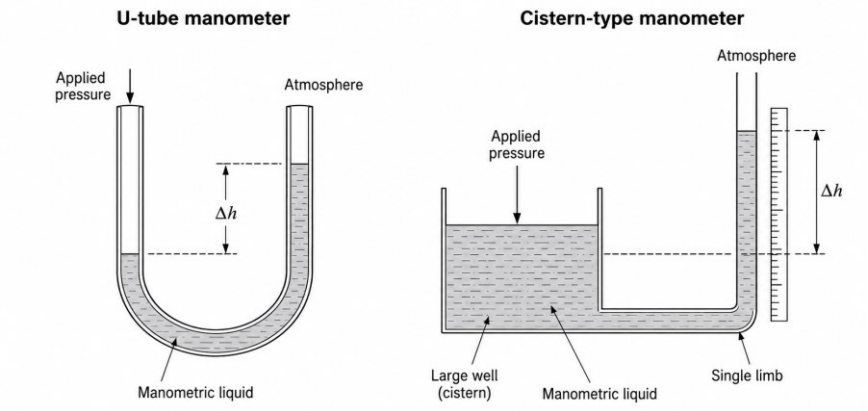


Fig. 9.9 U-tube and cistern manometers

7.3 Bourdon gauge

PREVIOUS YEAR QUESTIONS

- *Principle of operation of the Bourdon gauge; input and output variables.* [IFOS 2025 | P2/6(c)(i) | 8M]

Bourdon gauge : *a curved (C-shaped) elastic metal tube of flattened (oval) cross-section, closed at the free end. Applied internal pressure tends to straighten the tube; the small tip movement is amplified by a gear-and-pinion linkage to drive a pointer over a calibrated dial. Rugged, cheap, wide-range. (Input: pressure; output: tip displacement → pointer.)*

7.4 Diaphragm and elastic elements

PREVIOUS YEAR QUESTIONS

- *Explain with a neat diagram how a diaphragm can be used for measuring pressure difference.* [IFOS 2018 | P2/5(b) | 8M]

Diaphragm : *a thin flexible membrane clamped at its edge; a pressure difference across it makes it deflect, and the deflection ($\propto$ pressure difference) is measured by a strain gauge, LVDT or capacitance*

pick-off. Related elements: bellows and capsule. Ideal for low/differential pressures with electrical output.

▣ ***Diaphragm pressure-difference sensor***

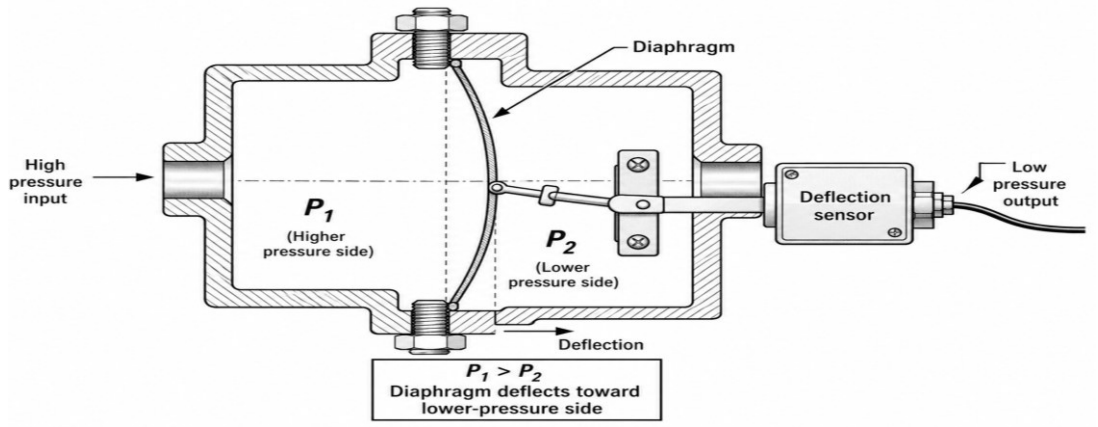


Fig. 9.10 Diaphragm measuring pressure difference

7.5 Pressure transducers

PREVIOUS YEAR QUESTIONS

- *What are pressure transducers used for? Write about the different types.* [IHP·PSC 2021| Q.8(d) | 10M]

Pressure transducers convert pressure into an electrical signal for remote reading, recording, data acquisition or dynamic measurement. Types: strain-gauge (diaphragm + gauges in a bridge — commonest), capacitive, piezoelectric (dynamic), potentiometric and LVDT/inductive. Used wherever the signal must be processed electronically (Chapters 7–8).

7.6 Vacuum (low-pressure) measurement

PREVIOUS YEAR QUESTIONS

- *Describe the two basic methods for measurement of low pressure. Draw a thermocouple vacuum gauge and explain the heater element.* [IFOS 2020| P2/8(b) | 15M]

Low (vacuum) pressures are measured by two basic approaches: (1) Direct — measure the small force/deflection the gas exerts (diaphragm/capacitance gauges) or compress a gas sample (McLeod gauge). (2) Indirect — measure a pressure-dependent property of the residual gas: its thermal conductivity (Pirani and thermocouple gauges) or its ionisation (ionisation gauge).

Thermocouple vacuum gauge : *a small heater element (fine wire) is heated by a constant current; gas molecules around it carry heat away by conduction. At lower pressure there are fewer molecules, so less heat is removed and the heater runs hotter; a thermocouple welded to the heater measures its temperature, which — through the gas's thermal conductivity — indicates the pressure. The heater element is both the pressure-sensitive part and the source of heat the thermocouple reads.*

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▣ *Thermocouple vacuum gauge*

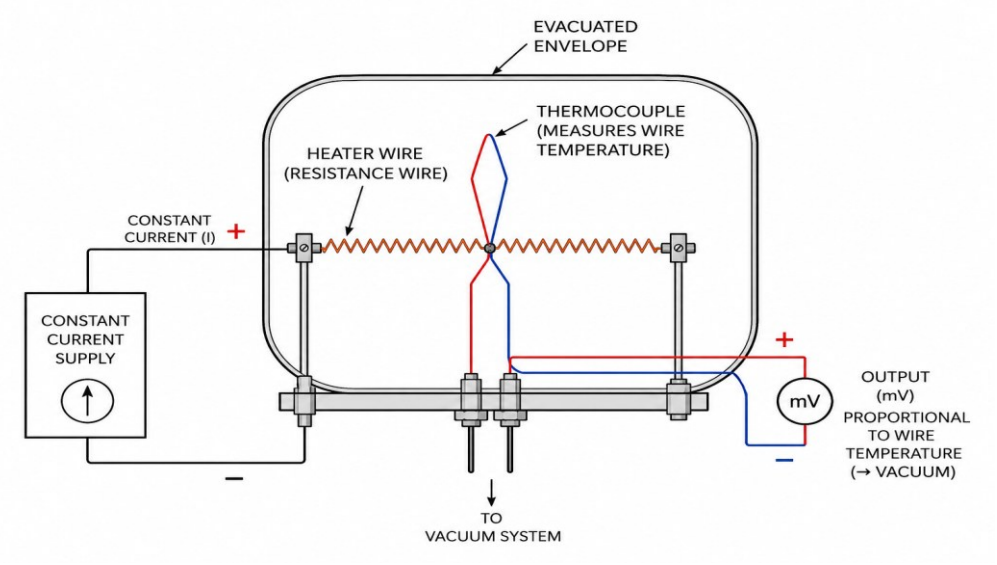


Fig. 9.11 Thermocouple vacuum gauge

8 LEVEL, SPEED, VIBRATION & ELECTRICAL MEASUREMENT

8.1 *Level measurement*

PREVIOUS YEAR QUESTIONS

- *Write the methods of measurement of liquid level in a glass tube. Advantages and disadvantages of the resistive method?* [IFOS 2020| P2/8(a) | 15M]

Liquid level is measured by direct methods (sight/glass-tube gauge, float, dip-stick) and inferential methods (hydrostatic pressure at the bottom ∝ level; buoyancy/displacer; electrical resistive/capacitive; ultrasonic/radar). Glass-tube (sight) gauge — a transparent tube connected to the vessel; by communicating vessels the liquid stands at the same level as in the vessel, read against a scale. Resistive method — resistance changes with the level of a conducting liquid. Advantages: simple, no moving parts, electrical output for remote reading/control. Disadvantages: works only with conductive liquids, affected by changing conductivity and by fouling/corrosion, needs contact.

8.2 *Speed measurement – the tachometer*

PREVIOUS YEAR QUESTIONS

- *Write in brief: Tachometer.* [HP·PSC 2021| Q.8(c) | 10M]

Tachometer : *an instrument to measure rotational speed (rpm). Types: mechanical (centrifugal, revolution counter); electrical tacho-generator (output voltage/frequency ∝ speed); and digital/optical or magnetic (counts pulses per revolution). Used on engines, pumps, fans and rotating machinery.*

8.3 *Vibration meter*

PREVIOUS YEAR QUESTIONS

- *Working principle of: Vibration meter.* [IFOS 2017| P2/6(b)(v) | 10M]

Vibration meter : *measures the amplitude, velocity, acceleration and frequency of mechanical*

vibration, usually with a seismic pickup or piezoelectric accelerometer whose output is proportional to the vibration; used for machinery condition monitoring and fault detection.

8.4 Electrical measurement – moving-iron instruments

PREVIOUS YEAR QUESTIONS

- *Explain the operational principle of moving-iron ammeter and voltmeter.*

[OPSC-CSE 2015-16| P2/7(c) | 20M]

Moving-iron instrument : *current through a fixed coil magnetises a soft-iron piece, which is attracted (attraction type) or repelled (repulsion type), deflecting the pointer. The force depends on the square of current, so it reads RMS and works on AC and DC; cheap and rugged but with a non-uniform scale. As an ammeter the coil has a few thick turns (low resistance, in series); as a voltmeter, many thin turns with a series resistance (high resistance, across the circuit).*

8.5 Amplifiers and the hydraulic amplifying element

PREVIOUS YEAR QUESTIONS

- *What is an amplifier and its different types? Explain the hydraulic amplifying element with a neat sketch.* [IFOS 2021| P2/8(a) | 15M]

An amplifier increases the magnitude (voltage, current or power) of a signal (Chapter 7); besides electronic amplifiers there are mechanical, pneumatic and hydraulic amplifying elements.

Hydraulic amplifying element : *a small input motion moves a spool/pilot valve that ports high-pressure oil to one side of a large power piston; the piston then develops a large output force and motion far greater than the small input – power amplification using fluid pressure. It is the basis of hydraulic servo/control systems (tractor hydraulics, power steering), where a light control input governs a heavy load.*

Hydraulic amplifying element

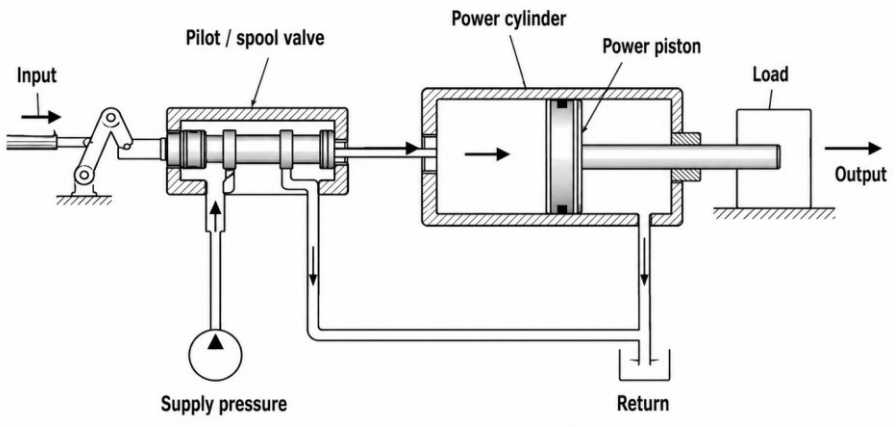


Fig. 9.12 Hydraulic amplifying element

8.6 Input and output variables of common elements

PREVIOUS YEAR QUESTIONS

- *Write the principle of operation and mention the input and output variables of: Bourdon gauge, Venturimeter/Orifice, Piezo-electric device, Solar cell, Thermocouple, Resistance strain gauge,*

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Hot-wire anemometer, Resistance thermometer. [IFOS 2025| P2/6(c) | 8M; IFOS 2024| P2/5(d) | 8M]

Element	Input	Output
Bourdon gauge	pressure	tip displacement (pointer)
Venturimeter / Orifice	flow rate	pressure difference (head)
Piezoelectric device	force / pressure	charge / voltage
Solar cell	light	voltage (emf)
Thermocouple	temperature difference	emf (mV)
Resistance strain gauge	strain	change in resistance
Hot-wire anemometer	flow velocity	change in resistance/current
Resistance thermometer (RTD)	temperature	change in resistance

◆ *Source: Sawhney (level, tachometer, vibration, moving-iron instruments, amplifiers).*

9 FACT SHEET · SUMMARY · LAST-NIGHT REVISION

Fact / Formula Sheet

Functional elements: sensing → conversion → manipulation → transmission → presentation

First-order response: $y = K \cdot x_o(1 - e^{-t/\tau})$; 63.2 % at $t = \tau$, ~99 % at 5τ

Thermocouple $E \approx \alpha \cdot \Delta T$ (Seebeck) ; Thermistor $R_T = R_o \cdot e^{\beta(1/T - 1/T_o)}$; RTD $R_t = R_o(1+\alpha t)$

Strain gauge $\Delta R/R = G \cdot \varepsilon$ ($G \approx 2$) ; Load cell $F = p \cdot A$

Power $P = 2\pi NT/60$ (W) ; Drawbar power = draft × speed

Flow $Q = C_d \cdot A_2 \cdot \sqrt{[2gh/(1-(A_2/A_1)^2)]}$; Manometer $p = \rho gh$; Radiation pyrometer $\propto T^4$

Summary

Every measurement system, whatever the quantity, is a chain of functional elements — primary sensing, variable conversion, variable manipulation, data transmission and data presentation — with signal conditioning preparing the signal. Instruments are judged by static characteristics (accuracy = closeness to true value; precision = repeatability; plus resolution, threshold, sensitivity, drift, span, readability) and dynamic characteristics (response/rise time; a first-order instrument responds as $y = Kx_o(1-e^{-t/\tau})$, 63 % at one time constant). Transducers are active (self-generating: thermocouple, piezoelectric, solar cell) or passive (vary R/L/C: strain gauge, RTD, LVDT), and a host of them serve precision agriculture. Temperature is measured by thermocouples (Seebeck emf, with Peltier/Thomson effects and the two thermocouple laws), RTDs (R rises with T), thermistors (R falls steeply with T) and pyrometers (non-contact radiation). Strain is sensed by resistance strain gauges ($\Delta R/R = G\varepsilon$) in a Wheatstone bridge; force by load cells (strain-gauge, hydraulic $F = pA$, pneumatic); torque by ±45° strain-gauge transducers; and power by dynamometers (absorption/transmission/driving) — including drawbar/draft dynamometers and BHP by a hydraulic brake ($P = 2\pi NT/60$). Flow is measured by differential-pressure meters (venturi, orifice; $Q \propto \sqrt{\Delta p}$), the variable-area rotameter and the velocity-sensing hot-wire anemometer. Pressure is measured by manometers ($p = \rho gh$), the Bourdon gauge, diaphragms and pressure transducers, and vacuum by thermal-conductivity (thermocouple/Pirani) gauges. Level, speed (tachometer), vibration and electrical quantities (moving-iron) complete the range — all feeding the data-acquisition and control systems of Chapter 8.

CHAPTER

10

COMPUTERS, ALGORITHMS & MULTIMEDIA

Computer fundamentals · CPU · Memory · I/O · Operating systems · Algorithms & flowcharts · Multimedia & AV aids

SYLLABUS : UPSC IFoS — Agricultural Engineering, Paper II, Section B — Topic 4 (Instrumentation & Computer Applications). Chapter 10: Computers — introduction, input/output devices, central processing unit, memory devices, operating systems, processors, keyboards and printers; algorithms, flowchart specification, programme translation and problem analysis in agricultural engineering; multimedia and audio-visual aids.

Chapter Outline

1. **Computer Fundamentals, Hardware/Software & Data Processing**
2. **The Central Processing Unit (CPU)**
3. **Memory Devices — Hierarchy, Primary & Secondary**
4. **Input, Output & Storage Devices**
5. **Operating Systems & Virtual Memory**
6. **Algorithms, Flowcharts & Program Development**
7. **Computer Applications in Agriculture (CAD, Optimization, Networks)**
8. **Multimedia & Audio-Visual Aids**
9. **Fact Sheet · Summary · Last-Night Revision**

1 COMPUTER FUNDAMENTALS, HARDWARE/SOFTWARE & DATA PROCESSING

1.1 The digital computer and its block diagram

PREVIOUS YEAR QUESTIONS

- *Write about digital computers. Draw digital computer system showing input and output devices.*

[IFOS 2021 | P2/5(e) | 8M]

Digital computer : *an electronic machine that accepts data and instructions (a program) as input, processes the data by performing arithmetic and logical operations on discrete binary (0/1) signals under stored-program, and produces the result as output — storing data and results in memory. It is fast, accurate, automatic, has a large memory and is programmable/versatile.*

A digital computer is organised into five functional units: the input unit (feeds data/instructions in), the memory unit (stores them), the arithmetic-logic unit (ALU, does the computation) and the control unit (CU, directs all operations) — the ALU and CU together forming the central processing unit (CPU) — and the output unit (delivers the result). Data flow along the data path; the control unit issues the control signals.

▣ Block diagram of a digital computer

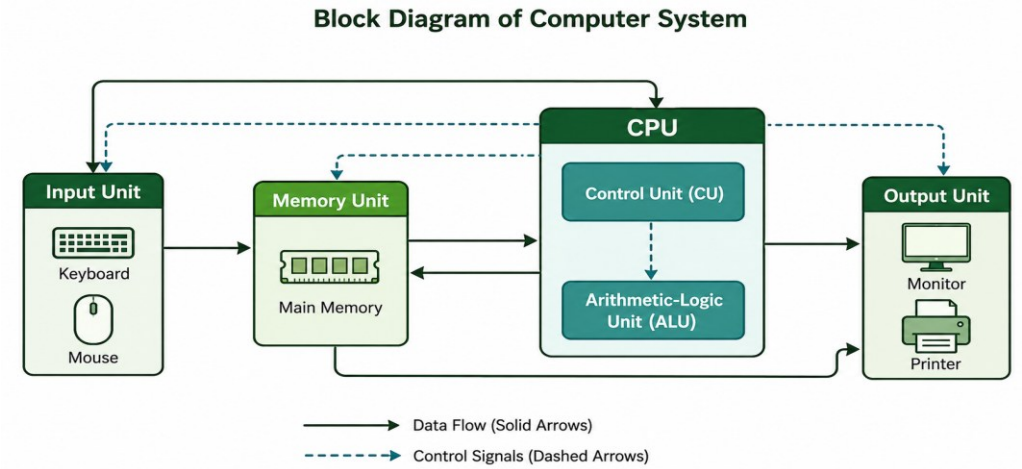


Fig. 10.1 Block diagram of a digital computer

Generation	Technology	Feature
1st (1940s-50s)	Vacuum tubes	bulky, slow, high power
2nd (late 50s)	Transistors	smaller, faster, reliable
3rd (1960s)	Integrated circuits (IC)	cheaper, compact
4th (1970s-)	Microprocessors (VLSI)	personal computers
5th (present)	AI / ULSI, parallel	intelligent systems

1.2 Characteristics of computers useful in agriculture

PREVIOUS YEAR QUESTIONS

- *Explain the major characters of computers that made them powerful and useful in agriculture.*

[IFOS 2024 | P2/6(d) | 7M]

The features that make the computer a powerful tool in agriculture are:

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Speed : Performs millions of operations per second, so large volumes of farm, weather, soil and market data are processed almost instantly.

Accuracy : Gives error-free results (errors are almost always due to wrong input — 'garbage in, garbage out'), vital for design calculations and financial records.

Storage : Stores enormous quantities of data (crop, soil, weather, land records) for years and retrieves them instantly.

Automation & diligence : Once programmed it works automatically and tirelessly without fatigue or loss of concentration — ideal for continuous process control and monitoring.

Versatility : The same machine runs GIS, simulation, accounting, design (CAD) and communication tasks.

These characteristics let computers drive precision farming, remote sensing/GIS, crop and weather modelling, farm management, expert/decision-support systems, process control in food processing and market information — raising productivity, precision, quality and profitability.

1.3 *Hardware and software*

PREVIOUS YEAR QUESTIONS

- *Write short note on: Hardware and Software.* [OPSC·Forest 2015-16 | P2/8(b) | 20M]

Hardware & software : *Hardware — the physical, tangible parts of the computer that can be seen and touched (CPU, memory chips, motherboard, keyboard, mouse, monitor, printer, disk drives). Software — the set of programs (instructions) that tell the hardware what to do; intangible. Software is of two kinds — system software (operating system, language translators, utilities that run the machine) and application software (user programs: word processors, spreadsheets, GIS, CAD, accounting). Hardware without software is inert; software needs hardware to run — the two are complementary.*

Basis	Hardware	Software
Nature	physical / tangible	logical / intangible
Made by	manufacturing	programming
Wear	wears out physically	does not wear; can have bugs
Example	CPU, keyboard, printer	Windows, MS-Excel, AutoCAD

1.4 *Data, information and data processing*

PREVIOUS YEAR QUESTIONS

- *What is Data? Describe the procedure of data processing to obtain information for decision-making.* [IFoS 2025 | P2/7(c) | 8M]

Data and information : *Data — raw, unprocessed facts and figures (numbers, text, readings) that by themselves carry no meaning. Information — processed, organised and meaningful data that is useful for decision-making. Data processing is the sequence of operations that converts raw data into information.*

The procedure (data-processing cycle) has three core stages — input, processing and output — with storage supporting all of them:

Data collection & input : Gather raw data and enter it (with verification/validation to ensure correctness).

Processing : Operate on the data — classifying, sorting, calculating, summarising, analysing — under program control to derive meaning.

Output : Present the resulting information as reports, tables, graphs or displays for the decision-maker.

Storage : Data, intermediate results and information are stored for future use and retrieval.

In agriculture, data processing turns soil-test readings, weather records, yield data and market prices into actionable information — fertiliser recommendations, sowing advisories, yield forecasts and profitability analyses — supporting sound farm decisions.

▣ *The data-processing cycle*

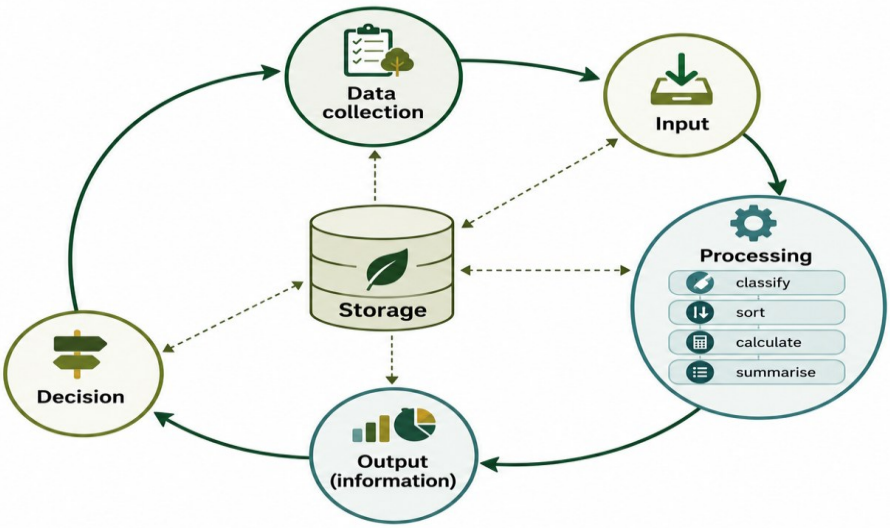


Fig. 10.2 Data-processing cycle: data to information

2 THE CENTRAL PROCESSING UNIT (CPU)

2.1 *CPU and its components*

PREVIOUS YEAR QUESTIONS

- *What are the different components used in CPU? Explain in brief each of them.* [IFoS 2022 | P2/6(c) | 15M]
- *What is the function of the central processing unit of a computer?* [IFoS 2018 | P2/5(e) | 8M]
- *Discuss the functions of CPU and memory devices in computers / role of CPU and memory devices in modern computers.* [IFoS 2017 | P2/8(b) | 10M; IFoS 2016 | P2/8(c) | 10M]

Central Processing Unit (CPU) : *the 'brain' of the computer — the unit that interprets and executes instructions and carries out all processing. Built on a single chip it is called a microprocessor. It has three main components: the arithmetic-logic unit, the control unit and the registers, linked by internal buses.*

Functions of the CPU: (i) fetch instructions from memory, decode and execute them; (ii) perform all arithmetic and logical operations; (iii) hold data, instructions and addresses temporarily in registers; (iv) control and coordinate memory, storage and I/O units; (v) synchronise all operations through the system clock.

Arithmetic-Logic Unit (ALU) : Performs all arithmetic operations (add, subtract, multiply, divide) and logical operations (comparisons: AND, OR, NOT, greater/less than). It is where the actual computation happens.

Control Unit (CU) : The manager — it fetches instructions from memory, decodes them, and issues timing and control signals that direct the ALU, memory and I/O units to carry them out. It does no processing itself but coordinates everything.

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Registers : Very small, very fast storage locations inside the CPU that hold data, instructions and addresses currently being worked on. Key registers: Program Counter (PC — address of the next instruction), Instruction Register (IR — current instruction), Memory Address/Data Registers (MAR/MDR), and the Accumulator (holds ALU results).

The CPU also relies on internal buses (address, data and control buses) to move information between its parts and to memory, and on a clock that synchronises operations (its frequency, in GHz, largely sets the speed). Function of the CPU: to fetch, interpret and execute the program instructions and to control the whole system. Memory devices support this by holding the program and data — registers and cache for immediate use, RAM for the work in progress, and secondary storage for permanent retention; the CPU can process only what memory supplies, so speed depends on both (memory devices are detailed in §3, and the fetch-decode-execute cycle in §2.2).

▣ ***Internal structure of the CPU***

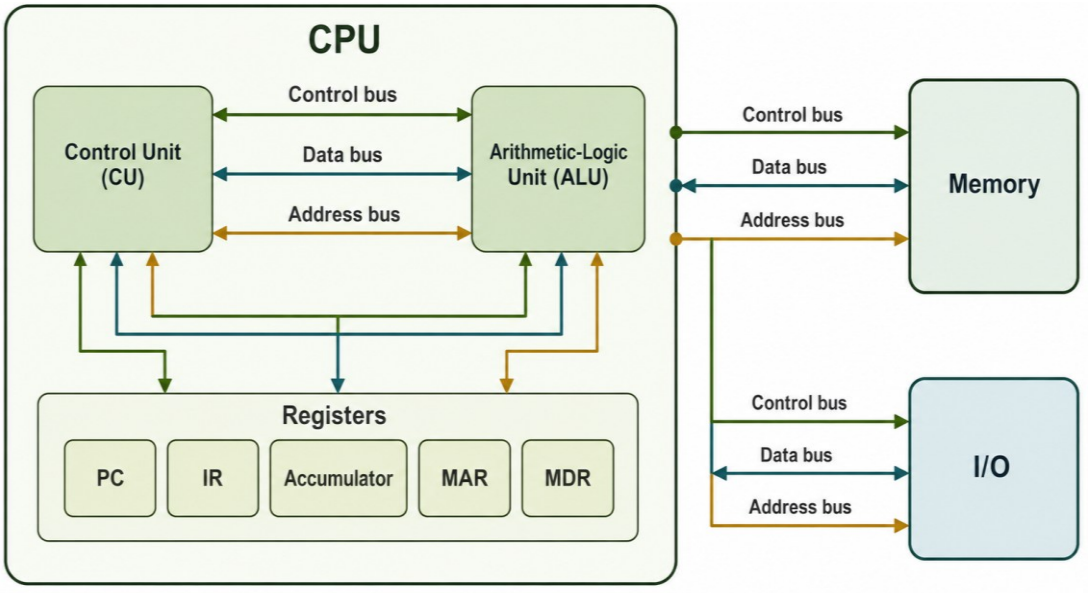


Fig. 10.3 Components of the CPU

2.2 The CPU (machine) cycle — fetch, decode, execute, store

PREVIOUS YEAR QUESTIONS

Explain the Central Processing Unit (CPU) of a computer. Also explain the main operations accomplished using CPU cycle. [IFoS 2024 | P2/7(d) | 7M]

The CPU executes each instruction through a repeating sequence called the machine cycle (or instruction cycle), with four main operations:

1. ***Fetch*** : The control unit reads (fetches) the next instruction from main memory, using the address in the Program Counter, and places it in the Instruction Register; the PC is incremented to point to the following instruction.
2. ***Decode*** : The control unit interprets (decodes) the instruction to determine what operation is required and which operands/addresses are involved.
3. ***Execute*** : The required operation is carried out — the ALU performs the arithmetic/logic, or data is moved, using the operands (fetched from memory/registers as needed).

4. ***Store (write-back)*** : The result is written back to a register or to memory.

The first two steps (fetch, decode) form the instruction phase and the last two (execute, store) the execution phase; the cycle repeats continuously, at millions of cycles per second, until the program ends.

▣ ***The CPU machine cycle***

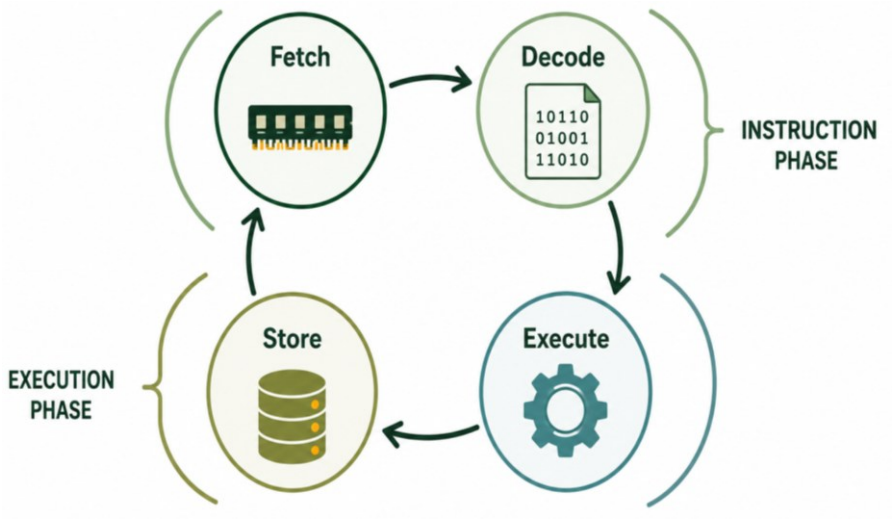


Fig. 10.4 The CPU (fetch-decode-execute-store) cycle

Microprocessor in agricultural data acquisition — the CPU/microprocessor at the heart of a data-acquisition system reads sensor signals (through an ADC), processes and stores them, and issues control outputs, enabling automatic monitoring and control of agricultural processes. This is treated fully in Chapter 8,

3 MEMORY DEVICES — HIERARCHY, PRIMARY & SECONDARY

3.1 *The data storage hierarchy*

PREVIOUS YEAR QUESTIONS

- *Explain the Central Processing Unit (CPU) of a computer. Also explain the main operations accomplished using CPU cycle.* [IFoS 2025 | P2/5(e) | 8M]

Data are organised in a rising hierarchy, each level built from the one below it:

1. ***Bit*** : the smallest unit — a single binary digit, 0 or 1.
2. ***Byte (character)*** : a group of 8 bits, representing one character (a letter, digit or symbol) — the basic addressable unit. (Nibble = 4 bits.)
3. ***Field*** : a group of related characters forming a meaningful item of data (e.g. a farmer's name, or a plot area).
4. ***Record*** : a collection of related fields describing one entity (e.g. all details of one farmer — name, village, plot area, crop).
5. ***File*** : a collection of related records of the same type (e.g. the records of all farmers in a village).
6. ***Database*** : an organised collection of related files/records, integrated and managed together so data can be shared and queried (e.g. the complete land-and-crop database of a district).

Thus, in ascending order: bit → byte (character) → field → record → file → database. Storage capacity is measured in bytes: 1 KB = 1024 bytes, 1 MB = 1024 KB, 1 GB = 1024 MB, 1 TB = 1024 GB.

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▣ *Data storage hierarchy*

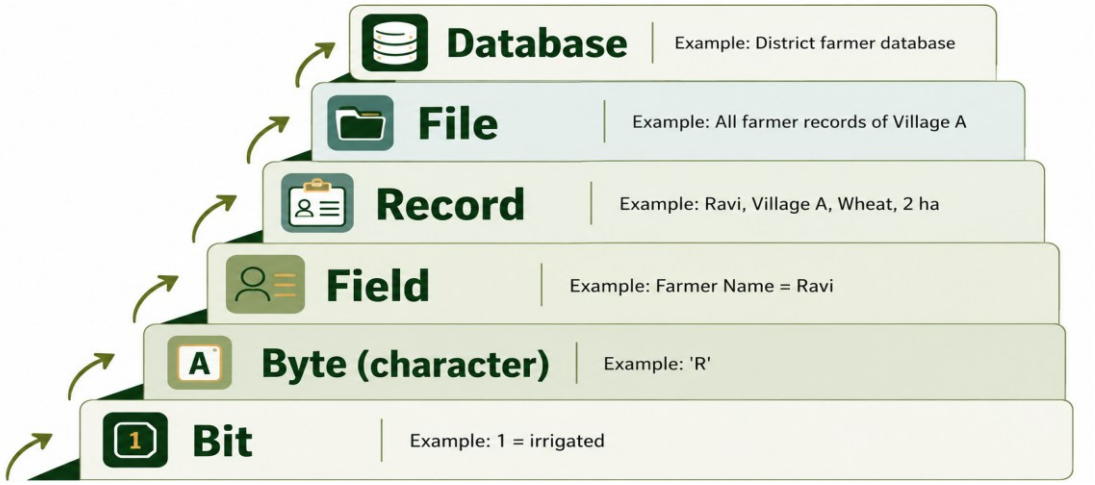


Fig. 10.5 Data storage hierarchy (ascending)

3.2 *Primary and secondary memory*

PREVIOUS YEAR QUESTIONS

- *Discuss the primary memory and secondary memory units used in computers.* [IFoS 2022 | P2/6(c) | 15M]
- *Explain, in detail, the primary and secondary memory devices.* [OPSC-CSE 2016-17 | P2/7(c) | 20M; OPSC-Forest 2015-16 | P2/8(a) | 20M]
- *What are the primary and secondary storage of a computer system?* [IFoS 2018 | P2/5(e) | 8M]

Primary (main) memory : *the internal memory directly accessible to the CPU, which holds the programs and data currently in use. It is fast, semiconductor-based, but limited in size and (for RAM) volatile. It comprises RAM and ROM, with cache and registers as still-faster levels. The CPU can access it directly and randomly.*

Secondary (auxiliary) memory : *external, non-volatile storage that holds programs and data permanently even when the power is off. It is much larger and cheaper per byte, but slower, and is not directly accessed by the CPU — data must first be loaded into primary memory. Examples: hard disk drive (HDD), solid-state drive (SSD), optical discs (CD/DVD), USB flash drives and magnetic tape.*

Feature	*Primary memory*	*Secondary memory*
Access by CPU	direct	indirect (via primary)
Speed	very fast	slower
Volatility	RAM volatile; ROM not	non-volatile
Capacity	limited	very large
Cost per byte	high	low
Purpose	current work	permanent storage
Examples	RAM, ROM, cache	HDD, SSD, CD/DVD, tape, USB

3.3 *RAM and ROM*

PREVIOUS YEAR QUESTIONS

- Explain about Random Access Memory (RAM) and Read Only Memory (ROM) in a computer. [IFoS 2024 | P2/5(c) | 8M]

RAM (Random Access Memory) : *the computer's main working memory: read/write and volatile (its contents are lost when power goes off). Any location can be accessed directly in the same time (random access). It holds the OS, programs and data currently being processed. Two types: Dynamic RAM (DRAM — stores each bit in a capacitor, needs periodic refreshing, cheap and dense, used as main memory) and Static RAM (SRAM — stores bits in flip-flops, faster and no refresh, costlier, used as cache).*

ROM (Read Only Memory) : *non-volatile memory whose contents are permanent and normally only read, not written. It retains its data without power and stores the firmware/boot program (BIOS) that starts the computer. Types: PROM (programmable once), EPROM (erasable by UV light) and EEPROM/flash (electrically erasable and reprogrammable).*

Feature	RAM	ROM
Operation	read and write	read only (mainly)
Volatility	volatile (lost on power-off)	non-volatile (retained)
Use	current programs & data	firmware / boot (BIOS)
Types	DRAM, SRAM	PROM, EPROM, EEPROM/flash

3.4 Secondary storage and memory hierarchy

Secondary storage devices are: magnetic — hard disk (large, random access), magnetic tape (sequential, for backup); optical — CD (~700 MB), DVD (~4.7 GB), Blu-ray (read by laser); and solid-state — SSD and USB flash drives (flash memory, no moving parts, fast and rugged). The complete memory hierarchy runs from fastest/smallest/costliest to slowest/largest/cheapest: registers → cache → main memory (RAM) → secondary storage (SSD/HDD) → tertiary (tape/optical). A memory device is judged by capacity, access time, cost per byte and volatility.

▣ The memory hierarchy

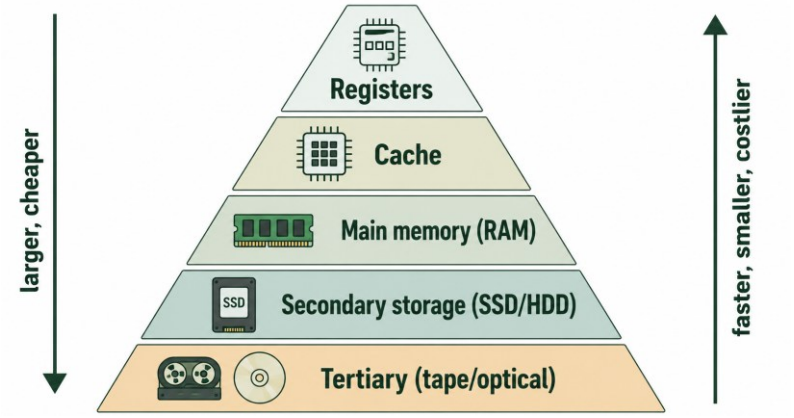


Fig. 10.6 Memory hierarchy

4 INPUT, OUTPUT & STORAGE DEVICES

4.1 Input devices

PREVIOUS YEAR QUESTIONS

- *Name any two input devices and two output devices of a computer.* [IFoS 2018 | P2/5(e) | 8M]
- *Draw digital computer system showing input and output devices.* [IFoS 2021 | P2/5(e) | 8M]

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Input device : *hardware that feeds data and instructions into the computer, converting them into the machine's electronic form.*

Common input devices: keyboard (keys → character codes; the chief text-input device), mouse/trackpad (pointing), scanner (images/documents), OCR/OMR/barcode readers, joystick, light pen, touch screen, microphone (audio), digital camera, and sensors/transducers (for data acquisition — Chapters 8-9). Two examples: keyboard and mouse.

Keyboard

The keyboard is the primary text-input device; pressing a key sends a unique code (ASCII/Unicode) to the CPU. A standard QWERTY keyboard has alphanumeric keys, numeric keypad, function keys (F1-F12), cursor/navigation keys and control keys (Ctrl, Alt, Shift, Enter).

4.2 Output devices

Output device : *hardware that delivers the processed results from the computer to the user, converting the machine's electronic form into a human-readable form (soft copy on screen or hard copy on paper).*

Common output devices: monitor/display (VDU — soft copy), printer and plotter (hard copy), speakers (audio), and projectors. Two examples: monitor and printer.

Printers

Printers give hard copy and are of two broad classes:

Impact printers : strike the paper through an inked ribbon (like a typewriter): dot-matrix (characters formed by a matrix of pins — cheap, noisy, allows carbon copies) and line printers. Good for multi-part stationery.

Non-impact printers : form characters without striking: inkjet (sprays ink droplets — cheap, good colour) and laser (uses a laser and toner like a photocopier — fast, high quality, quiet). Thermal printers are a further non-impact type.

Basis	Impact printer	Non-impact printer
Mechanism	strikes ribbon on paper	no physical strike
Examples	dot-matrix, line	inkjet, laser, thermal
Noise / speed	noisy, slower	quiet, faster
Carbon copies	possible	not possible

4.3 Display devices vs storage devices

PREVIOUS YEAR QUESTIONS

Differentiate: Display devices and Storage devices. [HP·PSC 2021 | Q.8(b) | 10M]

Display vs storage devices : *Display devices are output devices that present information visually to the user in soft-copy form — monitors (CRT, LCD, LED), projectors and screens; they show data but do not retain it. Storage devices hold data and programs (temporarily or permanently) for later use — RAM/ROM (primary) and hard disk, SSD, CD/DVD, USB, tape (secondary); they keep data but do not display it. In short, a display device shows information to the user, while a storage device saves information for the computer.*

Feature	Display device	Storage device
Category	output device	memory device

Function	shows information to user	stores data/programs
Data retention	temporary (while shown)	temporary or permanent
Examples	monitor, projector, LED screen	hard disk, SSD, RAM, USB, CD/DVD

5 OPERATING SYSTEMS & VIRTUAL MEMORY

5.1 The operating system — need and functions

PREVIOUS YEAR QUESTIONS

- *Why is an operating system needed in a computer?* [UK·PSC 2021 | Q.8(iii) | 10M; UK·PSC 2019 | Q.8(iii) | 10M]

Operating system (OS) : *the master system software that manages the computer's hardware and resources and provides an interface between the user/application programs and the hardware. It is the first program loaded on start-up and controls the running of all other programs. Examples: Windows, Linux, Unix, macOS, Android.*

An OS is needed because the user and application programs cannot directly manage the complex hardware; the OS acts as the go-between and resource manager, making the computer usable and efficient. Its main functions are:

Process (CPU) management : Schedules programs/processes and allocates CPU time (multitasking).

Memory management : Allocates and frees main memory among programs and implements virtual memory.

File management : Organises, stores, retrieves and protects files and directories.

Device (I/O) management : Controls input/output devices through their device drivers.

User interface : Provides a command-line (CLI) or graphical (GUI) interface.

Security & other services : User authentication, access control, error handling, and coordination of all resources.

Types of OS include batch, multiprogramming, multitasking, time-sharing, real-time, network and distributed systems — real-time systems being important for process control in agricultural engineering.

5.2 Virtual memory vs RAM

PREVIOUS YEAR QUESTIONS

- *Differentiate between virtual memory and Random Access Memory, and describe the advantages of virtual memory.* [UK·PSC 2021 | Q.8(iii) | 10M; UK·PSC 2019 | Q.8(iii) | 10M]

Virtual memory : *a memory-management technique of the OS in which part of the secondary storage (hard disk/SSD) is used as if it were additional main memory (RAM). When RAM is full, inactive portions of programs/data (pages) are moved to a reserved disk area (the swap file/page file) and brought back when needed. This lets the computer run programs larger than the physical RAM and run more programs at once. The OS translates the program's virtual addresses to physical addresses (paging).*

Feature	*RAM (Random Access Memory)*	*Virtual memory*
What it is	physical hardware (chips)	technique using disk space
Location	on the motherboard	on secondary storage (disk)

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Speed	very fast	much slower (disk access)
Cost	costly per byte	effectively free (uses disk)
Capacity	limited (physical)	large (extends RAM)
Role	actual working memory	apparent extension of RAM

Advantages of virtual memory

allows execution of programs larger than the available physical RAM.

permits more programs to run simultaneously (better multitasking).

uses expensive RAM more efficiently (only active pages kept in RAM).

lowers cost — cheap disk space substitutes for costly RAM.

frees the programmer from worrying about physical memory limits.

The trade-off: because disk is far slower than RAM, excessive paging ('thrashing') slows the system, so virtual memory supplements — but cannot replace — adequate RAM.

6 ALGORITHMS, FLOWCHARTS & PROGRAM DEVELOPMENT

6.1 *Algorithm and flowchart*

PREVIOUS YEAR QUESTIONS

Write short note on / explain in brief: Flow chart.

[OPSC·CSE 2016-17 | P2/8(a) | 20M; OPSC·Forest 2015-16 | P2/8(b) | 20M]

Algorithm : *a finite, step-by-step, unambiguous sequence of instructions to solve a given problem. A good algorithm is finite (ends after a finite number of steps), definite (each step precise), has clear input and output, and is effective (e-ach step doable). It is written independently of any programming language, often in pseudocode.*

Flowchart : *a pictorial (diagrammatic) representation of the sequence of steps/logic of an algorithm or process, drawn with standard symbols connected by flow-lines (arrows). It helps to plan, understand, communicate and debug the logic before coding.*

Symbol	Name	Meaning
Oval / rounded	Terminal	Start / Stop
Parallelogram	Input/Output	read data / print result
Rectangle	Process	calculation / assignment
Diamond	Decision	condition / branch (yes/no)
Arrow	Flow-line	direction of flow
Circle	Connector	join flow across breaks

▣ Standard flowchart symbols

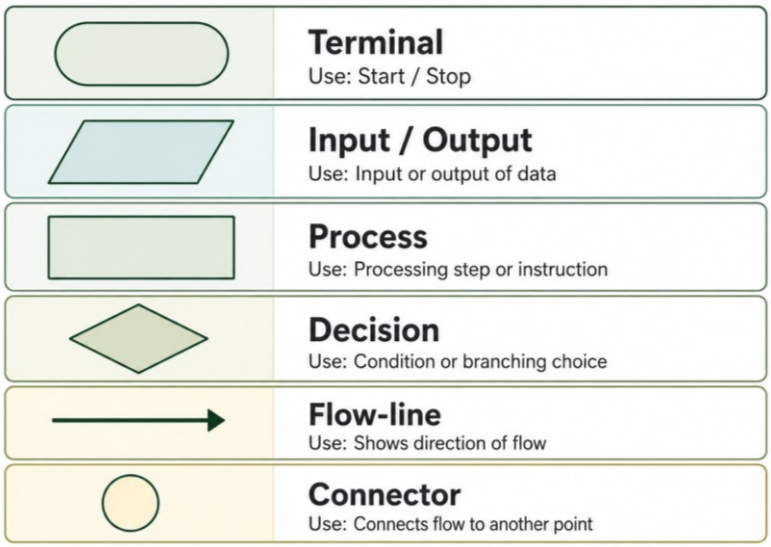


Fig. 10.7 Standard flowchart symbols

6.2 Example 1 — Sum of two numbers

PREVIOUS YEAR QUESTIONS

Write the algorithm and flowchart to find the sum of two numbers. [IFoS 2025 | P2/6(d) | 7M]

Algorithm

Step 1: Start. Step 2: Read the two numbers A and B. Step 3: Compute SUM = A + B. Step 4: Print SUM. Step 5: Stop.

◆ WORKED NUMERICAL — Sum of two numbers (trace) [IFoS 2025 · P2/6(d) · 7M]

Problem. *Verify the algorithm for A = 5, B = 3.*

Read. A = 5, B = 3.

Compute. SUM = A + B = 5 + 3.

Answer = SUM = 8 (printed).

▣ Flowchart — sum of two numbers

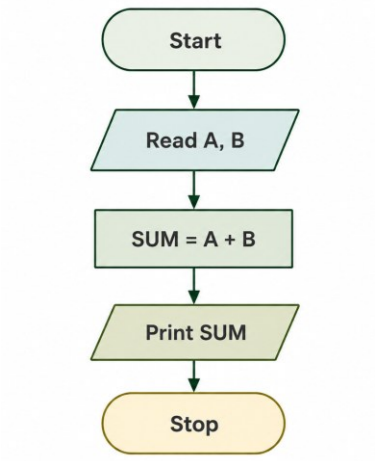


Fig. 10.8 Flowchart: sum of two numbers

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6.3 *Example 2 — Reynolds number for various data sets*

PREVIOUS YEAR QUESTIONS

Write the algorithm (in any programming language) for calculating the Reynolds number when various sets of values of pipe diameter D, fluid velocity v, density ρ and viscosity μ are given.

[IFoS 2018 | P2/8(c) | 10M]

Reynolds number : *a dimensionless number Re = ρvD/μ that characterises flow: Re < 2000 laminar, 2000–4000 transitional, Re > 4000 turbulent. Here ρ = density (kg/m³), v = velocity (m/s), D = pipe diameter (m), μ = dynamic viscosity (Pa·s).*

$$Re = \rho \cdot v \cdot D / \mu$$

Algorithm (for N data sets)

Step 1: Start. Step 2: Read N (number of data sets). Step 3: Set counter i = 1. Step 4: While i ≤ N, repeat steps 5-8. Step 5: Read D, v, ρ, μ for the i-th set. Step 6: Compute Re = (ρ × v × D) / μ. Step 7: If Re < 2000 print 'Laminar'; else if Re ≤ 4000 print 'Transitional'; else print 'Turbulent'; and print Re. Step 8: Increment i = i + 1. Step 9: (End while) Stop.

Equivalent code (C / pseudocode)

```
read N;  for(i = 1; i <= N; i++){ read D, v, rho, mu;  Re = (rho*v*D)/mu;  print Re;  if(Re<2000) print "Laminar"; else if(Re<=4000) print "Transitional"; else print "Turbulent"; }
```

◆ **WORKED NUMERICAL — *Reynolds number (illustrative check)*** [demonstrates the formula & branch]

Problem. *Water: ρ = 1000 kg/m³, v = 2 m/s, D = 0.05 m, μ = 0.001 Pa·s. Find Re and classify.*

Given:

ρ = 1000 kg/m³

v = 2 m/s

D = 0.05 m

μ = 0.001 Pa·s

Formula:

Re = (ρ × v × D) / μ

Substituting the values:

Re = (1000 × 2 × 0.05) / 0.001

Re = 100 / 0.001

Re = 100,000

Therefore,

Re = 1.0 × 10⁵

For pipe flow:

- Re < 2300 → Laminar flow
- Re = 2300–4000 → Transitional flow
- Re > 4000 → Turbulent flow

Since **Re = 100,000 > 4000**, the flow is:

Answer: Reynolds Number = 100,000; the flow is Turbulent.

▣ *Flowchart — Reynolds number (looped)*

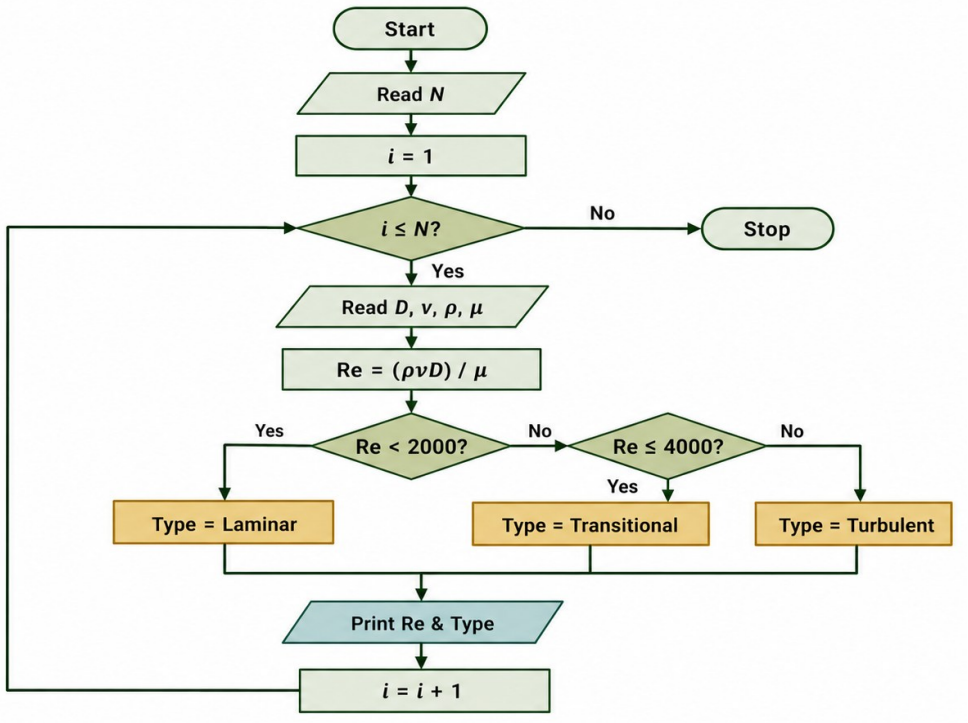


Fig. 10.9 Flowchart: Reynolds number for N data sets

6.4 Steps in developing a program

PREVIOUS YEAR QUESTIONS

Explain various steps involved in developing a programme using a computer.

[IFoS 2023 | P2/5(e) | 8M]

Program development follows a systematic sequence (the program development life cycle):

1. ***Problem definition / analysis*** : Understand the problem clearly — what inputs are given, what output is required and the constraints.
2. ***Algorithm & flowchart design*** : Work out the step-by-step logic (algorithm) and represent it as a flowchart/pseudocode.
3. ***Coding*** : translate the algorithm into a programming language (C, Python, FORTRAN) following its syntax.
4. ***Compilation / translation*** : Convert the source code into machine code using a compiler/interpreter; correct any syntax errors.
5. ***Testing & debugging*** : Run the program with known test data and remove logical errors (bugs) until the output is correct.
6. ***Documentation*** : Prepare comments and user/technical manuals describing the program.
7. ***Implementation & maintenance*** : Put the program into use and update/modify it as requirements change.

6.5 Program translation

Program translators : *system programs that convert a program from one language to another — usually high-level or assembly source code into machine code the CPU can execute.*

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Translator	Converts	Manner / feature
Assembler	assembly language → machine code	one-to-one translation
Compiler	whole high-level program → machine code	translates all at once; fast execution; lists all errors together
Interpreter	high-level program → machine code	line-by-line; slower execution; stops at first error (easy debugging)

A high-level language (HLL — C, Python, FORTRAN) is problem-oriented and portable; assembly language uses mnemonics; machine language (binary) is what the CPU actually runs. A loader/linker then places the machine code in memory for execution.

6.6 Process flow chart for product manufacturing

PREVIOUS YEAR QUESTIONS

Describe the process flow chart for product manufacturing.

[OPSC·CSE 2020-21 | P2/5(d)(v) | 5M; OPSC·CSE 2017-18 | P2/7(a) | 20M]

Process flow chart : *a diagram that shows, step by step, the sequence of operations, material flow and equipment used to convert raw material into a finished product. It uses standard symbols (operation, inspection, transport, delay, storage) and helps in planning, analysing, optimising and controlling a manufacturing/processing line.*

General manufacturing sequence: Raw material → Cleaning/grading → Processing operations (size reduction, mixing, heating/cooling, separation) → Quality inspection → Packaging → Storage → Dispatch. Example (fruit-juice/agro-product processing): Raw fruit → Washing & sorting → Extraction/pulping → Filtration → Pasteurisation (heating) → Cooling → Bottling/packaging → Labelling → Cold storage → Distribution — with inspection points along the line. Such a flow chart lets the engineer identify each unit operation, spot bottlenecks and optimise the process.

▣ Process flow chart — agro-product manufacturing

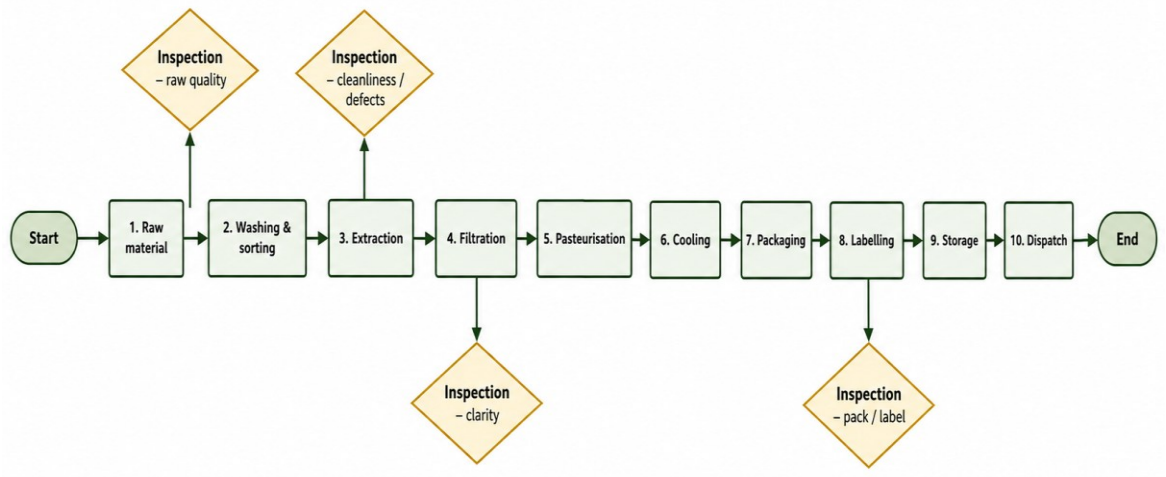


Fig. 10.10 Process flow chart for product manufacturing

7 COMPUTER APPLICATIONS IN AGRICULTURE

7.1 Computer-Aided Design (CAD)

PREVIOUS YEAR QUESTIONS

- *What is Computer-Aided Design (CAD)? Write its application in agricultural engineering.*
  [UK·PSC 2025 | Q.8(i) | 10M]

Computer-Aided Design (CAD) : *the use of computer software to create, modify, analyse and optimise a design, producing accurate 2-D drawings and 3-D models in place of manual drafting. Software such as AutoCAD and SolidWorks lets the designer visualise, test and refine a design before it is built; it is often coupled with CAE (engineering analysis) and CAM (manufacturing).*

Applications in agricultural engineering: design and drafting of farm machinery and implements (ploughs, seed drills, harvesters); tractors and their components; farm structures (grain silos, greenhouses, cattle sheds, storage buildings); irrigation and drainage systems; food-processing equipment (dryers, conveyors); land-development and layout plans; and stress/thermal analysis of components — giving faster, more accurate and optimised designs, easy modification and reduced prototyping.

7.2 Computer techniques in design optimization

PREVIOUS YEAR QUESTIONS

- *Illustrate at least five applications of computer techniques in design optimization of process/equipment used in processing of agricultural and horticultural produce.*
  [OPSC·CSE 2020-21 | P2/8(b) | 20M; OPSC·CSE 2017-18 | P2/7(c) | 20M]

MODEL Q *Design optimisation means using computer tools to find the best combination of geometry, material and operating variables for a process or machine before it is built, instead of arriving at them by trial-and-error fabrication. Five applications:****

1. **CAD/CAE solid modelling (AutoCAD, SolidWorks, CATIA).** A parametric 3-D model lets dimensions, clearances and layout be varied and re-checked before any metal is cut — e.g. altering tray spacing, plenum height and fan position in a tray dryer, or blade angle and clearance in an apple peeling-coring unit, to reach the smallest footprint that still gives the rated capacity.
2. **Finite Element Analysis (ANSYS Mechanical, Abaqus).** Stress, deflection, vibration and thermal expansion are computed so material is placed only where it is needed — e.g. optimising shell thickness and stiffener spacing of a grain silo, or shaft diameter of a screw conveyor, for minimum weight at the required factor of safety.
3. **Computational Fluid Dynamics (ANSYS Fluent, COMSOL).** Air-flow, heat and mass transfer are simulated to make treatment uniform — e.g. repositioning inlet duct and baffles of a tray dryer so tray-to-tray moisture variation falls from about ±8% to ±2%, or optimising stack arrangement and air velocity in a cold store to remove hot spots.
4. **Process modelling and simulation (MATLAB/Simulink, Aspen Plus).** Drying, thermal-processing and refrigeration models are solved to optimise the operating cycle — e.g. predicting the drying curve of onion slices to fix the least-energy time-temperature schedule, or computing F0 value in canning of mango pulp so that sterility is met with minimum quality loss.
5. **Optimisation algorithms and design of experiments (Design-Expert, MATLAB, LINGO).** Response-surface methodology, linear programming and genetic algorithms search the whole variable space for the best combination — e.g. RSM on osmotic dehydration of papaya (syrup concentration, temperature, time) to maximise water loss with least solid gain, or LP to allot a processing line's capacity across products at least cost.

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Also used: statistical analysis of process data and machine-vision grading data for quality optimisation, and control-system/PID tuning for automation of the line.

Together these let the engineer test many design and operating options quickly on the computer — instead of costly physical trials — to arrive at the most efficient, economical and reliable equipment and process.

7.3 *Computer networks*

PREVIOUS YEAR QUESTIONS

- *Explain in brief / short note: Computer networks.*

[OPSC·CSE 2016-17 | P2/8(a) | 20M; OPSC·Forest 2015-16 | P2/8(b) | 20M]

Computer network : *two or more computers interconnected to share data, hardware resources and communicate. By area they are LAN (local — a building), MAN (a city) and WAN (wide/global — e.g. the Internet); common topologies are bus, star and ring. Networks enable data and resource sharing, communication (email), remote access, e-agriculture/market portals, and telemetry/IoT for collecting farm and weather data from remote sensors (Chapter 8).*

7.4 *Applications of computers in agriculture and agro-processing*

PREVIOUS YEAR QUESTIONS

- *Explain in brief / short note: Applications of computer in agricultural processing.*

[OPSC·CSE 2016-17 | P2/8(a) | 20M; OPSC·Forest 2015-16 | P2/8(b) | 20M]

Computers pervade modern agriculture: precision farming (GPS/GIS/variable-rate technology); remote sensing and GIS for crop and land assessment; crop-growth and weather modelling/simulation; farm and financial management software; expert and decision-support systems; e-commerce and market information; process control and automation in food processing; CAD/CAE design; databases and record-keeping; and data acquisition/IoT (Chapter 8). Together they raise productivity, precision, quality and profitability while saving labour and inputs.

8 MULTIMEDIA & AUDIO-VISUAL AIDS

8.1 *Multimedia*

PREVIOUS YEAR QUESTIONS

- *Explain in brief / short note: Multimedia.*

[OPSC·CSE 2016-17 | P2/8(a) | 20M; OPSC·Forest 2015-16 | P2/8(b) | 20M]

Multimedia : *the integrated use of several forms of media — text, graphics/images, audio, video and animation — combined in a single computer-based, often interactive, presentation. It engages more than one sense at once, making communication richer and more effective. Elements: text, image/graphics, audio (sound/music/narration), video and animation. Applications: education and e-learning, training, presentations, advertising, entertainment, simulations and agricultural extension.*

8.2 *Audio-visual (AV) aids*

PREVIOUS YEAR QUESTIONS

- *What is Audio-visual aids? List out its types with examples. Enumerate the advantages of Audio-visual aids.* [MH·PSC 2024 | Q.5(d) | 8M]

Audio-visual aids : *teaching/communication tools that appeal to the senses of hearing (audio), sight (visual) or both (audio-visual) to make learning and extension more effective and lasting.*

Type	Examples
Audio aids	radio, audio recorder/tape, public-address system
Visual aids	charts, posters, models, photographs, chalkboard; projected (slides, OHP, filmstrips)
Audio-visual aids	television, films/video, LCD projector, computer/multimedia, animation

Advantages of AV aids

They capture attention and interest; improve understanding and retention; clarify abstract or complex ideas; save teaching time; reach large and even illiterate audiences (vital in rural extension); provide realistic, concrete experience; motivate learners; and help overcome language barriers.

8.3 *Application in the propagation of afforestation*

PREVIOUS YEAR QUESTIONS

- *Describe in brief the application of Multimedia and Audio-Visual aids in propagation of forestation.* [IFOS 2016 | P2/8(b) | 10M]

Multimedia and AV aids are powerful tools for promoting afforestation and forest conservation: awareness films, documentaries and posters on tree planting and conservation; training videos on nursery raising, planting and management techniques for farmers and foresters; TV/radio programmes and social-media campaigns; interactive multimedia in extension centres; and field demonstrations. Because they reach large, rural and illiterate audiences, make the message vivid and memorable, and motivate participation, they spread forestry knowledge and encourage community involvement far more effectively than words alone.

8.4 *Digital marketing using multimedia & AV aids in agro/food processing*

PREVIOUS YEAR QUESTIONS

- *Explain the role of digital marketing using multimedia and audio-visual aids in the Agro/Food Processing Industry.* [IFOS 2023 | P2/8(d) | 10M]

Digital marketing : *promoting products and services through digital channels (websites, social media, email, e-commerce, mobile apps), using multimedia and audio-visual content (product images, videos, animations, demonstrations).*

In the agro/food-processing industry it enables online branding and advertising (attractive product/recipe videos), social-media campaigns, e-commerce platforms for direct sales, virtual product demonstrations, and customer engagement and feedback. Its advantages — wide reach at low cost, targeted and measurable campaigns, interactivity, and direct farmer/processor-to-consumer selling — help small and large agro-food enterprises build markets, add value and compete, especially by reaching urban and export customers directly.

9 FACT SHEET · SUMMARY · LAST-NIGHT REVISION

Fact / Formula Sheet

Computer units: Input → Memory → CPU (CU + ALU) → Output ; CPU = brain (microprocessor on a chip)

CPU cycle: Fetch → Decode → Execute → Store (repeat)

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Data hierarchy (ascending): bit → byte(character) → field → record → file → database

1 byte = 8 bits ; 1 KB = 1024 B ; 1 MB = 1024 KB ; 1 GB = 1024 MB ; 1 TB = 1024 GB

RAM = volatile read/write (DRAM, SRAM) ; ROM = non-volatile read-only (PROM, EPROM, EEPROM)

Reynolds number Re = ρvD/μ (<2000 laminar, 2000–4000 transitional, >4000 turbulent)

Translators: assembler / compiler (all at once) / interpreter (line-by-line)

Multimedia = text + graphics + audio + video + animation

Summary

A digital computer accepts data and a stored program, processes discrete binary signals and delivers information, organised into five units — input, memory, ALU, control unit and output — the ALU and CU forming the CPU. Its speed, accuracy, storage, automation and versatility make it powerful in agriculture. Hardware is the physical machine; software is the programs (system + application). Data processing converts raw data (facts) into information (meaningful, for decisions) through input → processing → output, with storage. The CPU — ALU (computation), control unit (fetch, decode, direct) and registers (fast internal store) — executes each instruction through the machine cycle: fetch, decode, execute, store. Memory is organised as a hierarchy (registers → cache → RAM → secondary → tape) and, for data, as bit → byte → field → record → file → database. Primary memory (RAM volatile read/write; ROM non-volatile read-only) is fast and CPU-accessible; secondary memory (HDD, SSD, CD/DVD, USB, tape) is large, cheap and permanent. Input devices (keyboard, mouse, scanner, sensors) feed data; output devices (monitor, printer — impact/non-impact — plotter) deliver results; display devices show, storage devices save. The operating system manages processes, memory, files, devices and the user interface, and provides virtual memory — using disk as an apparent extension of RAM to run large/many programs. An algorithm is a finite step-by-step solution and a flowchart its diagram (oval, parallelogram, rectangle, diamond); worked examples give the sum of two numbers and the Reynolds number Re = ρvD/μ for N data sets. Program development runs from problem analysis → algorithm/flowchart → coding → translation (assembler/compiler/interpreter) → testing → documentation → implementation, and a process flow chart maps a manufacturing line. Computers serve agriculture through CAD (design of machinery, structures, equipment), design optimization (CAD/CAE, FEA, CFD, simulation, optimization algorithms), computer networks (LAN/MAN/WAN) and broad applications (precision farming, GIS, management, process control). Finally, multimedia (text+graphics+audio+video+animation) and audio-visual aids power education, extension, afforestation campaigns and digital marketing in the agro/food industry.

Last – Night revision

Digital computer = input + memory + ALU + CU + output; ALU+CU = CPU (microprocessor).

Computer strengths in agriculture: speed, accuracy, storage, automation, versatility.

Hardware = physical parts; software = programs (system + application). Data = raw facts; information = processed data.

CPU parts: ALU (arithmetic/logic), CU (fetch-decode-direct), registers (PC, IR, accumulator).

CPU cycle: Fetch → Decode → Execute → Store.

Data hierarchy ascending: bit → byte → field → record → file → database.

Primary memory (RAM volatile r/w; ROM non-volatile r-only) fast, CPU-direct; secondary (HDD/SSD/CD/USB) large, permanent.

RAM: DRAM (main, refresh) vs SRAM (cache, fast). ROM: PROM/EPROM/EEPROM.

Input: keyboard, mouse, scanner, sensors. Output: monitor, printer (impact = dot-matrix; non-impact = inkjet/laser).

Display device shows info; storage device saves it.

OS manages process/memory/file/device/UI; needed as hardware-user interface & resource manager.

Virtual memory = disk used as extra RAM (paging); runs large/more programs, saves cost; slower than RAM.

Algorithm = step-by-step solution; flowchart symbols: oval, parallelogram, rectangle, diamond, arrow.

Reynolds Re = ρvD/μ (<2000 laminar, >4000 turbulent); illustrative Re = 100000 (turbulent).

Program steps: analysis → algorithm/flowchart → coding → translation → testing → documentation → implementation.

Translators: assembler; compiler (whole, fast); interpreter (line-by-line, easy debug).

CAD = computer design (machinery, structures, equipment). Optimization: CAD/CAE, FEA, CFD, simulation, optimization algorithms.

Networks: LAN/MAN/WAN; topologies bus/star/ring. Multimedia = text+graphics+audio+video+animation.

AV aids: audio/visual/audio-visual; reach illiterate/rural audiences — used in afforestation & digital marketing.

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Last-Night Revision

- Functional elements: sensing → conversion → manipulation → transmission → presentation; signal conditioning.
- Accuracy = closeness to true value; Precision = repeatability. Resolution (smallest change), threshold (from zero), sensitivity, drift, span.
- First-order: $y = Kx_o(1-e^{-t/\tau})$; 63.2 % at τ. Errors: gross, systematic, random.
- Active transducer (self-gen: thermocouple, piezoelectric, solar cell) vs passive (R/L/C: strain gauge, RTD, LVDT).
- Thermocouple = Seebeck emf $E \approx \alpha \Delta T$; Peltier (reverse), Thomson; laws (intermediate metals/temperatures); thermopile = series.
- RTD $R_t = R_o(1+\alpha t)$ (Pt, linear); thermistor $R_T = R_o e^{\beta(1/T - 1/T_o)}$ (NTC, sensitive); pyrometer = non-contact.
- Strain gauge $\Delta R/R = G\varepsilon$ ($G \approx 2$), Wheatstone bridge + dummy for temp compensation.
- Force: balance/accel/elastic/hydraulic-pneumatic load cells ($F = pA$). Torque: ±45° strain gauges, full bridge, slip rings.
- Dynamometers: absorption (brake, BHP), transmission, driving. Drawbar power = draft×speed; $P = 2\pi NT/60$.
- Flow: venturi (low loss)/orifice (cheap, $Q \propto v\Delta p$), rotameter (variable area, direct-reading), hot-wire anemometer (velocity).
- Pressure: manometer $p = \rho gh$ (U-tube/cistern), Bourdon (C-tube), diaphragm; vacuum via thermocouple/Pirani gauge.
- Numericals: Seebeck 4.2 mV; thermistor 5.8 °C; cream steam 48.3 kg/h; BHP 15.7 kW; venturi 3.94 L/s.

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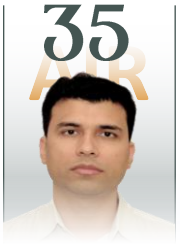
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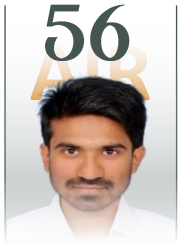
B Jaya Aswantha Reddy

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Sanskar Bharti

Test Series



Sachin Datt

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Anusha Srinivas

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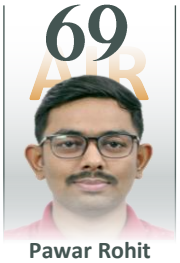
Ashish

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Saurabh Singh

Comprehensive Forestry Course



Pawar Rohit Sanjay

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Omkar Kumar

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Manav Gupta

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Prityesh Raj

Comprehensive Interview Guidance Program (CIGP)



Reshma Nivetha R

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Rajat Kataria

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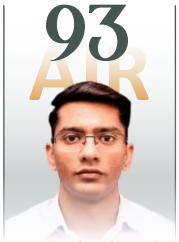
To all our successful candidates in

INDIAN FOREST SERVICE (IFOS) 2025



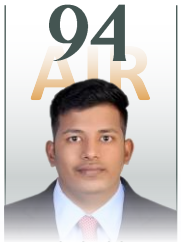
Rajat Kumar

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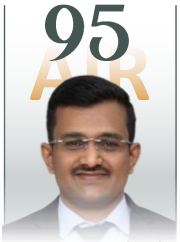
Kailash Chand Yadav

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Patil Shubham Jaysing

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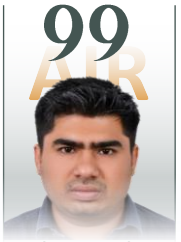
Hinge Harshad Pandurang

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Kushare Pratik Chandrashekhar

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Venkatesh M

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K Sai Goutham

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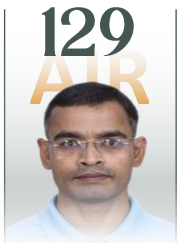
Himanshu Kumar

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Satyam Shivam Sundaram

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Satya Pal Arya

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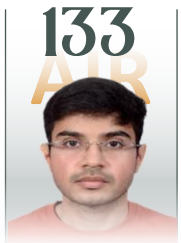
Aakash Verma

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Ajay Kumar Ushara

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Vikalp Mandawaria

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Prateek Kumar Meena

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