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# AGRICULTURAL ENGINEERING

TOOL KIT SERIES



# UPSC

## INDIAN FOREST SERVICE

## 2026 - 27

Linkage of Concepts with PYQs + Infused with Infographics & Maps

*Paper - 2*

*Section - A*

# *Quick Revision*

# MPPSC STATE FOREST SERVICE 2023




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# AGRICULTURE ENGINEERING

**MODULE – 3**

**EDITION : 2026**

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**SYLLABUS**

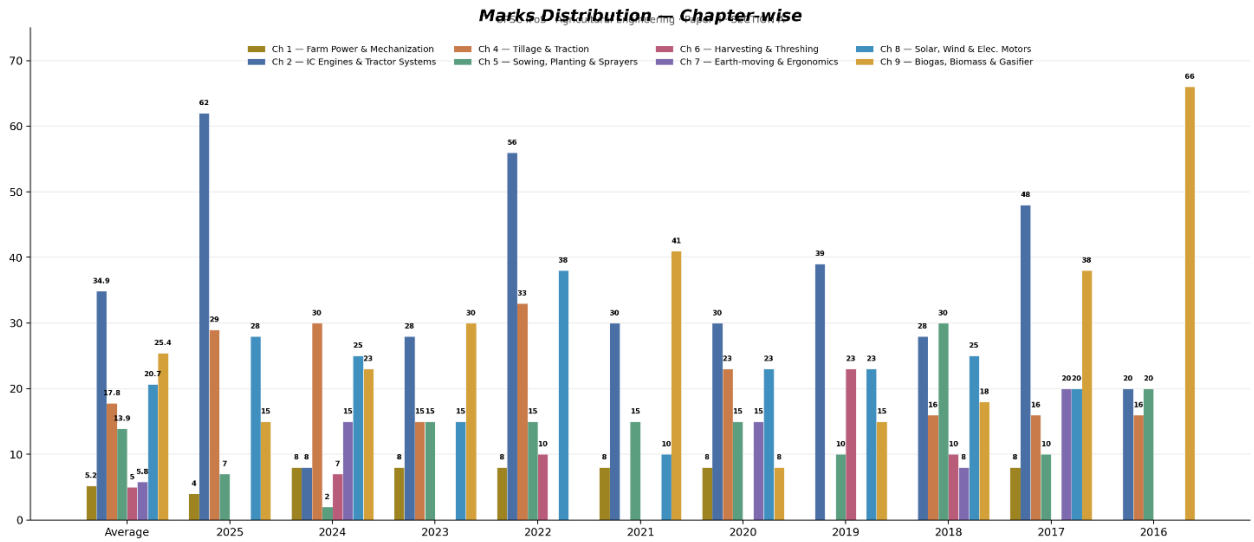
| | |
|---|---|
| **Indian Forest Service (IFoS)** [Paper 2 \| Section A] | ***Farm Power and Machinery:*** Agricultural mechanization and its scope. Sources of farm, power - animate and electro-mechanical. Thermodynamics, construction and working of internal combustion engines. Fuel, ignition, lubrication, cooling and governing system of IC engines. Different types of tractors and power tillers. Power transmission, ground drive, power take off (p.t.o.) and control systems. Operation and maintenance of farm machinery for primary and secondary tillage. Traction theory. Sowing transplanting and interculture implements and tools. Plant protection equipment – spraying and dusting. Harvesting, threshing and combining equipment. Machinery for earth moving and land development - methods and cost estimation. Ergonomics of man-machine system. Machinery for horticulture and agro-forestry, feeds and forages. Haulage of agricultural and forest produce<br><br>***Agro-energy:*** Energy requirements of agricultural operations and agro-processing. Selection, installation, safety and maintenance of electric motors for agricultural applications. Solar (thermal and photovoltaic), wind and bio-gas energy and their utilization in agriculture. Gasification of biomass for running IC engines and for electric power generation. Energy efficient cooking stoves and alternate cooking fuels. Distribution of electricity for agricultural and agro-industrial applications. |

Module - 3

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# INDIAN FOREST SERVICE (IFoS) PYQs | 2016 – 2025

## Farm Mechanization Power Management

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| **2025** | • Define depreciation and list the different methods employed in calculating depreciation. Also, indicate which method is common for farm machines. [P2/1(b·i) \| 4M] |
| **2024** | • What are the major farm operations performed in an irrigated mechanized wheat production system? Enlist the major farm equipment's used to carry out these operations. [P2/1(a) \| 8M] |
| **2023** | • Briefly write about different sources of farm power used in Indian agriculture. [P2/1(a) \| 8M] |
| **2022** | • Categorize the farmers based upon their holding size. Enlist the different types of machines suitable for each category of farmers. [P2/1(a) \| 8M] |
| **2021** | • Discuss the different sources of farm power available in India. What are their merits and demerits? [P2/1(a) \| 8M] |
| **2020** | • Write about the scope of agricultural mechanization for marginal and small land-holding fields in India. [P2/1(a) \| 8M] |
| **2017** | • Define farm mechanization index. Discuss the mechanization status of different farm operations in India. What is the power availability on Indian farms and their constituent sources compared to developed countries. [P2/1(a) \| 8M] |

## IC Engines Engine Theory

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| **2025** | • Define indicated thermal efficiency and relative efficiency of an IC engine. Why is relative efficiency preferred as a measure of engine performance?. [P2/1(a) \| 8M]<br>• Enlist the reasons for lubricating the different moving parts of IC engine. Also, state what you understand by 'Multigrade' lubricating oil. [P2/1(c) \| 8M]<br>• Define the following : (i) Cetane number (ii) Volumetric efficiency of IC engine (iii) Firing order in multicylinder engine (iv) Compression ratio. [P2/1(e) \| 8M]<br>• Write short notes on the following : (i) Pressurised radiator cap (ii) Nozzles of agricultural sprayers (iii) Accessories of tractor drawn mouldboard plough (iv) Gasification of biomass (v) Valve timing diagram of a 4-stroke cycle IC engine. [Note: Multi-chapter Q — IC-engine sub-parts only relevant for Ch 2; refer source paper for full Q.]. [P2/2(a) \| 15M]<br>• Write down the functions of a Carburettor. Explain with the help of a sketch the principle and working of a simple Float-type Carburettor. [P2/2(b) \| 15M]<br>• Write down the functions of Fuel Injection Pump of a tractor engine. Discuss the importance of fuel viscosity in fuel injection system. [P2/4(b·i) \| 8M] |
| **2024** | • Write short notes on the following : (i) Mechanical efficiency of IC engine (ii) Desirable |

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| | characteristics of lubricants used in tractor (iii) Power take-off shaft of tractor (iv) Tractive efficiency. [Note: Multi-chapter Q — IC-engine sub-parts only relevant for Ch 2; refer source paper for full Q.]. [P2/1(b) \| 8M] |
| **2023** | • Write short notes on the following : (i) Compression ratio of IC Engine (ii) Timing gears of IC Engine (iii) Harvesting methods for cereal crops (iv) Capacity of biogas plants. [Note: Multi-chapter Q — IC-engine sub-parts only relevant for Ch 2; refer source paper for full Q.]. [P2/1(c) \| 8M]<br>• With line diagram of each event, explain the working of a four-stroke compression ignition engine. [P2/2(a) \| 10M]<br>• Explain the fuel supply system of a compression ignition engine using a block diagram. [P2/4(a) \| 10M] |
| **2022** | • Write the basic difference between compression ignition (CI) engine and spark ignition (SI) engine. [P2/1(b) \| 8M]<br>• Determine the quantity of fuel to be injected per cycle per cylinder for a six-cylinder, 4-stroke diesel engine having brake-specific fuel consumption of 180 grams and developing 121 hp at 2500 r.p.m. [P2/1(e) \| 8M]<br>• Write the full forms of the following : (i) SAE (ii) API (iii) DI (iv) IDI (v) CRDI (vi) ASTM (vii) BIS (viii) RON (ix) MON (x) TDC. [P2/3(a) \| 10M]<br>• What is the composition and what are the properties of coolant used in cooling system of IC engine? Explain, with the help of labelled neat sketch, the working of forced feed cooling system of tractor engine. [P2/3(b) \| 15M]<br>• With the help of P-V diagram, derive the expression for efficiency of ideal Otto cycle. [P2/4(c) \| 15M] |
| **2021** | • Define the following terms : (i) Top Dead Centre (ii) Engine Displacement Volume (iii) Tappet Clearance (iv) Tilt Angle of a Standard Disc Plough (v) Field Performance Index (vi) Salvage Value of a Machine (vii) Total Solids (viii) Volatile Solids (ix) Hydraulic Retention Time (x) Solar Time. [Note: 10-bullet multi-chapter SN — only IC-engine sub-parts relevant for Ch 2; refer source paper for full Q.]. [P2/2(a) \| 20M]<br>• Explain the different components of battery ignition system of a four-cylinder engine through neat sketch. [P2/4(a) \| 10M] |
| **2020** | • With a line diagram of each stroke, explain the working of 4-stroke spark-ignition engine. [P2/2(a) \| 10M]<br>• What is the purpose of air cleaning system? Write about the working of oil-bath type air cleaning system of a farm tractor. [P2/3(a) \| 10M]<br>• A 4-cylinder 4-stroke CI engine with 100 mm × 120 mm size has a mean effective pressure of 6 kg/cm² . It works at a speed of 300 r.p.m. If the mechanical efficiency is 83%, calculate the developed brake horsepower of the engine. Write the functions of flywheel, timing gear and differential lock. [P2/4(a) \| 10M] |
| **2019** | • Explain the working and importance of the thermostat valve in the cooling system of an I.C. engine. [P2/1(a) \| 8M] |

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| | • Explain the working principles of a centrifugal governor with neat sketch diagram. How is the speed maintained constant under varying load conditions in an I.C. engine?. [P2/1(b) \| 8M]<br>• A high speed diesel engine running at 2000 rev/min has a single cylinder. During compression stroke, the fuel injection starts 20° before top dead centre and ends at the top dead centre. Calculate the duration (in seconds) of the fuel injection that takes place in the cylinder. [P2/1(e) \| 8M]<br>• What do you mean by valve timing diagram of a four-stroke I.C. engine? Describe the occurrence of events in a four-cylinder four-stroke engine in a tabular form, having standard firing order. [P2/2(b) \| 15M] |
| **2018** | • Explain the working of 4-stroke cycle diesel engine with the help of labelled sketch. [P2/1(b) \| 8M]<br>• Define the following : (i) Volumetric efficiency (ii) Octane number (iii) IHP (iv) Detonation (v) Ignition delay (vi) Theoretical field capacity (vii) Scouring (viii) Centre of resistance of MB plough (ix) Disc angle (x) Solar constant. [Note: 10-bullet multi-chapter SN — only IC-engine sub-parts relevant for Ch 2; refer source paper for full Q.]. [P2/2(c) \| 20M] |
| **2017** | • Differentiate between the following : (i) CI and SI engine (ii) Octane Number and Cetane Number (iii) Thermal efficiency and Mechanical efficiency (iv) Caster angle and Camber angle in tractor. [P2/1(b) \| 8M]<br>• Explain the importance of cooling system in a tractor. Describe the principle and working of a forced circulation system. Why thermostat is used?. [P2/2(a) \| 10M]<br>• Explain the working principle of internal combustion engine. How it differs from external combustion engine?. [P2/2(b) \| 10M]<br>• A 4-stroke engine has a mean effective pressure of 7 kg/cm² ; area of piston 730 cm² ; 45 cm stroke length; 110 kg-m torque due to brake load; 4·5 kg fuel consumption per hour and working speed 120 rpm. Calculate IHP, BHP, Mechanical efficiency and specific fuel consumption. [P2/2(c) \| 10M]<br>• Calculate the compression ratio and clearance volume of an engine whose dimensions are 100 × 120 mm and the length of clearance space at top dead centre being 8 mm. [P2/2(d) \| 10M] |
| **2016** | • Draw a neat figure showing different components of a fuel supply system of a general purpose tractor and describe its working. [P2/2(a) \| 10M]<br>• Describe the working of an oil bath type air cleaner. [P2/2(c) \| 10M] |

## Tractors Power Tillers Hydraulics

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| **2025** | • What type of governor is generally used in tractors manufactured in India? Explain its working principle and operation with the help of a suitable diagram. [P2/3(a) \| 15M] |
| **2024** | • Write the functions of the following : (i) Timing gear of an engine (ii) Flywheel of an |

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| | engine (iii) Fluted roller type mechanism (iv) Differential unit of a tractor (v) Straw walker of a combine harvester. [Note: Multi-chapter Q — only Ch 3 (tractor) sub-parts apply here; refer source paper for full Q.]. [P2/2(c) \| 15M] |
| **2023** | • Explain the working principle and uses of the following components of tractor power train : (i) Clutch (ii) Gear Box (iii) Differential (iv) Final Drives (v) Power Take-off. [P2/3(b) \| 15M] |
| **2021** | • Describe in brief : (i) Why do rear wheels of general purpose tractors have tyre inflation pressure less than the front wheels? (ii) Why is a differential lock provided in a tractor? (iii) Why do tractors have independent brake pedals? (iv) Why are drive wheel tyres provided with lugs in general purpose tractors?. [P2/1(b) \| 8M]<br>• With the help of a suitable block diagram indicate power transmission from engine to drive wheels in a tractor and describe the function of each component of the power train. [P2/3(a) \| 15M]<br>• At what speed will a four-wheel tractor overturn during turning if its weight is 2 tonnes, centre of gravity 1 m ahead of rear axle and 75 cm above the ground, wheel base is 2·20 m and wheel spacing 1·6 m? The distance between the centre of rotation and centre of gravity is 4 m. [P2/4(c) \| 15M] |
| **2020** | • Differentiate between the following in brief : (i) 2-Stroke and 4-Stroke engine (ii) Draft control and Position control hydraulic system (iii) Spraying and Dusting (iv) Seed drill and Transplanter [Note: Multi-chapter Q — only Ch 3 (tractor) sub-parts apply here; refer source paper for full Q.]. [P2/1(b) \| 8M]<br>• Justify the following : (i) Why is the size of rear wheels of tractor larger than the front wheels? (ii) Why is producer gas not used directly for domestic purpose? (iii) Why is the compression ratio of CI engines higher than SI engines? (iv) Why is thermostat valve used in cooling system? [Note: Multi-chapter Q — only Ch 3 (tractor) sub-parts apply here; refer source paper for full Q.]. [P2/1(c) \| 8M]<br>• With a flow chart, explain the working of tractor power train by mentioning the function of each component. [Note: Split sub-part from a multi-part Q — refer source paper for sibling sub-parts assigned to other chapters.]. [P2/2(b·ii) \| 10M] |
| **2019** | • What do you understand by draft sensing in hydraulics of a tractor? Discuss with the help of suitable diagram, the automatic position control systems on tractors. [P2/2(c) \| 15M]<br>• What are the different adjustments in the front wheels of tractors? Discuss with the help of suitable diagram. [P2/3(c) \| 15M]<br>• A multi-plate clutch is to be designed for a vehicle whose engine develops maximum torque of 13 Nm at 3500 r.p.m. The external diameter of the clutch facings is limited to 100 mm and the inner diameter may be assumed to be 0·2 times the external diameter. The maximum intensity of pressure may be taken as 80 kPa and μ = 0·3. Calculate the number of plates. Assume uniform wear. [P2/4(a) \| 10M]<br>• What is the purpose of traction aids in wheeled tractors? Discuss the different types of traction aids used in a wheeled tractor. [P2/2(a) \| 10M] |

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| **2018** | • How is power transmitted from the engine to the traction wheels and PTO shaft of two-wheel drive tractor? Explain with a schematic diagram. [P2/3(b) \| 10M] |
| **2016** | • Differentiate between the following in brief : (i) Naturally aspirated engine and Turbo-charged engine (ii) Centrifugal pump and Gear pump (iii) Single plate clutch system and Dual plate clutch system (iv) Wheel base and Track width [Note: Multi-chapter Q — only Ch 3 (tractor) sub-parts apply here; refer source paper for full Q.]. [P2/1(a) \| 8M]<br>• Draw a neat schematic diagram of a tractor power train and discuss the significance of each member of the power train. [P2/2(b) \| 10M]<br>• Answer the following : (i) Why do general purpose tractors have larger rear wheels and smaller front wheels? (ii) Why is a certain amount of valve clearance provided in valves of IC engines? (iii) Why do tractor rear wheels have lesser inflation pressure than the front wheels? (iv) Why is a breather provided in an engine? (v) Why does the radiator in a tractor cooling system have a pressure cap? [Note: Multi-chapter Q — only Ch 3 (tractor) sub-parts apply here; refer source paper for full Q.]. [P2/2(d) \| 10M] |

## Tillage Implements Traction Theory

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| **2025** | • A disc harrow with a draft of 18 N is required to be pulled at a speed of 4 km/h in a firm untilled field by a tractor having maximum PTO power rating of 40 kW. Calculate the actual PTO power needed to pull the harrow, if the tractive and transmission coefficient for a 2-wheel drive tractor for the untilled firm soil is 0·75. [Note: Split sub-part from a multi-part Q — refer source paper for sibling sub-parts assigned to other chapters.]. [P2/1(b·ii) \| 4M]<br>• (i) What types of disc harrow fall under the category of 'Double Action' disc harrow? Explain their working with a line sketch. [5 M] (ii) A tractor weighing 28·5 kN with a front wheel reaction of 9·0 kN, is in static position on a horizontal surface. The wheelbase is 2·08 m. Calculate the horizontal distance from the rear axle centreline to the centre of gravity. Also, calculate the rear wheel reaction and explain with reason if it is a 2-wheel drive or a 4-wheel drive tractor. [10 M]. [P2/3(b) \| 15M]<br>• Classify implements on the basis of how they are attached to a wheel-type Agricultural Tractor and discuss each. [P2/4(c) \| 10M] |
| **2024** | • Write about the effect of the following : (i) Overlapping of discs on field capacity of disc plough (ii) Liquid pressure in a sprayer on nozzle characteristics (iii) Level of oil in an oil-bath type air cleaner (iv) Drive wheel tyre pressure on tractive performance [Note: Multi-chapter Q — only Ch 4 (tillage / traction) sub-parts apply here; refer source paper for full Q.]. [P2/1(d) \| 8M]<br>• The line of pull of a 1·2 m width cultivator is inclined at 20° with horizontal and acting on the vertical plane along the direction of motion. If the pull required by the prime mover at 3 km/h forward speed is 10 kN, determine the drawbar power. [P2/2(a) \| 10M]<br>• Write about different adjustments of standard disc plough and mould board plough for effective field operation. [P2/3(a) \| 10M] |

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| | • Write the difference between the following : (i) Conventional tillage and Conservation tillage [Note: Fragment sub-bullet — parent Q has additional bullets distributed across other chapters per source design; refer original paper for context.]. [P2/1(c·i) \| 2M] |
| **2023** | • A track-type tractor with two tracks each of 300 mm width and 1500 mm length weighs 30 kN. While pulling an implement at a forward speed of 3·6 km/h, the tractor experiences a rolling resistance of 3 kN. Calculate : (i) Gross traction coefficient. (ii) Drawbar power in kW. Consider soil cohesion as 8 kPa and angle of internal friction as 30°. [P2/4(c) \| 15M] |
| **2022** | • What are the different factors affecting the penetration of disc harrow? Define gang angle and its adjustment. [P2/1(c) \| 8M]<br>• Distinguish between the following : (i) Wheel slip and Wheel skid (ii) Vertical suction and Horizontal suction of MB plough (iii) Coulter and Jointer in a plough (iv) Trailed type and Mounted type implement (v) Disc angle and Tilt angle of a disc plough. [P2/2(a) \| 10M]<br>• Write about the care and maintenance during operation and storage of the following : (i) Disc plough and disc harrow (ii) Sprayer and duster (iii) Rotavator [Note: Multi-chapter Q — only Ch 4 (tillage / traction) sub-parts apply here; refer source paper for full Q.]. [P2/**4(b)** \| **15M]** |
| **2020** | • Write about the objectives of primary and secondary tillage. [Note: Split sub-part from a multi-part Q — refer source paper for sibling sub-parts assigned to other chapters.]. **[P2/2(b·i)** \| **5M]**<br>• A 3-bottom 35 cm mould board plough is working at a depth of 20 cm. It requires a draft force of 18 kN working at a speed of 3 kilometres per hour. If the field efficiency is 70%, calculate the actual field capacity of the plough. Also calculate the unit draft and drawbar horsepower. (Consider the acceleration due to gravity as 10 $m/s^2$). [P2/3(b) \| 15M]<br>• Write short notes on the following : (i) Tractive efficiency (Traction Theory) [Note: Fragment sub-bullet — parent Q has additional bullets distributed across other chapters per source design; refer original paper for context.]. [P2/4(c·i) \| 3M] |
| **2018** | • Define tillage. What do you understand by primary tillage and secondary tillage? Classify implements on the basis of how they are attached to the tractor. [P2/1(a) \| 8M]<br>• What is traction? Explain with proper equations/expressions how the traction can be improved under (i) sandy soil, and (ii) clayey soil conditions. [P2/1(d) \| 8M] |
| **2017** | • Total draft of a 4-bottom trailed Mould Board plough is 2000 kg when it is moving at a speed of 6 km/h. Calculate : (i) the unit draft in $kg/cm^2$ if the depth of cut is 20 cm (ii) drawbar horse power required to operate the implement and (iii) field capacity. [P2/1(d) \| 8M]<br>• What is secondary tillage system? Write its objectives. Explain utility of spike tooth and spring tooth harrows. [P2/1(e) \| 8M] |
| **2016** | • Differentiate between the following in brief : (i) Indigenous and Soil turning ploughs (ii) Offset and Tandem disc harrow (iii) Seed drill and Planter (iv) Centre of resistance and |

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| | Centre of pull. [P2/1(b) \| 8M]<br>• Numerical : (i) A three-bottom, 40 cm mouldboard plough is working at a depth of 16 cm. Calculate the actual field capacity when the speed of operation is 4·5 km/h and field performance index is 0·75. (ii) Calculate the area covered (ha) in 8 hours for an animal drawn seed drill which has three furrow openers 180 mm apart. The speed of operation is 2 km/h. (iii) A 4 m width of cut combine is travelling at 50 m/min speed. In one minute time, 50 kg of grain was collected in the grain tank and 60 kg of material was discharged at the rear of the machine. Calculate the capacity of the combine on throughput basis. (iv) Calculate the vertical soil reaction on an implement weighing 350 kg, when a pull of 6·5 kN is exerted on it at an angle of 15° with the ground surface. [Note: Multi-chapter Q — only Ch 4 (tillage / traction) sub-parts apply here; refer source paper for full Q.]. [P2/1(d) \| 8M] |

## Sowing Plant Protection Equipment

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| **2025** | • What is Atomization? Discuss the main fluid properties that affect droplet size in agricultural spraying. [Note: Split sub-part from a multi-part Q — refer source paper for sibling sub-parts assigned to other chapters.]. [P2/4(b·ii) \| 7M] |
| **2024** | • Write the difference between the following : (i) Sowing and Transplanting operation [Note: Fragment sub-bullet — parent Q has additional bullets distributed across other chapters per source design; refer original paper for context.]. [P2/1(c·ii) \| 2M] |
| **2023** | • Explain the construction and working of a tractor-drawn seed drill. [P2/2(b) \| 15M] |
| **2022** | • Calculate the diameter and the peripheral distance between the two consecutive cells to get 20 cm seed spacing by a seed planter having speed ratio between ground wheel and rotor as 4 : 3. Assume wheel diameter as 70 cm, rotor speed for 93 percent fill as 27 m/min, and travel speed as 3·2 km/h. [P2/2(b) \| 15M] |
| **2021** | • What are the different types of sprayers used on agricultural farms? Explain the functioning of manually operated knapsack sprayer with suitable diagram. [P2/3(b) \| 15M] |
| **2020** | • What is the necessity of seed drill calibration? Explain the sequential steps followed in seed drill calibration. [P2/3(c) \| 15M] |
| **2019** | • Draw a neat sketch showing the basic components of a tractor mounted hydraulic sprayer having mechanical agitation. Explain the different factors that affect the amount of spray liquid applied per hectare by a field sprayer. [P2/3(a) \| 10M] |
| **2018** | • What is the function of furrow opener in a seed drill? Write down the different types of furrow openers, their construction and the soil conditions in which they are suitable. [P2/2(a) \| 10M]<br>• A tractor operated hydraulic sprayer has 13 nozzles at 40 cm spacing. The application rate and speed of travel are 800 lit/ha and 5 km/h, respectively. Determine the nozzle flow rate in lit/min. Also determine the working pressure and power requirement of the |

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| | pump if the nozzle diameter is 0·5 mm. Consider the coefficient of discharge and mechanical efficiency of the pump as 0·35 and 0·6, respectively. [P2/3(c) \| 20M] |
| **2017** | • What is the function of hydraulic nozzle in plant protection equipment? Enlist different types of hydraulic nozzles and their application. [P2/3(d) \| 10M] |
| **2016** | • List the different types of seed and fertilizer metering mechanisms used in modern seed-cum-fertilizer drills commonly used in India. How does the rate of application vary using these mechanisms?. [P2/3(a) \| 10M]<br>• List the different types of nozzles used for the application of agro-chemicals in manually operated sprayers used in India. How does their spray pattern differ? Write about their specific use in plant protection. [P2/3(b) \| 10M] |

## Harvesting Threshing Combine Equipment

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| **2024** | • Write about the principle of threshing for different types of threshing cylinders. [Note: Split sub-part from a multi-part Q — refer source paper for sibling sub-parts assigned to other chapters.]. [P2/4(c·i) \| 7M] |
| **2022** | • Enlist the different components of conventional reciprocating mower. Explain the effect of improper registration and alignment of cutter bar on its performance. [P2/4(a) \| 10M] |
| **2019** | • What are the different types of threshing cylinders/drums employed on mechanical threshers for different crops? Explain them briefly with the help of sketches. [P2/1(c) \| 8M]<br>• What are the functions of Combine harvester? Discuss the different types and sources of grain losses. [P2/4(c) \| 15M] |
| **2018** | • What is the function of a mower? Write down the different parts of a conventional reciprocating mower. What do you understand by Alignment and Registration of mower?. [P2/2(b) \| 10M] |

## Earth-moving Equipment Ergonomics

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| **2024** | • (i) Name different machines used for earth moving and land development operations. [5 M] (ii) Explain the working of a tractor operated post-hole digger for horticultural and forestry plantation. [10 M]. [P2/3(b) \| 15M] |
| **2020** | • (i) Write about the importance of ergonomics in farm machinery design. Enlist anthropometric parameters used in design of farm implements. [8 M] (ii) Define wheel base and wheel track. Explain the terms used in the empirical equation $F = Ac + W \tan \phi$, related to tire performance. [7 M] [Note: Multi-chapter Q — only Ch 7 (earth-moving / ergonomics) sub-parts apply here; refer source paper for full Q.]. [P2/4(b) \| 15M] |
| **2018** | • Define Ergonomics and Anthropometry. Describe in brief about the human factors considered in design of modern tractors. [P2/1(c) \| 8M] |
| **2017** | • What is the significance of ergonomics in farm machine design? Define human |

| | |
|---|---|
| | efficiency. Describe the methods to assess human energy consumption of a farm worker. What are various angles the agriculture worker has to work?. [P2/4(c) \| 10M]<br>• Why decibel scale is used for sound measurement? What is the sound pressure for a 80 dB(A) sound of a tractor? If the sound pressure is increased eight times, determine the resulting sound in dB(A). What are tractor seat vibration parameters? Discuss in detail. [P2/4(d) \| 10M] |

## solar wind electric motors

| | |
|---|---|
| **2025** | • What is Solar Constant? Write about the instruments that are used to measure solar energy. [P2/1(d) \| 8M]<br>• Discuss the different types of solar energy collectors and their applications. [P2/2(c) \| 10M]<br>• Write down the classification of Induction Motors. List the factors that should be considered for selecting the right type of motor. [P2/3(c) \| 10M] |
| **2024** | • Write short notes on the following : (i) BLDC motor (ii) Different renewable cooking fuels (iii) Working principle of a wind turbine [Note: Multi-chapter Q — only Ch 8 (solar / wind / motor) sub-parts apply here; refer source paper for full Q.]. [P2/2(b) \| 15M]<br>• Write the operating principle of a photovoltaic cell. Mention the efficiency of different types of silicon PV cells. [P2/4(b) \| 10M] |
| **2023** | • Briefly write about different devices and components of a solar photo-voltaic system. Write about the applications of solar dryer. [P2/2(c) \| 15M] |
| **2022** | • What do you understand by global radiation and diffuse radiation?. [P2/1(d) \| 8M]<br>• What do you understand by solar thermal energy collectors? Discuss the various design parameters affecting the performance of solar flat-plate collector. [P2/2(c) \| 15M]<br>• How do you classify the windmill? Discuss the different types of rotor blades used in the windmill. [P2/3(c) \| 15M] |
| **2021** | • Name the different components required in a Solar PV system for household application and describe the function of each component. [P2/2(b) \| 10M] |
| **2020** | • What factors are required to be considered for selection of electric motor used in agricultural operations? Write about the regular maintenance needed by an electric motor. [P2/1(e) \| 8M]<br>• Explain the functions of different components of a solar photovoltaic system used for power generation. Write a short note on solar flat plate collector. [P2/2(c) \| 15M] |
| **2019** | • Explain with the help of labelled diagram, the construction details of single reflector box solar cooker. What are the limitations of solar cookers?. [P2/1(d) \| 8M]<br>• What are different types of rotors of windmill? Describe the different components of |

| | |
|---|---|
| | wind-electric generating system with the help of suitable diagram. [P2/3(b) \| 15M] |
| **2018** | • Explain the principle of operation of concentrating type solar collector with a suitable diagram. What are the advantages and disadvantages of such collectors over flat plate solar collectors?. [P2/4(a) \| 15M]<br>• The cut-in wind speed of a horizontal axis wind generator having 8 m diameter blade span is 5·0 m/s. The wind turbine generates 4·0 kW electrical power at 6·5 m/s wind speed. Determine the overall efficiency of the wind turbine generator considering the density of air as 1·2 kg/m$^3$. [P2/4(c) \| 10M] |
| **2017** | • Describe the working of wind energy system with the help of line diagram along with main components. [P2/3(b) \| 10M]<br>• An agricultural machine has to be operated by solar energy. What should be the area of solar panel normal to Sun's rays (assuming very sunny day) in India with following parameters?. [P2/4(b) \| 10M] |

## Biogas Biomass & Gasifier

| | |
|---|---|
| **2025** | • Classify the digester of a biogas plant on the basis of construction as well as on the basis of gas storage. Also, discuss the utilization of biogas for different applications. [P2/4(a) \| 15M] |
| **2024** | • Enlist different types of fixed-bed biomass gasifiers and discuss different zones with temperature profiles. [P2/1(e) \| 8M]<br>• Write the effect of the following on biogas production from a cow manure-based biogas plant : (i) Manure-water ratio (ii) Ambient temperature (iii) Total solid content in manure (iv) pH of slurry (v) Ammoniacal nitrogen in slurry. [P2/4(a) \| 15M] |
| **2023** | • (i) What are the different methods of biomass conversion for energy generation? Enlist different processes of energy conversion under each method. [10 M] (ii) Name the different components of biomass gasifier-based electric power generation system. [5 M]. [P2/3(a) \| 15M]<br>• Using a neat diagram, explain the construction and working of KVIC-type biogas plant. [P2/4(b) \| 15M] |
| **2021** | • Distinguish between the following in brief : (i) Biogas and Producer Gas (ii) Compressed Natural Gas and Compressed Biogas (iii) AC Motor and DC Motor (iv) Solar Cell and Dry Cell [Note: Multi-chapter Q — only Ch 9 (biogas / biomass / gasifier) sub-parts apply here; refer source paper for full Q.]. [P2/1(d) \| 8M]<br>• List the factors affecting the following : (i) Biogas production from cattle manure (ii) Producer gas production from agricultural crop residues (iii) Draft requirement of a tractor drawn mouldboard plough (iv) Grain losses in a power thresher [Note: Multi-chapter Q — only Ch 9 (biogas / biomass / gasifier) sub-parts apply here; refer source |

| | |
|---|---|
| | paper for full Q.]. [P2/1(e) \| 8M]<br>• A cattle manure-based biogas plant has diameter and height of digester as 2 m and 5 m respectively. The plant is charged daily with 100 kg fresh manure mixing it in equal proportion with water. If the input slurry has density of 1·05 g/cc, calculate the volume of digester of the plant and also the daily biogas production from the plant if [...]. [P2/3(c) \| 10M]<br>• Draw a neat figure showing the different components of a Deenbandhu Biogas plant and describe its working. [P2/4(b) \| 15M] |
| **2020** | • What is gasification? Explain the working of up-draft type gasifier with a neat diagram. [P2/1(d) \| 8M] |
| **2019** | • With the help of suitable diagram, show the different components of floating dome type biogas plant. Compare the advantages and disadvantages of floating dome and fixed dome type digesters in a biogas plant. [P2/4(b) \| 15M] |
| **2018** | • Explain the working principle of a downdraft type gasifier with a suitable diagram. [P2/1(e) \| 8M]<br>• What are the different phases of anaerobic digestion for bio-gas production? What are the advantages of anaerobic digestion?. [P2/3(a) \| 10M] |
| **2017** | • List the factors to be considered for the design of biogas plant. Briefly discuss the components of a biogas plant with the help of neat sketch. [P2/1(c) \| 8M]<br>• Describe in brief various energy efficient cooking stoves and alternate cooking fuels. [P2/3(a) \| 10M]<br>• Find out height and diameter of the digester of a biogas plant, whose design is to be matched with input feed from dairy of 80 cows and 40 calves. Following assumptions may be made : [...]. [P2/3(c) \| 10M]<br>• Calves produce half gobar (dung) compared to cows. Average gobar (dung) available per cattle per day = 10 kg. Average biogas available per kg gobar (dung) per day = 0·03 $m^3$. Average content of solid in gobar (dung) = 18%. Average bulk density of gobar (dung) = 1100 $kg/m^3$. Optimum ratio of gobar (dung) : water in slurry = 1 : 1. Discuss about [...]. [P2/4(a) \| 10M] |
| **2016** | • Differentiate between the following in brief : (i) Gas engine and Dual fuel engine (ii) CNG and Bio-CNG (iii) Anaerobic process and Aerobic process (iv) Active solar heating and Passive solar heating [Note: Multi-chapter Q — only Ch 9 (biogas / biomass / gasifier) sub-parts apply here; refer source paper for full Q.]. [P2/1(c) \| 8M]<br>• Discuss the major differences between the following : (i) Biogas and Producer gas (ii) Biodiesel and Bio-ethanol (iii) Single phase electric motor and Three phase electric motor (iv) Downdraft gassifier and Updraft gassifier. [P2/1(e) \| 8M]<br>• What are the modifications required to run a constant speed diesel engine on dual fuel (biogas + diesel) mode and why? [Note: Multi-chapter Q — only Ch 9 (biogas / biomass / |

| | |
|---|---|
| | gasifier) sub-parts apply here; refer source paper for full Q.]. [P2/3(c) \| 10M]<br>• Calculate the volume of a biogas digester and power available from it assuming the following : [...]. [P2/4(a) \| 15M]<br>• Number of animals = 8. Retention time = 20 days. Temperature of digestion = 35°C. Dry matter consumed per animal per day = 2 kg. Burner efficiency = 70%. Methane content in biogas = 70%. Density of dry matter in slurry = 50 kg/m³. Biogas yield per unit dry mass = 0·2 m³/kg. Heat of combustion of methane = 28 MJ/m³ at STP. Write short notes on [...]. [P2/4(b) \| 15M]<br>• Write the major differences between the following : (i) Tar and Particulate matter (ii) Briquetting and Charring (iii) Wind mill and Water mill (iv) Mechanical efficiency and Thermal efficiency (v) Total solids and Volatile solids. [P2/4(c) \| 10M] |

***Reference resources***

***Farm Power & Machinery***

- *Principles of Farm Machinery — R. A. Kepner, Roy Bainer & E. L. Barger (CBS Publishers)*
- *Farm Machinery and Equipment — C. P. Nakra (Dhanpat Rai)*
- *Elements of Farm Machinery — A. C. Srivastava (Oxford & IBH)*
- *Engineering Principles of Agricultural Machines — Srivastava, Goering, Rohrbach & Buckmaster (ASABE)*
- *Farm Power and Machinery Engineering — A. M. Michael & T. P. Ojha (Jain Brothers) — standard text for tractors, PTO, transmission*

***Tillage, Traction & Ergonomics***

- *Soil Dynamics in Tillage and Traction — W. R. Gill & G. E. Vanden Berg (USDA / CBS reprint)*
- *Off-Road Vehicle Engineering Principles — Wong (traction theory)*

***Plant Protection, Harvesting, Post-Harvest Machinery***

- *Plant Protection Equipment — S. K. Nag & B. S. Panesar*
- *Combine Harvesters — Klenin, Popov, Sakun (Russian classic, CBS reprint)*

***Agro-Energy (Solar, Wind, Biogas, Biomass)***

- *Non-Conventional Energy Sources — G. D. Rai (Khanna Publishers) — most widely used*
- *Renewable Energy Sources and Emerging Technologies — D. P. Kothari, K. C. Singal & R. Ranjan (PHI)*
- *Solar Photovoltaics — Fundamentals, Technologies and Applications — Chetan Singh Solanki (PHI)*
- *Wind Energy Explained — Manwell, McGowan & Rogers (Wiley)*
- *Biomass Gasification and Pyrolysis — Practical Design and Theory — Prabir Basu (Academic Press)*
- *Renewable Energy Engineering and Technology — V. V. N. Kishore (TERI Press)*

***Electric Motors for Agricultural Applications***

- *Electrical Technology, Vol. II – AC & DC Machines – B. L. Theraja & A. K. Theraja (S. Chand)*

***ICAR / Institutional Handbooks (very useful for IFoS)***

- *Handbook of Agricultural Engineering – ICAR, New Delhi*
- *Farm Machinery Design and Data Handbook – CIAE Bhopal*
- *TNAU / IARI e-course notes on Farm Power & Machinery and Renewable Energy (free, PDF)*

CHAPTER

# 1

# FARM MECHANIZATION, POWER SOURCES & FARM MANAGEMENT

*Mechanization status & index · Sources of farm power · Selection by holding size · Field capacity & efficiency · Depreciation & cost of operation · Custom hiring · Break-even*

**SYLLABUS (Paper II | Farm Power & Machinery):** Status, scope and levels of farm mechanization in India; mechanization index; state-vs-country comparison of farm power availability. Sources of farm power — human, animal (draught), mechanical, electrical, biomass; their merits and demerits. Selection of farm machines based on holding size and category of farmer (marginal, small, medium, large). Farm-management economics — fixed cost, variable cost, depreciation methods (straight-line, declining-balance, sum-of-years-digits), salvage value, economic life, break-even analysis, custom hiring of tractors, hourly cost of operation, cost estimation of field operations. Machine field capacity (theoretical, effective), field efficiency, percent time loss, material efficiency.

## Chapter Outline


1. **Farm Mechanization: Status, Scope & Levels in India**
2. **Mechanization Index & Farm-Power Availability**
3. **Sources of Farm Power**
4. **Selection of Farm Machines by Holding Size**
5. **Machine Field Capacity & Efficiency**
6. **Farm-Management Economics I — Cost Structure & Depreciation**
7. **Farm-Management Economics II — Cost of Operation, Custom Hiring & Break-Even**

**MIND-MAP — *Chapter 1 concept map***

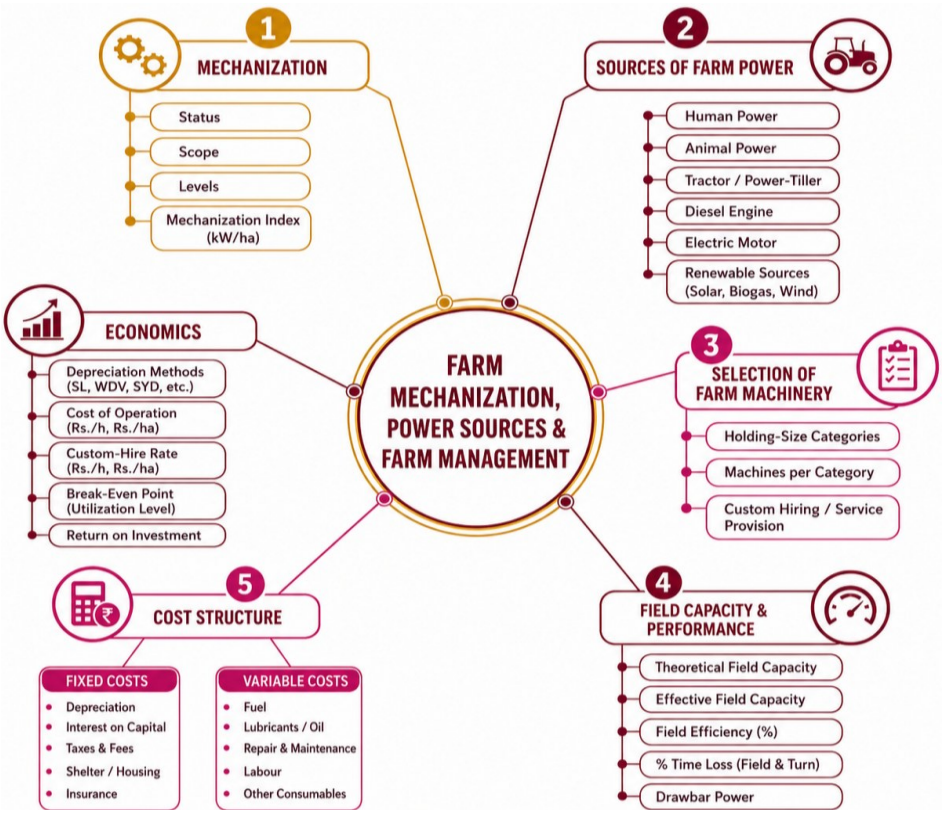



*Fig. 1.0 Concept map of Chapter 1 — mechanization, power sources and machinery economics.*

## 1 FARM MECHANIZATION: STATUS, SCOPE & LEVELS IN INDIA

***Farm mechanization*** : the ***application of engineering and technology*** — tools, implements and power sources — to agricultural operations so as to reduce human drudgery, improve timeliness and precision, raise productivity of land and labour, and cut the cost and losses of production. It is ***land-saving and yield-raising*** in the Indian context, not labour-displacing.

**BENEFITS / ROLE OF MECHANIZATION (UK·PSC 2021)**

Timeliness of operations (critical as cropping intensity rises); higher productivity of land and labour; better quality of work and precise placement of costly inputs; reduced post-harvest losses; reduced drudgery and dignified work that keeps youth in farming; and higher, more stable farm incomes. In the ***21st century*** it must meet shrinking holdings, rising labour cost and scarcity, climate stress, precision/conservation agriculture and the demand for value addition.

**STATUS OF MECHANIZATION IN INDIA**

**Mechanization is uneven** : high in the wheat-rice belt (Punjab, Haryana, western UP), low in the east and the rain-fed/hilly regions. By operation, ***tillage, sowing, threshing and irrigation are highly mechanized***, while ***transplanting, weeding, plant protection and harvesting of many crops remain largely manual***. Engineering interventions can raise food availability 15-25% (farm mechanization 10-15%, post-harvest management 5-10%, value addition 25-400%).

**SCOPE FOR SMALL & MARGINAL HOLDINGS (IFOS 2020)**

Over 85% of Indian holdings are marginal/small, so individual ownership of big machines is uneconomic. The scope lies in ***small, light, low-cost, multi-purpose machines*** (power tillers, mini-tractors, self-propelled


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reapers, seed drills, knapsack/power sprayers, threshers), ***custom hiring / Custom-Hiring Centres and cooperatives***, subsidised credit, and matching implements suited to fragmented fields and diverse crops.

**FARM OPERATIONS IN A MECHANIZED CROP SYSTEM (IFOS 2024)**

| Operation (irrigated wheat) | Equipment |
|---|---|
| Primary tillage | mould-board / disc plough, sub-soiler |
| Secondary tillage & levelling | disc harrow, cultivator, rotavator, laser leveller |
| Sowing & fertilising | seed-cum-fertilizer drill / zero-till drill |
| Irrigation | pump set (diesel engine / electric motor) |
| Plant protection | boom / knapsack sprayer, duster |
| Harvesting & threshing | combine harvester (or reaper + thresher) |
| Transport | tractor-trailer |

**PROBLEMS & FOCAL AREAS**

**Problems :** shrinking, fragmented holdings; wide inter-state power-availability variation; high machinery investment (>₹50,000 cr/yr) with poor selection guidance; productivity plateau; costly credit. **Focal areas —** mechanization of rain-fed farming, horticulture, sugarcane, cotton, pulses and oilseeds; precision & resource-conservation machinery; and post-harvest/value-addition equipment.

**PREVIOUS YEAR QUESTIONS**

- What are the major farm operations performed in an irrigated mechanized wheat production system? Enlist the major farm equipment used to carry out these operations.
  [IFoS 2024 | P2/1(a) | 8M]
- Write about the scope of agricultural mechanization for marginal and small land-holding fields in India.
  [IFoS 2020 | P2/1(a) | 8M]
- What are the benefits of agricultural mechanization? Describe the role of mechanization in meeting the challenges of agriculture in the 21st century in India.
  [UK·PSC RFO (Mains) 2021 | Q.5(i) | 10M]
- Discuss the present status and scope of agricultural mechanization in your state as compared to that of the country. [state-vs-country data in §2]
  [OPSC·CSE (Main) 2020-21 | Paper-II Q.1(a)(i) | 10M]

## 2 MECHANIZATION INDEX & FARM-POWER AVAILABILITY

**LEVEL VS DEGREE OF MECHANIZATION**

***Level of mechanization*** = the extent of use of mechanical power and equipment on a farm; the most-used index is the ***farm-power availability per unit area, kW/ha***. A farm with 2 kW/ha is more mechanized than one with 1 kW/ha. ***Degree of mechanization*** = the extent to which a given operation is mechanized; cumulated (weighted by energy consumption) it gives the ***mechanization index / indicator***.

Degree of mechanization: $DOM = \Sigma(DOM_i \mid EC_i) / \Sigma EC_i$ Machine level: $OM = (CAF \cdot N \cdot Cap \cdot H \cdot D)/(A \cdot R)$

*$DOM_i$ = degree of mechanization of operation i; $EC_i$ = energy-consumption weight; CAF = crop-area factor; N = no. of machines; Cap = effective field capacity (ha/h); H = h/day; D = days available; A = crop area; R = replications. Index <0.50 = low, >0.75 = high level.*

**FARM-POWER AVAILABILITY IN INDIA**

Average farm-power availability rose from about **0.30 kW/ha in 1960-61 to about 1.5-1.8 kW/ha by 2010-12**. Over the same period the share of ***animate sources fell from ~92% to ~13-14%*** while ***mechanical + electrical sources rose from ~8% to ~86%***. Food-grain productivity is positively linked to unit power availability (Y = 674.18·ln X + 1480.8, $R^2$ = 0.99). ***[India power/productivity figures are time-sensitive ]***

**STATE-VS-COUNTRY & INDIA-VS-DEVELOPED COMPARISON (IFOS 2017; OPSC 2016)**

| State (2001) | Farm power (kW/ha) | Foodgrain (kg/ha) |
|---|---|---|
| Punjab | 3.50 | 4,032 |
| Haryana | 2.25 | 3,088 |
| Uttar Pradesh | 1.75 | 2,105 |
| West Bengal | 1.25 | 2,217 |
| Tamil Nadu / Karnataka | 0.90 | ~1,400-2,260 |
| Odisha / Bihar / MP | 0.60-0.80 | 800-1,600 |
| All India | 1.35 | 1,723 |

India's average (~1.5 kW/ha) is still well below developed countries (USA/Japan/Europe ~**2-15 kW/ha**), and India relies far more on animate power and small tractors; developed agriculture is almost wholly mechanical/electrical with high-power self-propelled machines.

**PREVIOUS YEAR QUESTIONS**

- Define farm mechanization index. Discuss the mechanization status of different farm operations in India. What is the power availability on Indian farms and their constituent sources compared to developed countries?

  [IFoS 2017 | P2/1(a) | 8M]

- What is the status of farm mechanization in Odisha as compared to that of the country? Compare the availability of animate power, mechanical power and electrical power in your state with that of India.

  [OPSC·CSE (Main) 2016-17 | Paper-II Q.1(a) | 20M]

***FIGURE 1.1 – Farm-power availability & source shift***

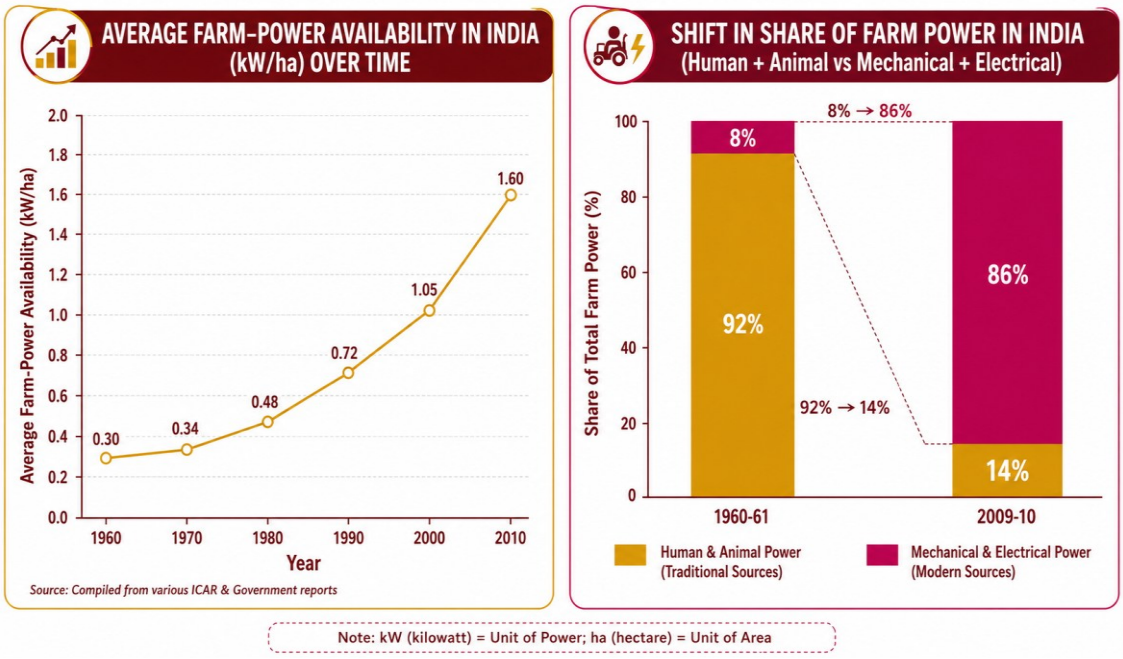



*Fig. 1.1 Rising farm-power availability and the shift from animate to mechanical/electrical power.*


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## 3 SOURCES OF FARM POWER

Farm power is needed for ***mobile*** field jobs and ***stationary*** jobs (pumping, threshing). The sources are:

| Source | Merits | Demerits |
|---|---|---|
| Human (≈0.1 hp) | cheap, flexible, no fuel; only option for hills, transplanting, picking | very low output, slow, seasonal, drudgery |
| Draught animal (pair ≈1 hp) | versatile, works in mud/rain, locally reared, dung→FYM/biogas, saves fuel | slow, low efficiency, year-round feed cost, seasonal |
| Tractor / power tiller | high output, timely, versatile with matching implements | high capital, fuel-dependent, needs skill & repair, uneconomic on tiny farms |
| Diesel / oil engine | portable, independent of grid, high power | costly fuel, noise, maintenance |
| Electric motor | cheap to run, clean, low maintenance, reliable | needs grid, fixed/stationary, load-shedding |
| Renewable (biomass/biogas, wind, solar) | clean, renewable, decentralised | low/variable power density, high initial cost |

**TREND IN INDIA**

Source-wise power availability (~2009, kW/ha): tractor 0.64, electric motor 0.41, diesel engine 0.31, human 0.145, draught animal 0.145, power tiller 0.008. ***Animate power is declining*** (draught-animal population 80 M → 53 M; annual use 1200-1800 h → 250-500 h) while ***tractors, engines and motors rise*** — one tractor replaces ~5 pairs of bullocks, one power tiller ~2 pairs.

**PREVIOUS YEAR QUESTIONS**

- Briefly write about different sources of farm power used in Indian agriculture.
  [IFoS 2023 | P2/1(a) | 8M]
- Discuss the different sources of farm power available in India. What are their merits and demerits?
  [IFoS 2021 | P2/1(a) | 8M]
- Compare the present status and trend of different farm power sources in your state in comparison to the country.
  [OPSC·CSE (Main) 2020-21 | Paper-II Q.1(b)(i) | 10M]

***FIGURE 1.2 — Sources of farm power***

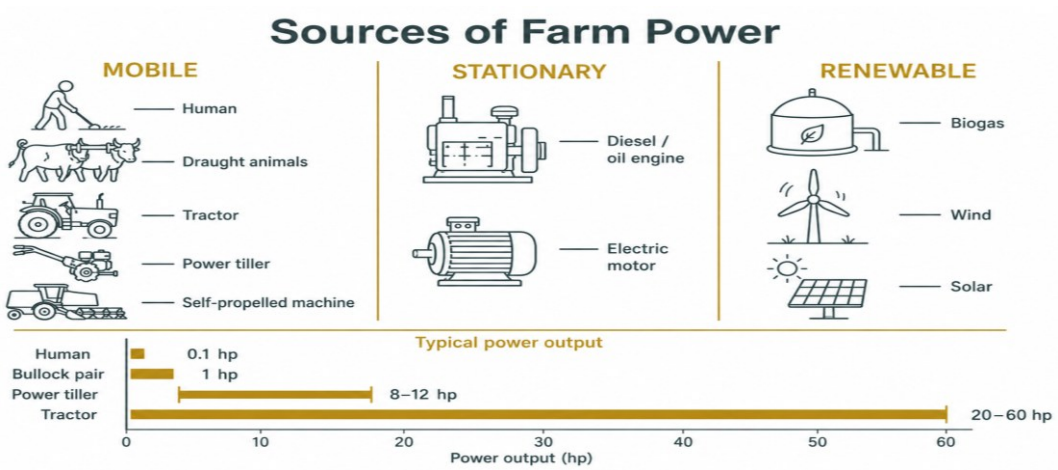



*Fig. 1.2 Classification of farm power sources with typical power output.*

## 4 SELECTIONS OF FARM MACHINES BY HOLDING SIZE

**CATEGORIES OF FARMERS BY HOLDING SIZE**

| Category | Holding size | Suitable machines |
|---|---|---|
| Marginal | < 1 ha | hand tools, improved implements, bullock/power-tiller units, knapsack sprayer; mostly custom hiring |
| Small | 1 - 2 ha | power tiller, mini-tractor, seed drill, self-propelled reaper; custom hiring |
| Semi-medium | 2 - 4 ha | mini/small tractor (20-30 hp) + matching implements, thresher |
| Medium | 4 - 10 ha | tractor (35-45 hp), seed-cum-fertilizer drill, sprayer, thresher/combine (hired) |
| Large | > 10 ha | high-hp tractor (>45 hp), combine harvester, laser leveller, full implement set |

**FACTORS IN MACHINE SELECTION**

Holding size and fragmentation; crops and cropping pattern; power availability; ***timeliness and area to be covered*** (matching field capacity to the available days); capital and credit; running & repair cost; local availability of service, spares and fuel; and versatility (multi-crop/multi-operation use). The tractor and its implements must be ***size-matched*** (implement width to tractor draft/PTO power).

**CUSTOM HIRING (OPSC 2020)**

Custom hiring — renting machine services by the hour/area — is popular with small and marginal farmers because it gives ***access to costly high-capacity machines without owning them***: no large capital outlay, no idle-machine fixed cost on a tiny holding, timely operations (combine, laser leveller), and professional operation & maintenance. Custom-Hiring Centres, cooperatives and FPOs, backed by subsidy, make ownership viable for the custom operator through high annual use.

**PREVIOUS YEAR QUESTIONS**

- Categorize the farmers based upon their holding size. Enlist the different types of machines suitable for each category of farmers.

  [IFoS 2022 | P2/1(a) | 8M]

- Why is the custom hiring of tractors becoming popular among small and marginal farmers?

  [OPSC-CSE (Main) 2020-21 | Paper-II Q.3(a)(ii) | 12M]

## 5 MACHINE FIELD CAPACITY & EFFICIENCY

Field capacity fixes how much area a machine covers per hour — the basis of matching machines to the farm and of every cost-per-hectare estimate.

***Field capacities & efficiency*** — ***Theoretical field capacity (TFC)*** = the rate if the machine used its full width at full speed with no stops. ***Effective field capacity (EFC)*** = the actual rate, allowing for overlaps and time losses. ***Field efficiency*** = EFC/TFC (%).

TFC = (W × S)/10 (ha/h; W in m, S in km/h) EFC = TFC × field efficiency

Field efficiency = EFC/TFC

*Time losses: turning at headlands, filling seed/fertilizer/spray, adjustments, unloading, idle travel. % time loss = (lost time)/(total time)×100. Material efficiency = useful output/(useful + wasted) input.*


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Drawbar power: dbp (hp) = D·S/270 (D in kgf, S in km/h)
dbp (kW) = D·S/3.6 (D in kN, S in km/h)
Draft D = unit soil resistance × cutting cross-section
*D = draft; S = speed. For a plough, cutting cross-section = total width × depth of cut.*

◆ ***WORKED NUMERICAL — Power to pull a four-bottom plough*** **[MH·PSC Forest 2024 | Q.8(a) | 15M (field-capacity/power part)]**

**Problem.** *Determine the horsepower required to pull a four-bottom 32 cm plough working to a depth of 14 cm. The tractor operates at 5.5 km/h and the soil resistance is 0.8 kg/cm². [The question also has a Rittinger/Kick wheat-milling part — a size-reduction/processing topic; answer it in the processing chapter.]*

**Given.** 4 bottoms × 32 cm = 128 cm cutting width; depth 14 cm; S = 5.5 km/h; unit soil resistance 0.8 kg/cm².

**Draft.** cutting cross-section = 128 × 14 = 1792 cm² ; D = 0.8 × 1792 = 1433.6 kgf

**Drawbar power.** dbp = D·S/270 = 1433.6 × 5.5 / 270 = 29.2 hp (= 21.8 kW)

**Result. Drawbar power ≈ 29.2 hp; allowing for transmission & traction losses (~55-60% tractive efficiency), a tractor of ≈ 50 hp is required.**

◆ ***WORKED NUMERICAL — Field capacity of a cultivator*** **[OPSC·CSE (Main) 2024-25 | Paper-II Q.4 | 15M]**

**Problem.** *A tractor with a 3.5 m cultivator cultivates 50 ha at 5.0 km/h. Find the time to complete the operation and the theoretical field capacity. If the operator reports a time loss of 0.75 h per 10 h of field operation, what is the effective field capacity?*

**Theoretical field capacity.** TFC = W·S/10 = 3.5 × 5.0 / 10 = 1.75 ha/h

**Theoretical time.** = area/TFC = 50/1.75 = 28.6 h

**Field efficiency.** time loss 0.75 h per 10 h ⇒ efficiency = (10 − 0.75)/10 = 92.5%

**Effective field capacity.** EFC = 1.75 × 0.925 = 1.62 ha/h ; actual time = 50/1.62 = 30.9 h

**Result. TFC = 1.75 ha/h (theoretical time 28.6 h); EFC = 1.62 ha/h (actual time ≈ 30.9 h).**

◆ ***WORKED NUMERICAL — TFC & percent time loss of a corn planter*** **[OPSC·CSE (Main) 2018-19 | Paper-II Q.1(d) | 20M]**

**Problem.** *Find the theoretical field capacity (ha/h) and percent time loss for 4-row and 6-row corn planters set for 600 mm rows. Row length 400 m, forward speed 6 km/h. The only time losses are 5 s per row for turning at each end and 60 s for filling the seed and fertilizer cans every second round.*

**Width & TFC.** 4-row W = 4×0.6 = 2.4 m ⇒ TFC = 2.4×6/10 = 1.44 ha/h ; 6-row W = 3.6 m ⇒ TFC = 3.6×6/10 = 2.16 ha/h

**Planting time per pass.** = length/speed = 400/(6000/3600) = 240 s ; a round = 2 passes = 480 s

**Turning.** 5 s/row at each end, both ends per round = 2 × 5 × rows ⇒ 4-row 40 s/round, 6-row 60 s/round

**Per two rounds.** 4-row: plant 960 s + turn 80 s + fill 60 s = 1100 s ⇒ % time loss = 140/1100 = 12.7%

6-row: plant 960 s + turn 120 s + fill 60 s = 1140 s ⇒ % time loss = 180/1140 = 15.8%

**Result. 4-row: TFC 1.44 ha/h, time loss 12.7% (EFC ≈ 1.26 ha/h); 6-row: TFC 2.16 ha/h, time loss 15.8% (EFC ≈ 1.82 ha/h).**

**PREVIOUS YEAR QUESTIONS**

- Define: Theoretical field capacity; Effective field capacity; Percentage of time lost; Material efficiency. [The question also asks about butter manufacturing from homogenization & cream separation — a dairy-processing topic; answer it in the processing chapter.]
  [OPSC·CSE (Main) 2015-16 | Paper-II Q.5(a) | 20M]
- How is power measurement essential for optimising the performance of tractors and what role does it play in cost estimation for hiring tractors? [cost/hiring in §7]
  [OPSC·CSE (Main) 2023-24 | Paper-II Q.10(a) | 15M]

***FIGURE 1.3 — Field capacity & headland turning losses***

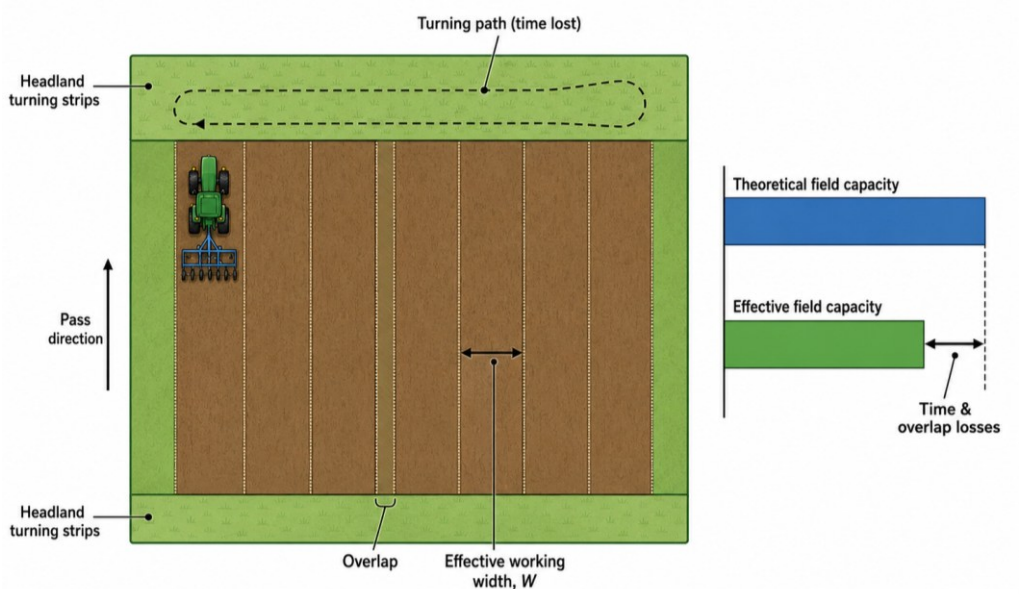



*Fig. 1.3 Working width, overlap and headland turning — why EFC is less than TFC.*

## 6 FARM-MANAGEMENT ECONOMICS I — COST STRUCTURE & DEPRECIATION

The cost of owning and operating a machine decides the profitability of mechanization and the custom-hire rate. Costs split into two families.

| Fixed costs (depend on ownership) | Variable / operating costs (depend on use) |
|---|---|
| Depreciation | Repair & maintenance |
| Interest on investment | Fuel |
| Taxes | Oil / lubrication |
| Shelter (housing) | Labour / operator |
| Insurance | — |

**Fixed cost sub-heads (HP·PSC 2021) :** depreciation, interest, taxes, insurance and shelter (housing) — often remembered as **D-I-R-T-I** (Depreciation, Interest, Repairs*, Taxes, Insurance; *repairs are strictly variable). They accrue whether or not the machine works.

**DEPRECIATION (IFOS 2025)**

***Depreciation*** **:** the ***loss in the value of a machine*** due to age, wear and tear, and obsolescence — usually the largest single cost. Salvage value = the resale value at the end of the economic life (taken ≈10% of purchase price); economic life = the years of most-economic use.

Straight-line: $D = (P - S)/L$ Declining-balance: $D_{n+1} = P(1 - X/L)^n (X/L)$ SYD: $D_n = (L - n)(P - S)/[L(L+1)/2]$


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*P purchase price; S salvage value; L life (years); n age; X = 1-2 (2 = double-declining). Methods: (1) estimated-value, (2) straight-line, (3) declining-balance, (4) sum-of-years-digits, (5) sinking-fund. The straight-line method is the common one for farm machines.*

◆ ***WORKED NUMERICAL — Depreciation of a tractor by the three methods*** **[IFoS 2025 | P2/1(b·i) | 4M (illustration)]**

**Problem.** *A tractor is purchased for ₹3,00,000 with a life of 15 years and salvage value 10% of purchase price. Find the depreciation by the straight-line, sum-of-years-digits and (6th-year) declining-balance methods.*

**Given.** P = ₹3,00,000; L = 15 yr; S = 0.10 × 3,00,000 = ₹30,000.

**Straight-line.** D = (P − S)/L = (3,00,000 − 30,000)/15 = ₹18,000/year (constant).

**Sum-of-years-digits.** Yd = 15×16/2 = 120; (P−S)/Yd

= 2,70,000/120 = 2250;

1st-year D = (15−0) ×2250 = ₹33,750;

2nd = ₹31,500 …

**Declining-balance (X=2).** $V_5 = 3,00,000(1-2/15)^5 = 1,46,684$ ; $V_6 = 3,00,000(1-2/15)^6 = 1,27,126$ ⇒ 6th-year D = ₹19,558.

**Result. Straight-line ₹18,000/yr (flat); SYD & declining-balance charge more in early years; the straight-line method is standard for farm machines.**

**INTEREST, TAXES, SHELTER & INSURANCE**

Interest (average-investment): I = [(P + S)/2] × i

Insurance + shelter ≈ 2% of P per year

*i = interest rate (12-16% typical). Fixed cost per hour = (D + I + taxes + shelter + insurance) ÷ annual hours of use.*

**PREVIOUS YEAR QUESTIONS**

- Define depreciation and list the different methods employed in calculating depreciation. Also, indicate which method is common for farm machines.

  [IFoS 2025 | P2/1(b·i) | 4M]

- While estimating the cost of operation of any agricultural machines, what are the sub-heads included in fixed cost?

  [HP·PSC RFO (Mains) 2021 | Q.5(b) | 10M]

***FIGURE 1.4 — Depreciation methods compared***

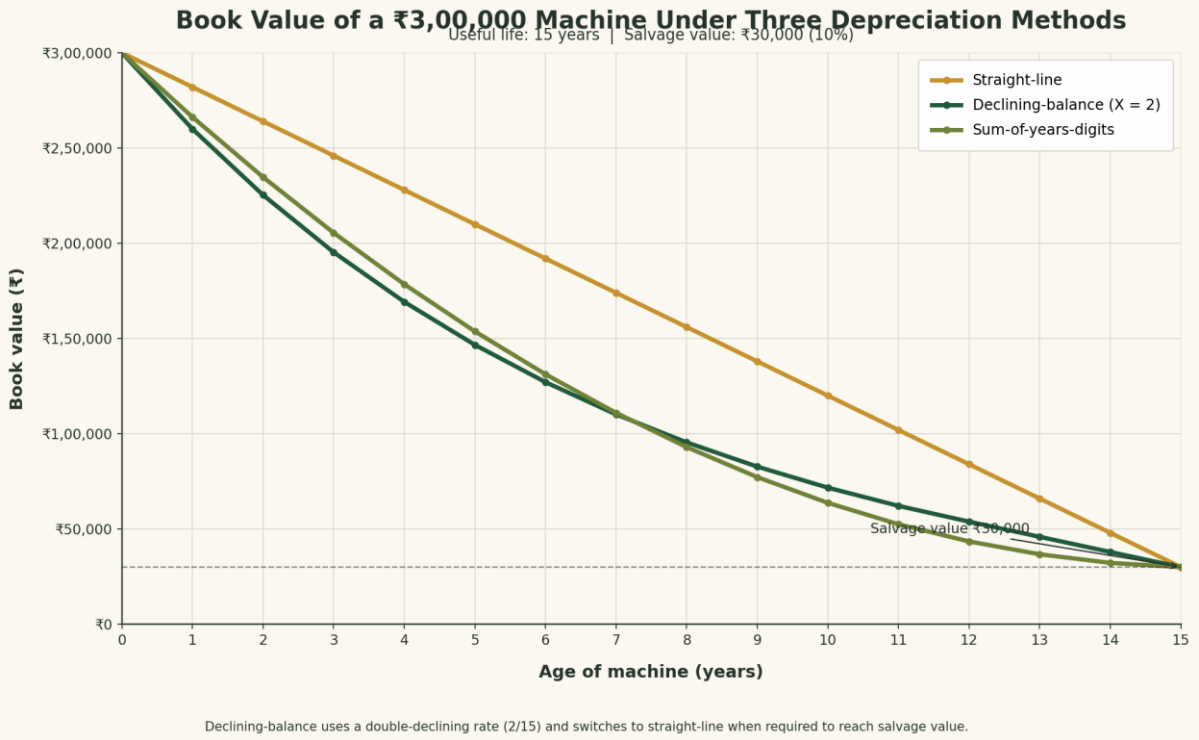



*Fig. 1.4 Book value under straight-line, declining-balance and sum-of-years-digits depreciation.*

## 7 FARM-MANAGEMENT ECONOMICS II — COST OF OPERATION, CUSTOM HIRING & BREAK-EVEN

### VARIABLE COSTS & COST OF OPERATION

Fuel: F = 0.15 P (diesel) or 0.25 P (petrol), l/h (P in kW)

Oil cost = 0.20 × fuel cost

R&M (IS:9164): TAR = $a \cdot X^b$

*TAR = cumulative R&M as % of price; X = 100×(accumulated hours/wear-out life); a,b per machine (tractor 0.10, $X^{1.5}$; plough/cultivator 0.301, $X^{1.3}$). Total cost/h = fixed cost/h + variable cost/h; cost per ha (or per t) = cost per hour ÷ output per hour.*

### COST-ESTIMATION PROCEDURE FOR A FIELD OPERATION (OPSC 2016)

1) list the machine + power unit and their price, life, salvage, annual use;
2) compute the fixed cost/h (depreciation + interest + taxes + shelter + insurance);
3) compute the variable cost/h (fuel + oil + R&M + labour);
4) total cost/h = fixed + variable;
5) divide by the effective field capacity (ha/h) to get ₹/ha (or by output t/h to get ₹/t).

◆ ***WORKED NUMERICAL — Hourly cost of operating a tractor*** **[OPSC·CSE (Main) 2020-21 | Paper-II Q.1(a)(ii) | 10M]**

**Problem.** *Determine the hourly cost of operating a tractor costing ₹5.0 lakh with a useful life of 12 years at about 1000 hours/year. It develops 35 bhp and consumes 8 litres of fuel/hr. Assume zero salvage value and no overhead charge.*

**Fixed cost/h.** Depreciation = (P−S)/(L·H) = 5,00,000/(12×1000) = ₹41.67/h

Interest = [(P+S)/2 × i]/H = (2,50,000 × 0.15)/1000 = ₹37.50/h (at 15%)

Shelter + insurance = (0.02 × 5,00,000)/1000 = ₹10.00/h ⇒ Fixed = ₹89.17/h

**Variable cost/h.** Fuel = 8 L/h × ₹60/L = ₹480 ; oil = 0.20 × 480 = ₹96 ⇒ Variable = ₹576/h (diesel taken at


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₹60/L)

**Result. Hourly cost ≈ ₹89 (fixed) + ₹576 (fuel+oil) = ₹665/h (diesel price assumed ₹60/L; excludes R&M/labour as 'no overhead').**

◆ ***WORKED NUMERICAL — Custom-hire charge of a mini-tractor*** **[OPSC·CSE (Main) 2015-16 | Paper-II Q.2(c) | 20M]**

**Problem.** *A mini-tractor costing ₹2,15,000 is bought by a small farmer (2 ha). To run it on custom hire earning ₹100 per hour profit, find the hire charge (₹/h). Salvage 10% of cost; life 10 yr; 2500 h/yr; interest 1%/month; taxes, insurance & housing 1% of cost/yr; diesel 1.5 L/h @ ₹45/L; oil 0.05 L/h @ ₹100/L; repair & maintenance 10% of cost/yr.*

**Fixed cost/h.** S = 0.10×2,15,000 = 21,500 ; Dep = (2,15,000−21,500)/(10×2500) = ₹7.74/h

Interest (12%/yr) = [(2,15,000+21,500)/2 × 0.12]/2500 = ₹5.68/h ; taxes/ins/housing = (0.01×2,15,000)/2500 = ₹0.86/h ⇒ Fixed = ₹14.28/h

**Variable cost/h.** diesel = 1.5×45 = ₹67.5 ; oil = 0.05×100 = ₹5.0 ; R&M = (0.10×2,15,000)/2500 = ₹8.60 ⇒ Variable = ₹81.10/h

**Total & charge.** cost = 14.28 + 81.10 = ₹95.38/h ; hire charge = 95.38 + 100 (profit) = ₹195.38/h

**Result. Custom-hire charge ≈ ₹195/hour.**

**BREAK-EVEN POINT (OPSC 2016)**

***Break-even point (BEP) :*** the level of ***annual use (hours or hectares)*** at which the total cost of owning a machine equals the cost of the alternative (custom hiring), i.e. profit = 0. Below the BEP, custom hiring is cheaper; above it, owning is cheaper.

BEP (area) = Fixed cost per year / (custom-hire rate − own variable cost per unit)

*Graphically: plot total-cost lines for OWN (steep intercept = fixed cost, gentle slope = variable/ha) and HIRE (through origin, slope = hire rate/ha); their intersection is the BEP. For a product: BEP = fixed cost/(selling price − variable cost per unit).*

◆ ***WORKED NUMERICAL — Break-even area for owning vs custom hiring*** **[cost-analysis numerical (illustrative)]**

**Problem.** *A farmer's annual fixed cost of owning a tractor is ₹60,000. Its variable cost is ₹400/ha and custom hiring costs ₹800/ha. Find the break-even area.*

**Formula.** BEP = fixed cost /(hire rate − own variable cost) = 60,000/(800 − 400)

**Result. BEP = 150 ha/year. If the farmer works more than 150 ha/yr, owning is cheaper; below it, custom hiring pays.**

**PREVIOUS YEAR QUESTIONS**

- Elaborate the procedure of cost estimation of performing field operations by farm machinery. What is break-even point (B.E.P.)? Explain it graphically.

  [OPSC·CSE (Main) 2016-17 | Paper-II Q.1(c) | 20M]

- Determine the hourly cost of operating a tractor costing ₹5.0 lakh (12-yr life, 1000 h/yr, 35 bhp, 8 L/h fuel, zero salvage, no overhead).

  [OPSC·CSE (Main) 2020-21 | Paper-II Q.1(a)(ii) | 10M]

- How is power measurement essential for optimising tractor performance, and what role does it play in cost estimation for hiring tractors?

  [OPSC·CSE (Main) 2023-24 | Paper-II Q.10(a) | 15M]

***FIGURE 1.5 — Break-even point (own vs custom hire)***

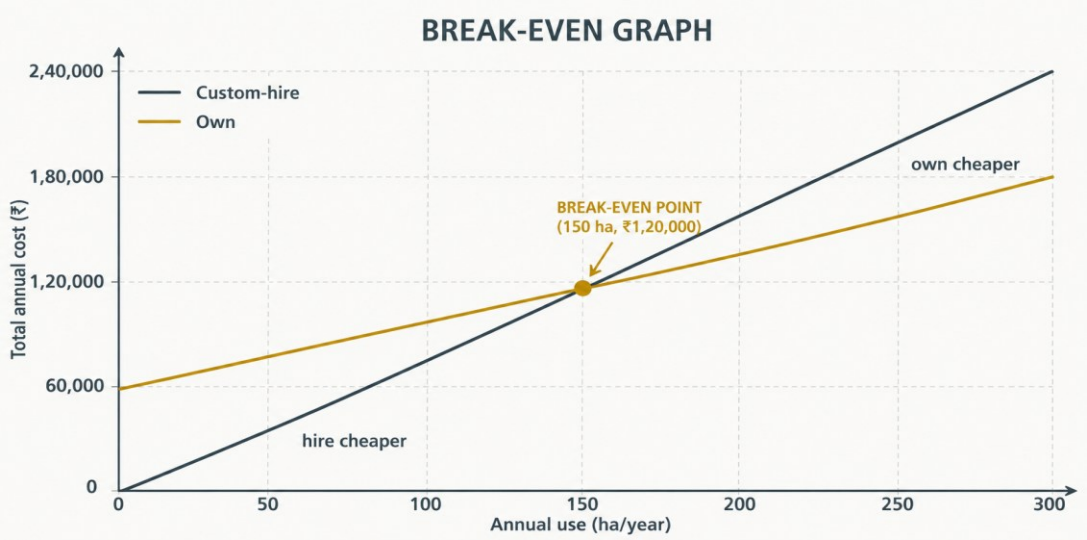



*Fig. 1.5 Break-even point where owning cost equals custom-hire cost.*

**FORMULA SHEET — CHAPTER 1**

| Quantity | Formula |
|---|---|
| Mechanization level index | farm-power availability (kW/ha) |
| Degree of mechanization | DOM = $\Sigma(DOM_i \cdot EC_i)/\Sigma\ EC_i$ |
| Theoretical field capacity | TFC = W·S/10 (ha/h; W m, S km/h) |
| Effective field capacity | EFC = TFC × field efficiency |
| Field efficiency | = EFC/TFC ; %time loss = lost/total ×100 |
| Drawbar power | dbp(hp) = D·S/270 ; dbp(kW) = D·S/3.6 |
| Draft (plough) | D = unit soil resistance × width × depth |
| Straight-line depreciation | D = (P − S)/L |
| Declining-balance | $D_{n+1} = P(1-X/L)^n(X/L)$ |
| Sum-of-years-digits | $D_n = (L-n)(P-S)/[L(L+1)/2]$ |
| Interest (avg investment) | I = [(P+S)/2]·i |
| Insurance + shelter | ≈ 2% of P/year |
| Fuel | F = 0.15P (diesel), 0.25P (petrol) l/h, P in kW |
| Oil cost | = 0.20 × fuel cost |
| R&M (IS:9164) | TAR = $a \cdot X^b$ (% of price) |
| Break-even area | BEP = fixed cost /(hire rate − own variable) |

**SUMMARY**

- Farm mechanization applies engineering to farm operations to cut drudgery, improve timeliness/precision and raise land & labour productivity; in India it is land-saving, not labour-displacing.
- Status is uneven (high in the wheat-rice belt); tillage/sowing/threshing/irrigation are highly mechanized, transplanting/weeding/harvesting largely manual; scope for small farms lies in light low-cost machines and custom hiring.
- Level of mechanization = power availability per hectare (kW/ha); India rose from 0.30 to ~1.6 kW/ha, animate share fell 92%→14%, mechanical+electrical rose 8%→86%; still below developed countries.
- Sources of farm power: human, draught animal, tractor/power tiller, diesel engine, electric motor, renewable — animate declining, mechanical/electrical rising (a tractor replaces ~5 bullock pairs).


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- Select machines by holding size (marginal <1 ha → large >10 ha) and by crop, timeliness, capital and running cost; custom hiring gives small farmers access to costly machines without ownership.
- Field capacity: TFC = W·S/10; EFC = TFC × field efficiency; field efficiency = EFC/TFC; losses from turning, filling and overlap; drawbar power dbp = D·S/270 (hp).
- Machinery cost = fixed (depreciation, interest, taxes, shelter, insurance) + variable (fuel, oil, R&M, labour).
- Depreciation methods: straight-line D=(P−S)/L (common for farm machines), declining-balance, sum-of-years-digits, sinking-fund, estimated-value; interest on average investment I=[(P+S)/2]i.
- Cost of operation per hour = fixed/h + variable/h; per hectare = cost/h ÷ EFC; custom-hire rate = cost/h + profit.
- Break-even point = annual use where owning cost = custom-hire cost = fixed cost/(hire rate − own variable); own above it, hire below it.

**LAST-NIGHT REVISION**

| Must-remember | Value / formula |
|---|---|
| Mechanization level | kW/ha (power availability) |
| India power availability | 0.30 (1960) → ~1.6 kW/ha ; animate 92%→14% |
| Punjab / All-India | 3.50 / 1.35 kW/ha |
| Human / bullock pair | ≈0.1 hp / ≈1 hp |
| Holding categories | marginal <1 \| small 1-2 \| semi-med 2-4 \| medium 4-10 \| large >10 ha |
| TFC | W·S/10 (ha/h) |
| Field efficiency | EFC/TFC |
| Drawbar power | dbp(hp) = D·S/270 |
| Fixed costs | depreciation, interest, taxes, shelter, insurance |
| Variable costs | fuel, oil, R&M, labour |
| Straight-line depreciation | D = (P−S)/L (common for farm machines) |
| Interest | I = [(P+S)/2]·i |
| Fuel (diesel) | F = 0.15P l/h ; oil = 0.20×fuel |
| Break-even area | fixed cost /(hire − own variable) |
| Custom hiring | access to costly machines; no capital, timely, professional |

CHAPTER

# 2

# IC ENGINES & ENGINE THEORY

*SI/CI · 2-stroke & 4-stroke · Otto / Diesel / Dual cycles · Performance & efficiency · Fuel, ignition, cooling & lubrication systems · Governor · Valve timing*

**SYLLABUS (Paper II | Farm Power & Machinery) :** Internal-combustion engines — principles, classification (SI vs CI; 2-stroke vs 4-stroke), comparison with external-combustion engines. Air-standard cycles — Otto, Diesel, Dual; P-V & T-S diagrams; thermal/relative efficiency derivations. Engine performance — IHP, BHP, mechanical/volumetric/thermal/relative efficiency, mean effective pressure, specific fuel consumption (SFC, BSFC), detonation, pre-ignition, knocking, octane and cetane numbers, ignition delay. Engine geometry — TDC, BDC, stroke, bore, compression ratio, clearance and swept volumes, tappet clearance, engine displacement. Engine systems — fuel injection/supply, cooling (forced-feed, thermo-siphon, thermostat, radiator), lubrication (multigrade oils, oil rings, valve train), ignition (battery, magneto), air cleaner (oil-bath), governor (centrifugal, hunting), carburettor, valve-timing diagram, firing order, flywheel, timing gears.

## Chapter Outline


1. **IC Engines: Principle & Classification**
2. **Engine Terminology & Geometry**
3. **Working Cycles — 4-Stroke SI & CI, 2-Stroke**
4. **Air-Standard Cycles — Otto, Diesel & Dual**
5. **Engine Performance & Efficiency**
6. **Combustion, Knock & Fuel Ratings**
7. **Fuel Supply — SI & the Carburettor**
8. **Fuel Supply — CI (FIP, Nozzle, CRDI)**
9. **Ignition Systems — Battery & Magneto**
10. **Cooling System**
11. **Lubrication System**
12. **Governor & Air Cleaner**
13. **Valve Timing, Firing Order & Engine Components**

**MIND-MAP — *Chapter 2 concept map***

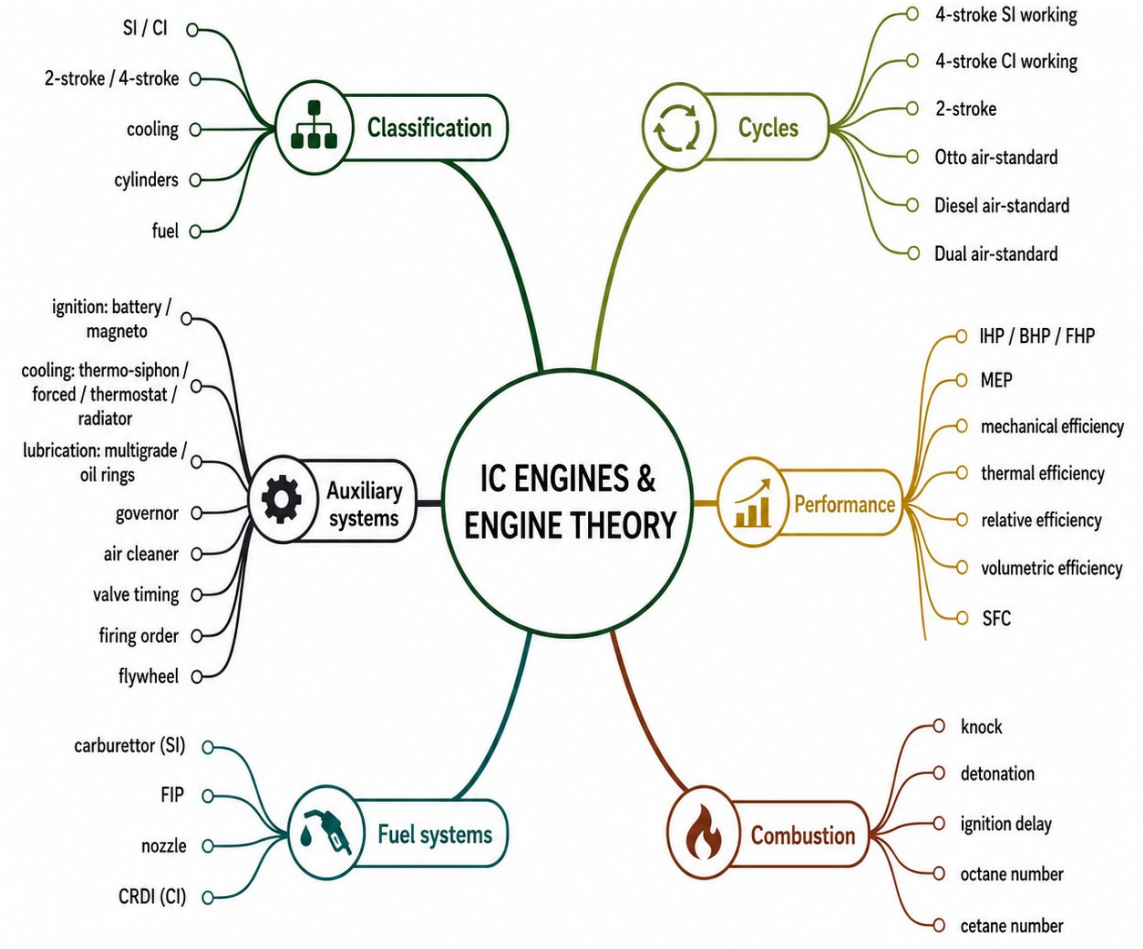



*Fig. 2.0 Concept map of Chapter 2 — IC-engine theory, cycles, performance and systems.*

## 1 IC ENGINES: PRINCIPLE & CLASSIFICATION

***Internal-combustion (IC) engine*** : a heat engine in which the fuel is burnt ***inside the cylinder*** and the high-pressure combustion gases act directly on the piston to do work unlike an ***external-combustion (EC) engine*** (e.g. a steam engine) where fuel is burnt outside, in a separate boiler, and the working fluid (steam) is generated there.

| Basis | IC engine | EC engine (steam) |
|---|---|---|
| Combustion | inside the cylinder | outside, in a boiler/furnace |
| Working fluid | the combustion gases themselves | a separate fluid (steam) heated by the fuel |
| Efficiency | higher (25-40%) | lower (15-20%) |
| Size / weight | compact, light, quick-starting | bulky, heavy, slow to start |
| Fuel | high-grade (petrol, diesel, gas) | any fuel incl. coal/solid |
| Use | tractors, automobiles, pumps | power plants, ships, locomotives (older) |

**WORKING PRINCIPLE OF AN IC ENGINE (IFOS 2017)**

Air (SI: air + fuel) is drawn in and compressed; the fuel is burnt near the end of compression; the resulting ***high-pressure gas expands and pushes the piston*** down the cylinder; the reciprocating motion of the piston is converted by the connecting rod and crankshaft into rotary motion. A flywheel smooths the intermittent power impulses.

**CLASSIFICATION OF IC ENGINES**

| Basis | Types |
|---|---|
| Ignition | spark ignition (SI, petrol) \| compression ignition (CI, diesel) |
| Cycle | four-stroke (1 cycle / 2 revolutions) \| two-stroke (1 cycle / 1 revolution) |
| Fuel | petrol \| diesel \| gas/CNG \| alcohol \| dual-fuel \| gasohol |
| Cooling | air-cooled (fins) \| liquid/water-cooled (jacket + radiator) |
| Cylinder arrangement | single \| in-line \| V \| opposed/flat \| radial |
| Air intake | naturally aspirated \| supercharged \| turbocharged |
| Valve position | I-head (overhead) \| L-head \| F-head \| T-head |

**PREVIOUS YEAR QUESTIONS**

- Explain the working principle of internal combustion engine. How does it differ from external combustion engine?

[IFoS 2017 | P2/2(b) | 10M]

- Explain the working of the IC engine used in most Indian tractors. Why is a cooling system essential in internal-combustion engines? Differentiate between air-cooled and water-cooled systems. [cooling in §10]

[OPSC·CSE (Main) 2015-16 | Paper-II Q.2(a) | 20M]

***FIGURE 2.1 — IC engine: parts & working principle***

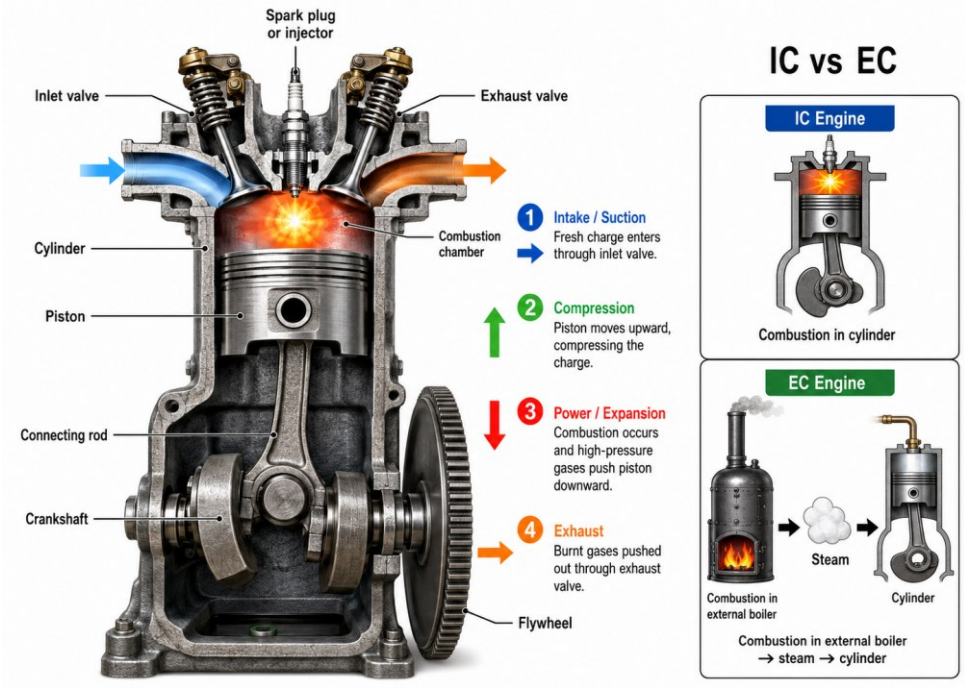



*Fig. 2.1 Principal parts and working of an IC engine: IC vs EC combustion.*

## 2 ENGINE TERMINOLOGY & GEOMETRY

| Term | Meaning |
|---|---|
| TDC / BDC | top/bottom dead centre — piston's extreme positions (farthest / nearest the crankshaft) |
| Bore (D) | inner diameter of the cylinder |
| Stroke (L) | distance travelled by the piston, TDC↔BDC (= 2 × crank radius) |


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| | |
|---|---|
| Clearance volume (Vc) | minimum cylinder volume, piston at TDC |
| Swept / displacement volume (Vs) | volume swept in one stroke = $(\pi/4)D^2L$ (×k for the engine) |
| Compression ratio (r) | (Vs + Vc)/Vc = total volume ÷ clearance volume |
| Tappet clearance | small valve-train gap (cold) allowing for thermal expansion |
| Ignition delay | period from ignition/injection initiation to actual combustion start |

$V_s = (\pi/4)\cdot D^2\cdot L$ $r = (V_s + V_c)/V_c = 1 + V_s/V_c$ Engine displacement = $V_s$ × no. of cylinders

*D bore (cm/m); L stroke; Vs swept volume; Vc clearance volume. Compression ratio r: petrol 6-10:1, diesel 14-20:1. Air-fuel ratio (economy) 13.5-15:1; stoichiometric petrol ≈14.7:1.*

◆ **WORKED NUMERICAL — *Compression ratio & clearance volume*** **[IFoS 2017 | P2/2(d) | 10M]**

**Problem.** *Calculate the compression ratio and clearance volume of an engine whose dimensions are 100 × 120 mm and the length of the clearance space at top dead centre is 8 mm.*

**Given.** bore D = 100 mm = 10 cm; stroke L = 120 mm = 12 cm; clearance length $l_c$ = 8 mm = 0.8 cm.

**Swept volume.** $V_s = (\pi/4)D^2L = 0.7854 \times 10^2 \times 12 = 942.5$ cc

**Clearance volume.** $V_c = (\pi/4)D^2\cdot l_c = 0.7854 \times 10^2 \times 0.8 = 62.8$ cc

**Compression ratio.** $r = (V_s + V_c)/V_c = (942.5 + 62.8)/62.8 = 16.0$ (also $r = 1 + L/l_c = 1 + 12/0.8 = 16$)

**Result. Clearance volume ≈ 62.8 cc; compression ratio = 16 : 1.**

**PREVIOUS YEAR QUESTIONS**

- Define the following: (i) Top Dead Centre (ii) Engine Displacement Volume (iii) Tappet Clearance … [10-part multi-chapter short note — only the IC-engine terms are answered here; tilt angle, field-performance index, salvage value, total/volatile solids, HRT and solar time belong to their own chapters].

  [IFoS 2021 | P2/2(a) | 20M]

- Define the following: (i) Cetane number [§6] (ii) Volumetric efficiency of IC engine [§5] (iii) Firing order in multicylinder engine [§13] (iv) Compression ratio.

  [IFoS 2025 | P2/1(e) | 8M]

## 3 WORKING CYCLES — 4-STROKE SI & CI, 2-STROKE

**FOUR-STROKE SI (PETROL) ENGINE**

1. **Suction :** piston TDC→BDC, inlet valve open, air-fuel mixture drawn in.
2. **Compression:** BDC→TDC, both valves closed, mixture compressed; spark near TDC ignites it.
3. **Power (expansion) :** burnt gas expands, piston TDC→BDC — the work stroke.
4. **Exhaust:** BDC→TDC, exhaust valve open, gases pushed out. One power stroke every ***two revolutions***; valve overlap = both valves briefly open near TDC.

**FOUR-STROKE CI (DIESEL) ENGINE**

Same four strokes, but ***only air is drawn in and compressed*** (to higher pressure/temperature); ***fuel is injected late in compression*** and self-ignites in the hot air; combustion proceeds at nearly constant pressure. No spark plug, no carburettor.

**TWO-STROKE ENGINE**

Inlet, transfer and exhaust ***ports*** (opened/closed by the piston) replace valves; the cycle is completed in ***one revolution*** — suction+compression on the up-stroke, power+exhaust on the down-stroke, with crankcase compression and cross-flow scavenging. One power stroke every revolution.

| Basis | Two-stroke | Four-stroke |
|---|---|---|
| Power strokes | one per revolution | one per two revolutions |
| Power (same size/speed) | ≈ nearly double (theoretically 2×) | less |
| Valves | ports (no valves) | inlet & exhaust valves + cam train |
| Construction | simple, light, cheap | complex, heavier |
| Efficiency & fuel use | lower (scavenging loss, some fuel lost) | higher, better fuel economy |
| Cooling / life | runs hotter, more wear | cooler, longer life |

| Basis | SI (petrol) engine | CI (diesel) engine |
|---|---|---|
| Ignition | spark plug | self-ignition by compression |
| Cycle | Otto (constant-volume heat addition) | Diesel/Dual (constant-pressure) |
| Compression ratio | 6-10 : 1 | 14-20 : 1 |
| Fuel & supply | petrol via carburettor / MPFI | diesel via injection pump & nozzle |
| Charge compressed | air-fuel mixture | air only |
| Efficiency | lower (~25-30%) | higher (~35-40%) |
| Use | cars, motorcycles, small engines | tractors, trucks, pumps, gensets |

**PREVIOUS YEAR QUESTIONS**

- With a line diagram of each stroke, explain the working of a 4-stroke spark-ignition engine.
  [IFoS 2020 | P2/2(a) | 10M]
- With line diagram of each event, explain the working of a four-stroke compression-ignition engine.
  [IFoS 2023 | P2/2(a) | 10M]
- Explain the working of a 4-stroke cycle diesel engine with the help of a labelled sketch.
  [IFoS 2018 | P2/1(b) | 8M]
- Write the basic difference between compression-ignition (CI) engine and spark-ignition (SI) engine.
  [IFoS 2022 | P2/1(b) | 8M]
- Differentiate two-stroke and four-stroke single-cylinder engines.
  [OPSC·CSE (Main) 2020-21 | Paper-II Q.1(c)(i) | 10M]
- Compare two- and four-stroke-cycle engines on the basis of efficiency, power, utility and simplicity in design.
  [OPSC·Forest (Main) 2015-16 | Paper-II Q.1(a) | 20M]

***FIGURE 2.3 — Four-stroke SI & CI cycles***

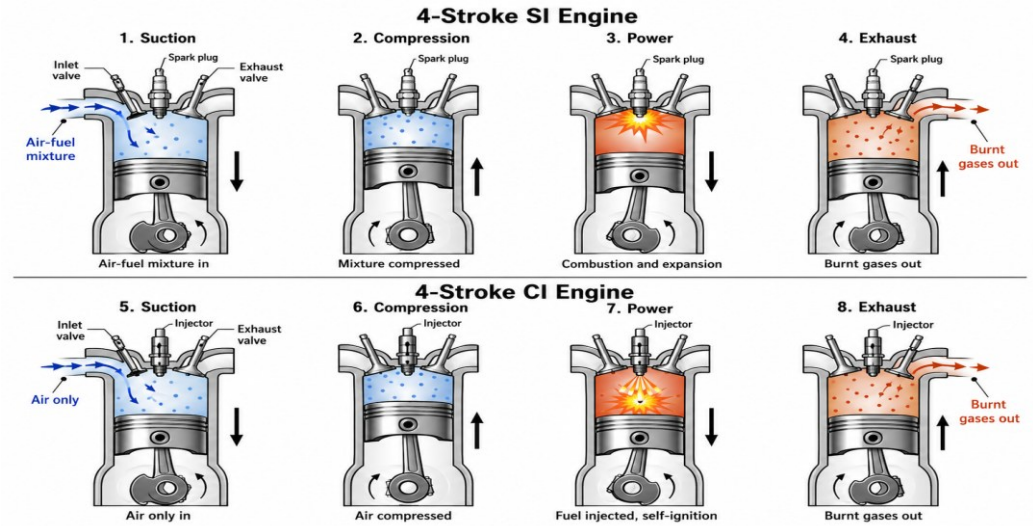



*Fig. 2.3 The four strokes of SI (top) and CI (bottom) engines.*


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## 4 AIR-STANDARD CYCLES — OTTO, DIESEL & DUAL

The ideal thermodynamic cycles that engines approximate are analysed on ***air-standard*** assumptions: the working fluid is a fixed mass of air behaving as an ideal gas with constant specific heats; all processes are reversible; heat is added/rejected from external reservoirs (combustion → heat addition); the cycle is closed. These give the maximum attainable efficiency.

### OTTO CYCLE (CONSTANT-VOLUME HEAT ADDITION — SI ENGINES)

Processes: 1-2 isentropic compression; 2-3 ***constant-volume*** heat addition; 3-4 isentropic expansion; 4-1 constant-volume heat rejection. Efficiency:

$$\eta_{Otto} = 1 - Q_R/Q_S = 1 - (T_4 - T_1)/(T_3 - T_2) = 1 - 1/r^{(\gamma-1)}$$

*Derivation: for isentropics $T_2/T_1 = T_3/T_4 = r^{(\gamma-1)}$; substituting gives $\eta = 1 - 1/r^{(\gamma-1)}$. r = compression ratio; γ = cp/cv = 1.4 (air). Efficiency rises with r only (independent of load).*

### DIESEL CYCLE (CONSTANT-PRESSURE HEAT ADDITION — CI ENGINES)

$$\eta_{Diesel} = 1 - (1/r^{(\gamma-1)}) \mid [(\rho^{\gamma} - 1)/(\gamma(\rho - 1))]$$

*ρ = cut-off ratio = $V_3/V_2$ (volume ratio during heat addition). The bracket > 1, so for the SAME r Otto > Diesel; but diesels use much higher r, so in practice diesel efficiency is higher. Efficiency falls as load (cut-off) increases.*

### DUAL (LIMITED-PRESSURE) CYCLE & COMPARISON

$$\eta_{Dual} = 1 - (1/r^{(\gamma-1)}) \mid [(\alpha \cdot \rho^{\gamma} - 1)/((\alpha - 1) + \gamma \cdot \alpha \cdot (\rho - 1))]$$

*α = pressure ratio (constant-volume part), ρ = cut-off ratio (constant-pressure part). Comparison: for the SAME compression ratio → $\eta_{Otto} > \eta_{Dual} > \eta_{Diesel}$; for the SAME peak pressure & heat input → $\eta_{Diesel} > \eta_{Dual} > \eta_{Otto}$.*

◆ ***WORKED NUMERICAL — Air-standard efficiency of a diesel engine*** **[OPSC·CSE (Main) 2020-21 | Paper-II Q.1(b)(ii) | 10M]**

**Problem.** *A diesel engine has a compression ratio of 14 and cut-off takes place at 6% of the stroke. Find the air-standard efficiency. Take γ = 1.4.*

**Cut-off ratio.** cut-off at 6% of stroke ⇒ $\rho = 1 + 0.06(r - 1) = 1 + 0.06(14 - 1) = 1.78$

**Formula.** $\eta = 1 - (1/r^{(\gamma-1)}) \cdot [(\rho^{\gamma} - 1)/(\gamma(\rho - 1))]$

**Substitution.** $r^{(\gamma-1)} = 14^{0.4} = 2.874$ ; $\rho^{\gamma} = 1.78^{1.4} = 2.242$

$\eta = 1 - (1/2.874) \times [(2.242 - 1)/(1.4 \times 0.78)] = 1 - 0.348 \times 1.137 = 1 - 0.396$

**Result. Air-standard efficiency ≈ 0.604 = 60.4%.**

◆ ***WORKED NUMERICAL — Otto-cycle efficiency (illustration)*** **[cf. IFoS 2022 | P2/4(c) | 15M (derive & apply)]**

**Problem.** *Using the derived expression, find the air-standard efficiency of an Otto (petrol) engine of compression ratio 8, with γ = 1.4.*

**Formula.** $\eta_{Otto} = 1 - 1/r^{(\gamma-1)}$

**Substitution.** $= 1 - 1/8^{0.4} = 1 - 1/2.297 = 1 - 0.435$

**Result. $\eta_{Otto} = 0.565 = 56.5\%$ (rising with compression ratio).**

**PREVIOUS YEAR QUESTIONS**

- With the help of a P-V diagram, derive the expression for the efficiency of an ideal Otto cycle. [IFoS 2022 | P2/4(c) | 15M]
- Explain the working principle of the Otto cycle with the help of the P-V and T-S diagram. [OPSC·CSE (Main) 2023-24 | Paper-II Q.2(a) | 15M]
- Derive the thermal efficiency of the Otto cycle. [OPSC·CSE (Main) 2022-23 | Paper-II Q.1(a) | 10M]
- What do you mean by Otto cycle and Diesel cycle? Explain with neat diagram giving an expression for thermal efficiency. [OPSC·CSE (Main) 2017-18 | Paper-II Q.1(a) | 20M]

***FIGURE 2.4 — Otto, Diesel & Dual cycles (P-V and T-S)***

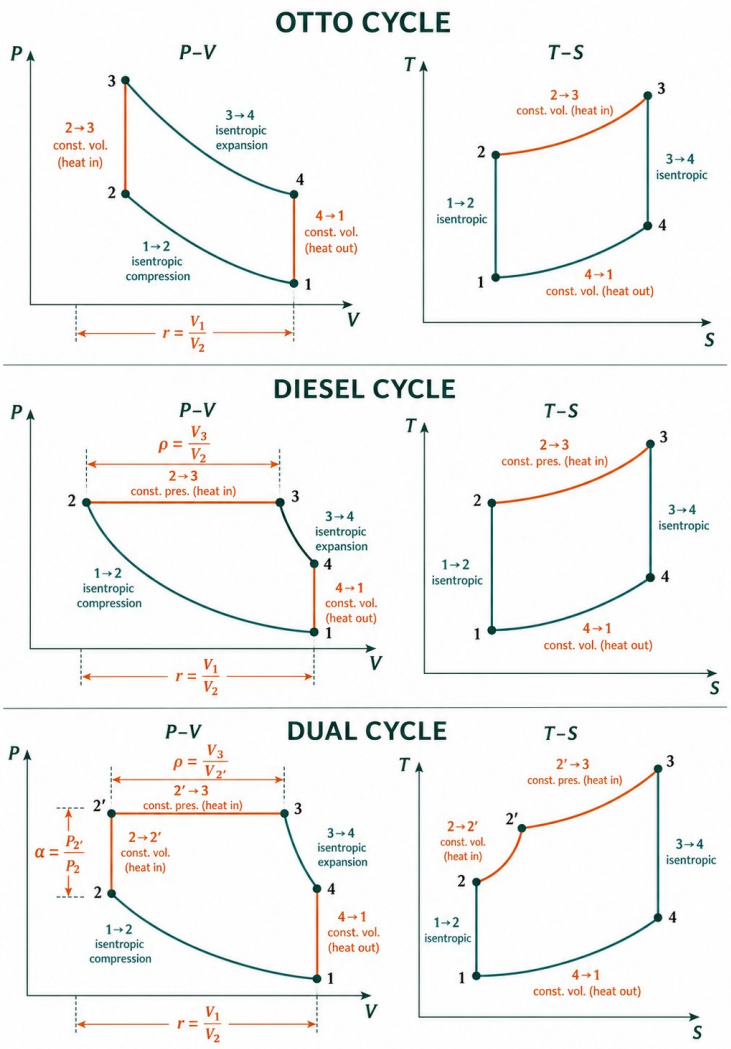



*Fig. 2.4 P-V and T-S diagrams of the Otto, Diesel and Dual air-standard cycles.*

## 5 ENGINE PERFORMANCE & EFFICIENCY

### POWER TERMS

$IP = p_m \cdot L \cdot A \cdot N \cdot k$ $\quad BP = 2\pi NT/60$ $\quad FP = IP - BP$

*IP indicated power (from cylinder gas pressure); $p_m$ mean effective pressure; L stroke (m); A piston area ($m^2$); N power strokes/s (= (rpm/60)/2 for 4-stroke); k cylinders; BP brake power (T = torque N·m, N rpm); FP friction power. Metric hp: divide W by 735.5, or IP(hp) = $p_m \cdot L \cdot A \cdot N \cdot k/(75\times60)$ with $p_m$ kgf/$cm^2$, A $cm^2$, N power strokes/min.*

### EFFICIENCIES & FUEL CONSUMPTION

$\eta_{mech} = BP/IP$ $\quad \eta_{ith} = IP/(\dot{m}_f \cdot CV)$ $\quad \eta_{bth} = BP/(\dot{m}_f \cdot CV)$ $\quad \eta_{rel} = \eta_{thermal}/\eta_{air\text{-}standard}$ $\quad \eta_{vol}$ = air inducted/swept volume $\quad$ SFC = fuel-rate/power

*$\dot{m}_f$ fuel mass flow; CV calorific value. Relative efficiency compares the real engine with its own ideal cycle — preferred because it isolates design/operating quality, independent of compression ratio or fuel used. BSFC = fuel-rate/BP.*

◆ ***WORKED NUMERICAL — Brake horsepower of a CI engine*** **[IFoS 2020 | P2/4(a) | 10M]**

**Problem.** *A 4-cylinder 4-stroke CI engine of 100 mm × 120 mm has a mean effective pressure of 6 kg/$cm^2$ at 300 rpm. If the mechanical efficiency is 83%, calculate the brake horsepower. (Also: functions of flywheel, timing gear and differential lock — see §13 & tractor chapter.)*

**Given.** k = 4; D = 10 cm ⇒


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$A = (\pi/4) \times 10^2 = 78.54\ cm^2$;

$L = 12\ cm = 0.12\ m$; $p_m = 6\ kg/cm^2$;

$N = 300/2 = 150$ power strokes/min; $\eta_mech = 0.83$.

**Indicated power.** $IP = p_m \cdot L \cdot A \cdot N \cdot k/(75\times60) = 6\times0.12\times78.54\times150\times4/4500 = 7.54\ hp$

**Brake power.** $BHP = \eta_mech \times IP = 0.83 \times 7.54 = 6.26\ hp$

**Result. Brake horsepower ≈ 6.26 hp.**

◆ ***WORKED NUMERICAL — IHP, BHP, mechanical efficiency & SFC*** **[IFoS 2017 | P2/2(c) | 10M]**

**Problem.** *A 4-stroke engine has mean effective pressure 7 kg/cm², piston area 730 cm², stroke 45 cm, brake torque 110 kg-m, fuel consumption 4.5 kg/h and speed 120 rpm. Calculate IHP, BHP, mechanical efficiency and specific fuel consumption.*

**IHP.** $= p_m \cdot L \cdot A \cdot N \cdot k/(75\times60) = 7\times0.45\times730\times(120/2)\times1/4500 = 30.66\ hp$

**BHP.** $= 2\pi NT/(60\times75) = 2\pi\times120\times110/(4500) = 18.43\ hp$

**Mechanical efficiency.** $= BHP/IHP = 18.43/30.66 = 60.1\%$

**SFC.** $= fuel/BHP = 4.5/18.43 = 0.244\ kg/hp\cdot h$

**Result. IHP 30.7 hp; BHP 18.4 hp; η_mech 60.1%; SFC 0.244 kg/hp·h.**

◆ ***WORKED NUMERICAL — Power, fuel consumption & SFC*** **[OPSC·CSE (Main) 2022-23 | Paper-II Q.3(b) | 5M]**

**Problem.** *A tractor engine rotates at 2100 rpm and develops a torque of 79 N·m, using 1.17 kg of fuel in 15 min. Calculate the power developed, fuel consumption and specific fuel consumption.*

**Power.** $BP = 2\pi NT/60 = 2\pi\times2100\times79/60 = 17372\ W = 17.37\ kW$

**Fuel consumption.** $= 1.17\ kg / 15\ min = 1.17 \times 4 = 4.68\ kg/h$

**SFC.** $= FC/BP = 4.68/17.37 = 0.269\ kg/kW\cdot h = 269\ g/kW\cdot h$

**Result. Power 17.4 kW; fuel 4.68 kg/h; SFC 269 g/kW·h.**

◆ ***WORKED NUMERICAL — BHP, air-flow rate & compression ratio*** **[OPSC·CSE (Main) 2020-21 | Paper-II Q.1(c)(ii) | 10M]**

**Problem.** *A 2-cylinder 4-stroke CI engine (volumetric efficiency 0.88) has stroke-to-bore ratio 1.12:1, stroke 100 mm, clearance volume 100 cc per cylinder and mean effective pressure $6\times10^5$ Pa. The piston makes 3000 strokes/min. Find (a) BHP (b) air-flow rate (m³/min) (c) compression ratio.*

**Geometry.** bore $B = L/1.12 = 100/1.12 = 89.3\ mm$;

$A = (\pi/4)\times0.0893^2 = 62.6\times10^{-4}\ m^2$;

$Vs = A\cdot L = 626\ cc$; $r = (626+100)/100 = 7.26$

**Speed.** 3000 strokes/min = 1500 rpm ⇒

power strokes = 1500/2 = 750 /min per cylinder

**Power.** $P = p_m \cdot L \cdot A \cdot (N/60) \cdot k = 6\times10^5\times0.10\times62.6\times10^{-4}\times(750/60)\times2 = 9.39\ kW$

**Air-flow.** $= Vs \times \text{power strokes} \times k \times \eta_vol = 626\times10^{-6} \times 750 \times 2 \times 0.88 = 0.826\ m^3/min$

**Result. BHP ≈ 9.39 kW (12.6 hp); air-flow 0.826 m³/min; compression ratio 7.26.**

◆ ***WORKED NUMERICAL — Effect of bore & stroke change on BHP*** **[UK·PSC RFO (Mains) 2015 | Q.6(ii) | 10M]**

**Problem.** *By how many times will the BHP of an engine increase or decrease if the piston diameter is increased by 20% and the stroke length decreased by 20%, all other factors remaining the same?*

**Relation.** Power $\propto p_m \cdot L \cdot A \cdot N \propto L \cdot D^2$ (other factors constant)

**Substitution.** factor $= (D')^2/D^2 \times L'/L = (1.2)^2 \times (0.8) = 1.44 \times 0.8 = 1.152$

**Result. BHP increases by a factor 1.152, i.e. about +15.2%.**

**PREVIOUS YEAR QUESTIONS**

- Define indicated thermal efficiency and relative efficiency of an IC engine. Why is relative efficiency preferred as a measure of engine performance? [IFoS 2025 | P2/1(a) | 8M]
- Differentiate: (i) CI and SI engine [§3] (ii) Octane and Cetane number [§6] (iii) Thermal efficiency and Mechanical efficiency (iv) Caster and Camber angle [tractor chapter]. [IFoS 2017 | P2/1(b) | 8M]
- What are the various types of efficiencies of an IC engine? Differentiate between them. Discuss the working parameters which can help to improve the efficiency of an engine.
  [OPSC·Forest (Main) 2023-24 | Paper-II Q.1(a) | 20M]
- What are the primary factors influencing the thermal efficiency of internal-combustion engines, and how do they impact fuel-energy conversion into useful work?
  [OPSC·CSE (Main) 2023-24 | Paper-II Q.2(b) | 15M]

**MODEL Q** Power numericals: IP = $p_m \cdot L \cdot A \cdot N \cdot k$ (N = rpm/2 for 4-stroke, in power strokes/min; use /75/60 for metric hp with kgf-cm² & cm²); BP = $2\pi NT/60$; $\eta_{mech}$ = BP/IP; SFC = fuel-rate ÷ power. Keep units consistent (SI: Pa, m, m², kW).***

## 6 COMBUSTION, KNOCK & FUEL RATINGS

### NORMAL COMBUSTION & ABNORMAL COMBUSTION

In normal combustion a flame front spreads smoothly from the spark (SI) or from the injected spray (CI). Abnormal combustion causes ***knock***:

**Detonation (SI knock) :** the unburnt end-gas ahead of the flame auto-ignites spontaneously, giving a sharp pressure rise and a metallic knock — loss of power/efficiency and possible damage; worsened by high compression ratio, low-octane fuel, advanced timing.

**Pre-ignition :** the charge is ignited by a hot spot before the spark.

**Diesel knock (CI) :** a long ignition delay lets too much fuel accumulate and burn suddenly; reduced by high cetane fuel.

**Ignition delay :** the period between the start of injection (or spark) and the actual start of combustion; a long delay in a CI engine causes diesel knock.

### FUEL RATINGS — OCTANE & CETANE NUMBERS

| Basis | Octane number (SI fuel) | Cetane number (CI fuel) |
|---|---|---|
| Measures | resistance to knock (anti-knock quality) | ease/quickness of self-ignition (ignition quality) |
| Reference fuels | iso-octane (100) & n-heptane (0) | cetane (100) & α-methyl-naphthalene (0) |
| Definition | % iso-octane in the blend that knocks like the fuel | % cetane in the blend that ignites like the fuel |
| High value means | less knock — good petrol | short delay — smooth diesel |
| Relation | high-octane fuels have low cetane (inverse) | and vice versa |

**RON & MON :** the Research and Motor octane numbers are measured under mild and severe test conditions respectively; a fuel's road rating lies between them. *[Cetane and RON/MON reference-fuel details supplemented from standard sources — three Ganesan pages were unavailable; flagged per SOP.]*

**ABBREVIATIONS (FULL FORMS) (IFOS 2022)**

**SAE** Society of Automotive Engineers | **API** American Petroleum Institute | **DI/IDI** direct / indirect injection | **CRDI** common-rail direct injection | **ASTM** American Society for Testing and Materials | **BIS** Bureau of Indian Standards | **RON/MON** research / motor octane number | **TDC** top dead centre.

**PREVIOUS YEAR QUESTIONS**

- Define: (i) Volumetric efficiency [§5] (ii) Octane number (iii) IHP [§5] (iv) Detonation (v) Ignition delay … [10-part multi-chapter — IC-engine terms answered here; theoretical field capacity, scouring, centre of resistance, disc angle and solar constant in their chapters].

  [IFoS 2018 | P2/2(c) | 20M]
- Write the full forms of: (i) SAE (ii) API (iii) DI (iv) IDI (v) CRDI (vi) ASTM (vii) BIS (viii) RON (ix) MON (x) TDC.

  [IFoS 2022 | P2/3(a) | 10M]
- Differentiate between Octane number and Cetane number.

  [AP·PSC RFO (Mains) 2012 | Q.2(A) | 5M]

## 7 FUEL SUPPLY — SI & THE CARBURETTOR

**SI FUEL-SUPPLY SYSTEM**

Fuel tank → fuel filter → *fuel pump* (or gravity) → carburettor (or fuel injector) → intake manifold → cylinder. Its job is to deliver a combustible *air-fuel mixture of the right ratio* (≈15:1) at all speeds and loads.

**Carburettor :** a device that *mixes air and petrol in the correct proportion* and supplies the mixture to the engine. Functions: atomise and vaporise the fuel, meter it to the airflow, mix them uniformly, and vary the quantity of mixture (via the throttle) with load and speed.

**SIMPLE FLOAT-TYPE CARBURETTOR — WORKING (IFOS 2025)**

A *float chamber* keeps the fuel at a constant level (a float + needle valve shut off the supply when full). Air drawn by the engine speeds up through a *venturi (choke tube)*, creating a low pressure at the throat; this suction draws fuel out of the *main jet/nozzle* (its tip set just above the fuel level) where it atomises into the air stream. A *throttle valve* downstream controls the quantity of mixture (and hence power); a *choke* enriches the mixture for cold starting.

**PREVIOUS YEAR QUESTIONS**

- Write down the functions of a carburettor. Explain, with the help of a sketch, the principle and working of a simple float-type carburettor.

  [IFoS 2025 | P2/2(b) | 15M]
- State the different components of a carburettor and explain, with a neat sketch, the spark plug in a petrol engine. [spark plug in §9]

  [OPSC·CSE (Main) 2016-17 | Paper-II Q.3(b) | 15M]

***FIGURE 2.5 — Simple float-type carburettor***

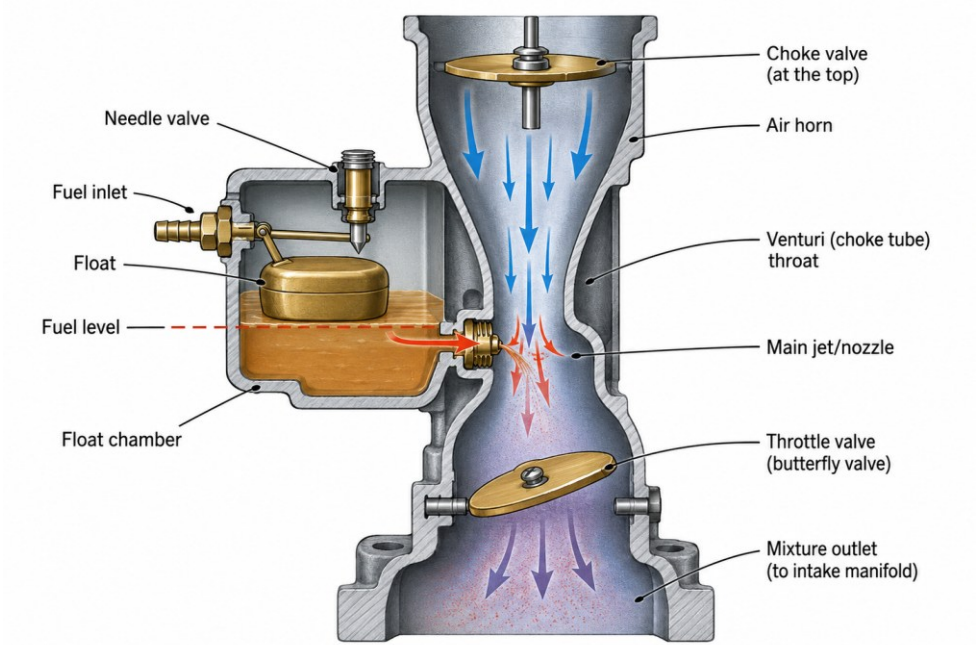



*Fig. 2.5 Simple float-type carburettor — venturi suction draws fuel from the main jet.*

## 8 FUEL SUPPLY — CI (FIP, NOZZLE, CRDI)

**CI FUEL-SUPPLY SYSTEM**

Fuel tank → primary filter → ***feed/lift pump*** → secondary (fine) filter → ***fuel-injection pump (FIP)*** → high-pressure pipes → ***injector/nozzle*** → cylinder; a return line carries surplus fuel back. The FIP meters an exact quantity of fuel and delivers it at high pressure, at the right instant, to each injector; the nozzle atomises it into the combustion chamber.

**FUEL-INJECTION PUMP & FUEL VISCOSITY (IFOS 2025)**

**FIP functions:** meter the precise fuel quantity per cycle (varying with load via the governor/rack), raise it to injection pressure (200-1000+ bar), and time the injection.

**Fuel viscosity :** diesel must have the right viscosity: too ***low*** and it leaks past the plunger and gives poor lubrication and wear; too ***high*** and it is hard to pump and atomises into coarse droplets, worsening combustion. Correct viscosity ensures accurate metering, good atomisation and self-lubrication of the pump.

**ELECTRONIC INJECTION / CRDI**

Modern engines use ***common-rail direct injection (CRDI)***: a high-pressure pump charges a common rail, and an ***electronic control unit (ECU)*** opens solenoid/piezo injectors with precise, multiple injections per cycle — better fuel economy, lower emissions and quieter running.

◆ ***WORKED NUMERICAL — Duration of fuel injection*** **[IFoS 2019 | P2/1(e) | 8M (also OPSC 2018-19 | Q.3(b))]**

**Problem.** *A high-speed diesel engine running at 2000 rev/min has a single cylinder. During the compression stroke the fuel injection starts 20° before TDC and ends at TDC. Calculate the duration (in seconds) of the fuel injection.*

**Given.** N = 2000 rpm; injection crank angle = 20°.

**Time per revolution.** = 60/N = 60/2000 = 0.03 s (= 360°)

**Duration.** = (angle/360) × (60/N) = (20/360) × 0.03 = $1.667\times10^{-3}$ s

**Result. Injection duration ≈ 1.67 ms (0.00167 s).**


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◆ ***WORKED NUMERICAL — Fuel injected per cycle per cylinder*** **[IFoS 2022 | P2/1(e) | 8M]**

**Problem.** *Determine the quantity of fuel injected per cycle per cylinder for a six-cylinder 4-stroke diesel engine with brake-specific fuel consumption 180 g (per hp·h) developing 121 hp at 2500 rpm.*

**Given.** k = 6; BSFC = 180 g/hp·h; BP = 121 hp; N = 2500 rpm; 4-stroke.

**Fuel per hour.** = BSFC × BP = 180 × 121 = 21 780 g/h

**Cycles per hour per cylinder.** = (N/2) × 60 = 1250 × 60 = 75 000

**Fuel per cycle per cylinder.** = 21 780 / (75 000 × 6) = 0.0484 g = 48.4 mg

**Result. ≈ 48.4 mg of fuel per cycle per cylinder.**

**PREVIOUS YEAR QUESTIONS**

- Explain the fuel supply system of a compression-ignition engine using a block diagram.
  [IFoS 2023 | P2/4(a) | 10M]
- Write down the functions of the fuel-injection pump of a tractor engine. Discuss the importance of fuel viscosity in the fuel-injection system.
  [IFoS 2025 | P2/4(b·i) | 8M]
- Draw a neat figure showing the different components of a fuel-supply system of a general-purpose tractor and describe its working.
  [IFoS 2016 | P2/2(a) | 10M]
- Describe the operation of a 4-stroke IC engine with illustrations. Explain how fuel injection is done in CI engines. In what way are electronics applied in modern fuel-injection systems? [4-stroke in §3]
  [OPSC·CSE (Main) 2024-25 | Paper-II Q.1 | 15M]
- What are the basic differences in the fuel-supply system of a petrol engine and a diesel engine? Support your answer with neat sketch diagrams.
  [OPSC·CSE (Main) 2018-19 | Paper-II Q.1(b) | 20M]

***FIGURE 2.6 — CI fuel supply: FIP, nozzle & CRDI***

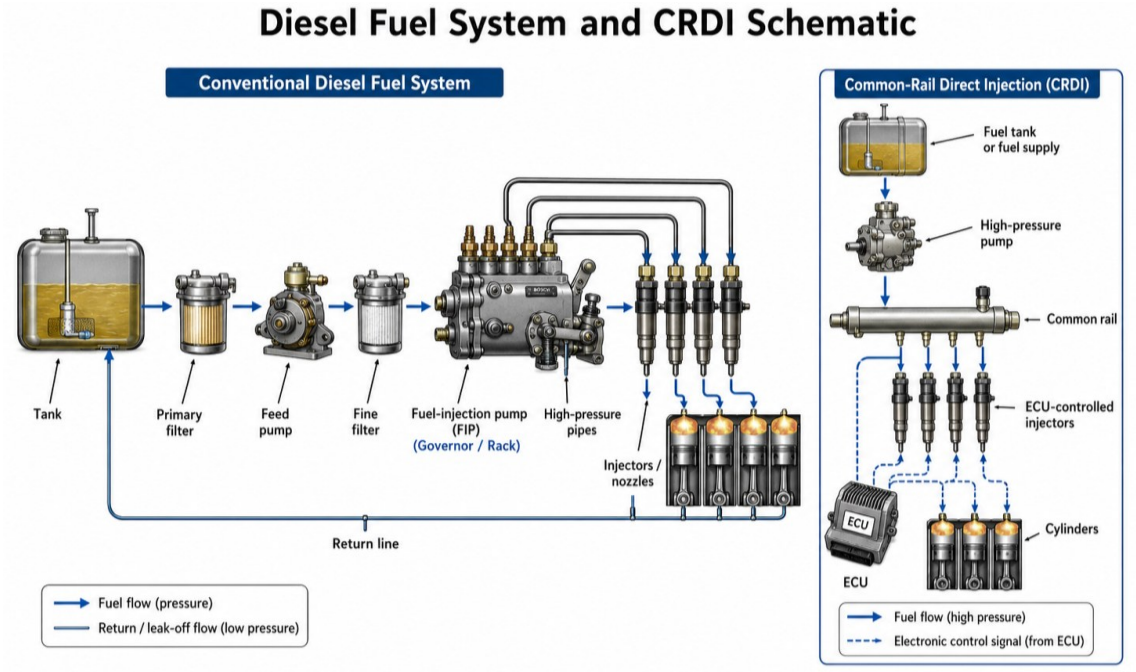



*Fig. 2.6 Diesel fuel-supply system (FIP + nozzle) and modern CRDI.*

## 9 IGNITION SYSTEMS — BATTERY & MAGNETO

An SI engine needs a high-voltage spark (~15-30 kV) at the plug at the right instant. Two systems supply it.

### BATTERY (COIL) IGNITION SYSTEM (IFOS 2021)

Components: ***battery, ignition switch, ballast resistor, ignition coil*** (primary + secondary windings), ***contact breaker (points) & cam, capacitor (condenser)***, ***distributor*** and spark plugs. Working: the battery drives low-voltage current through the coil primary; the breaker points open (timed by the cam), collapsing the magnetic field and ***inducing a high voltage in the secondary***; the distributor routes this to the correct spark plug in the firing order. The condenser prevents arcing at the points.

### MAGNETO IGNITION SYSTEM

A ***magneto*** (a permanent-magnet AC generator driven by the engine) generates its own current — no battery. Simpler and reliable at speed (spark strengthens with rpm), used on tractors, small engines and stationary units; but the spark is weak at starting/low speed.

**PREVIOUS YEAR QUESTIONS**

- Explain the different components of the battery-ignition system of a four-cylinder engine through a neat sketch.

  [IFoS 2021 | P2/4(a) | 10M]

- What are a magneto ignition system's main component and working principles, and how does it produce the high-voltage spark needed for internal-combustion engines?

  [OPSC·CSE (Main) 2023-24 | Paper-II Q.3(b) | 15M]

***FIGURE 2.7 — Battery & magneto ignition***

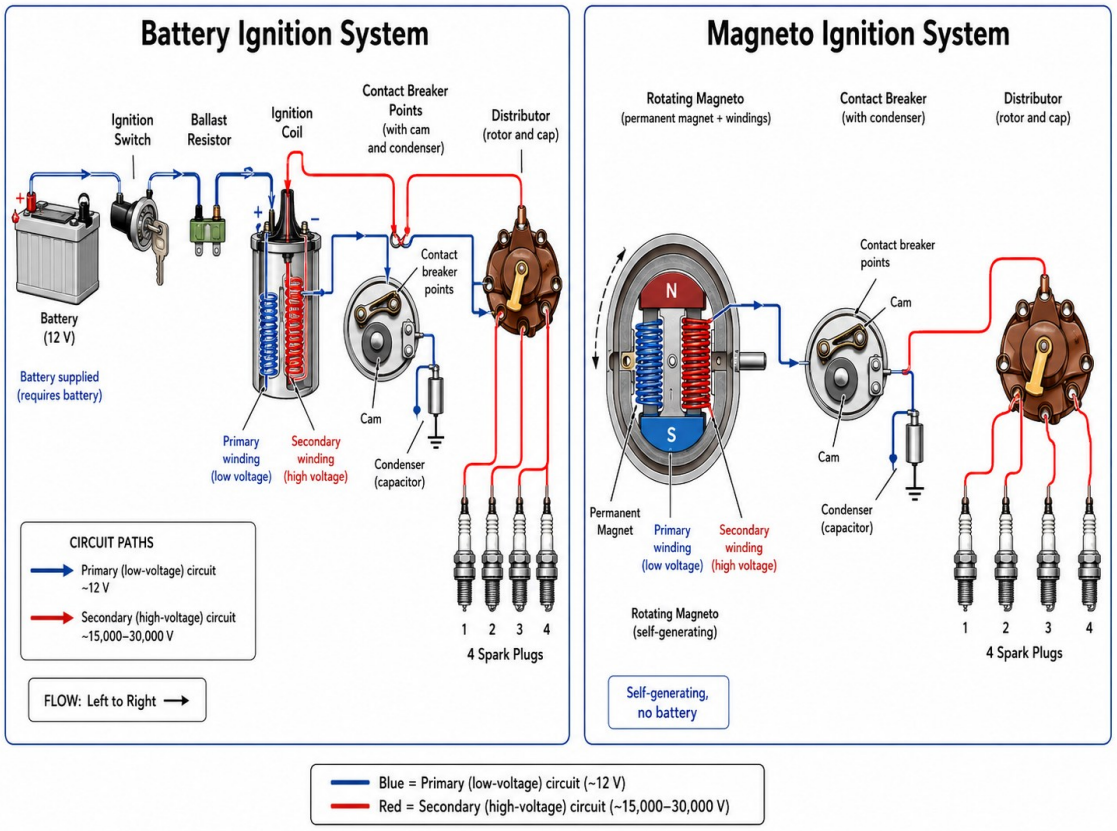



*Fig. 2.7 Battery-coil ignition (left) and magneto ignition (right).*


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## 10 COOLING SYSTEM

Only ~30% of the fuel energy becomes work; much of the rest is heat that must be removed or the engine will overheat, seize and lose strength. A cooling system keeps the engine at its ***optimum working temperature*** (≈80-90 °C).

| Basis | Air cooling | Water (liquid) cooling |
|---|---|---|
| Method | fins on cylinder + fan/airflow | water jacket + radiator + pump |
| Used on | small/stationary engines, motorcycles | tractors, cars, trucks |
| Merits | simple, light, no leaks/coolant | uniform, effective cooling; quieter |
| Demerits | uneven, noisy, limited to small engines | complex, needs coolant & maintenance |

**WATER-COOLING METHODS**

**Thermo-siphon (UK·PSC 2021) :** natural circulation by density difference: hot (lighter) water rises from the jacket to the radiator top, cools, and (denser) falls back — no pump; simple but slow and needs a tall radiator.

**Forced / pump circulation (IFoS 2017, 2022) :** a water pump circulates coolant through jacket → thermostat → radiator → back; a fan draws air through the radiator. Faster, reliable, used on all modern tractors.

**THERMOSTAT, RADIATOR, PRESSURISED CAP & COOLANT**

**Thermostat (IFoS 2019) :** a temperature-sensitive valve that stays closed until the engine warms up (blocking flow to the radiator so the engine reaches working temperature quickly), then opens to admit coolant — keeping the temperature steady and improving efficiency and wear.

**Radiator :** a finned tube matrix that dissipates the coolant's heat to the air.

**Pressurised radiator cap (IFoS 2025) :** seals the system and raises its pressure, which raises the boiling point of the coolant so it can run hotter without boiling; a spring valve releases excess pressure and a vacuum valve admits coolant back on cooling.

**Coolant :** water plus ***ethylene-glycol anti-freeze*** and corrosion inhibitors; lowers freezing point, raises boiling point, prevents rust and scale.

**PREVIOUS YEAR QUESTIONS**

- Explain the working and importance of the thermostat valve in the cooling system of an IC engine.
  [IFoS 2019 | P2/1(a) | 8M]
- What is the composition and what are the properties of coolant used in the cooling system of an IC engine? Explain, with a labelled sketch, the working of the forced-feed cooling system of a tractor engine.
  [IFoS 2022 | P2/3(b) | 15M]
- Explain the importance of cooling system in a tractor. Describe the principle and working of a forced-circulation system. Why is a thermostat used?
  [IFoS 2017 | P2/2(a) | 10M]
- What are the main requirements of an efficient cooling system in an IC engine? Briefly describe the principle and advantages of the thermo-siphon cooling system.
  [UK·PSC RFO (Mains) 2021 | Q.6(iv) | 10M]
- Write a short note on: Pressurised radiator cap.
  [IFoS 2025 | P2/2(a)(i) | part of 15M]

*FIGURE 2.8 — Forced-feed cooling system*

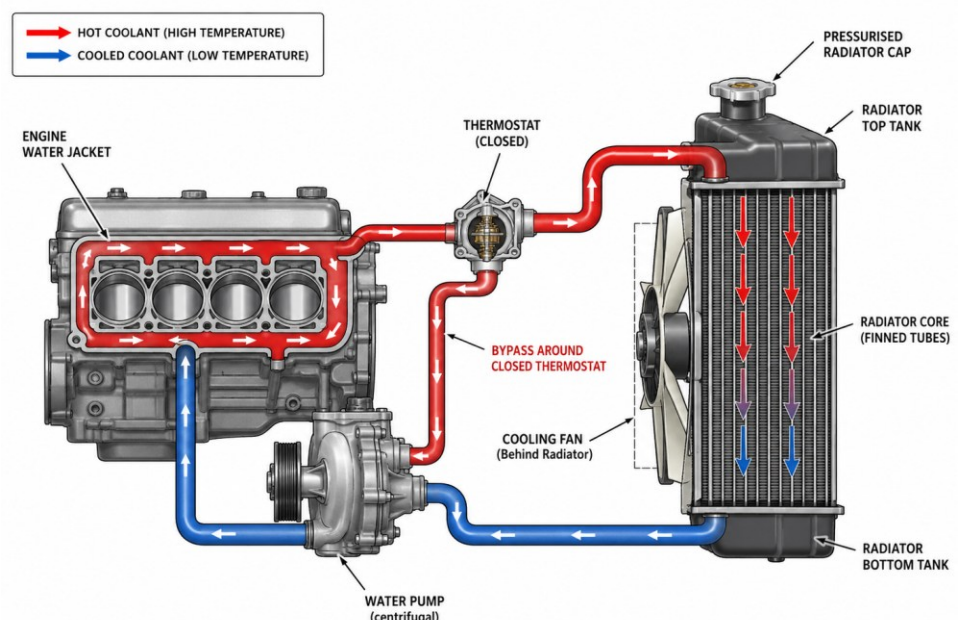



*Fig. 2.8 Forced-feed (pump) cooling system with thermostat and radiator.*

## 11 LUBRICATION SYSTEM

### WHY LUBRICATE (IFOS 2025)

Lubrication of the moving parts serves to: ***reduce friction and wear*** between rubbing surfaces (crankshaft/bearings, piston/cylinder, valve train); ***cool*** the parts by carrying away heat; ***seal*** the piston-ring/cylinder gap against blow-by; ***clean*** by carrying away carbon/metal particles to the filter; ***cushion*** shock loads on bearings; and ***prevent corrosion***.

### SYSTEMS & COMPONENTS

**Splash system :** dippers on the connecting rods splash oil from the sump (small engines).

**Forced-feed (pressure) system :** an ***oil pump*** draws oil from the sump through a strainer and filter and delivers it under pressure through drilled galleries to the crankshaft, camshaft and valve gear (standard on tractors).

**Oil rings (OPSC 2022) :** the lower piston rings that scrape excess oil off the cylinder wall back to the sump, controlling oil consumption while leaving a lubricating film; the connecting rod carries oil to the piston pin.

**Valve train :** cam, tappet, push-rod and rocker are oil-fed to reduce wear.

### LUBRICATING OIL & MULTIGRADE (IFOS 2025)

***Multigrade oil :*** a lubricating oil (e.g. **SAE 20W-40**) whose viscosity satisfies two SAE grades — thin enough to flow at cold start (the 'W'/winter number) yet thick enough to protect at operating temperature (the high number). Achieved with viscosity-index improvers; it gives all-season protection, easier cold starting and less wear.

**Desirable properties of a tractor lubricant (IFoS 2024) :** correct viscosity and high viscosity index, good oiliness/film strength, thermal & oxidation stability, low pour point, high flash point, anti-corrosion and detergent-dispersant additives, and low volatility.

**PREVIOUS YEAR QUESTIONS**

- Enlist the reasons for lubricating the different moving parts of an IC engine. Also state what you


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understand by 'multigrade' lubricating oil.

[IFoS 2025 | P2/1(c) | 8M]

- Write short notes on: (i) Mechanical efficiency of IC engine [§5] (ii) Desirable characteristics of lubricants used in tractor … [PTO shaft & tractive efficiency in the tractor chapter].

[IFoS 2024 | P2/1(b) | 8M]

- Explain the characteristic features of the lubrication system of a tractor engine with a schematic diagram. Explain the role of oil rings and connecting rod on the effectiveness of engine lubrication.

[OPSC·CSE (Main) 2022-23 | Paper-II Q.14(a),(b) | 13M+7M]

- What are the components of a tractor engine's lubrication system and why is lubrication important for engine function?

[OPSC·CSE (Main) 2023-24 | Paper-II Q.4(a) | 15M]

- What is the importance of lubrication system in a tractor? Explain briefly any one system of lubrication.

[UK·PSC RFO (Mains) 2015 | Q.5(iii) | 10M]

***FIGURE 2.9 — Forced-feed lubrication system***

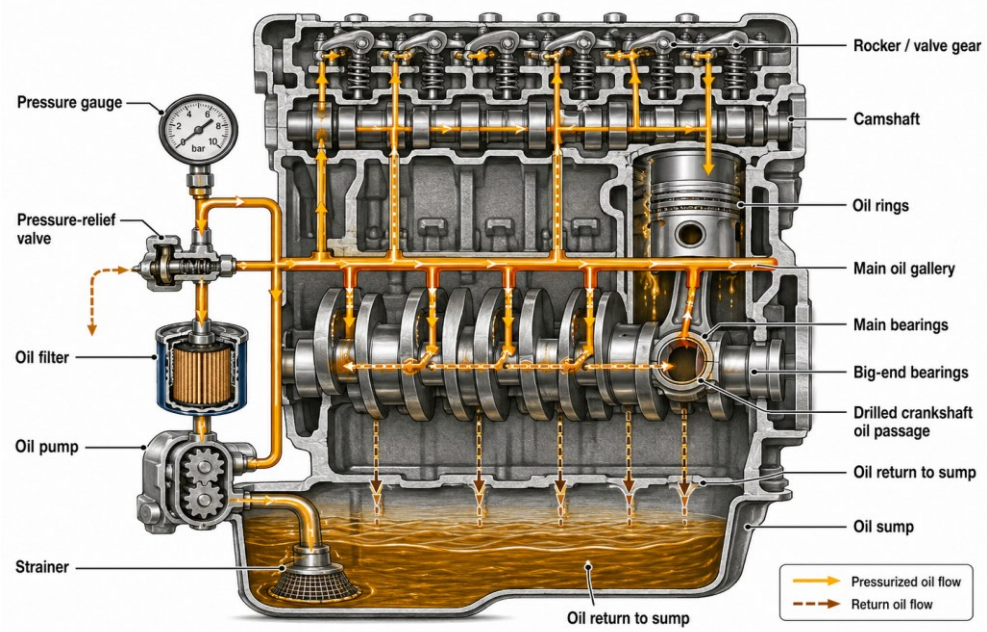



*Fig. 2.9 Forced-feed lubrication — pump, filter and galleries to the bearings and valve train.*

## 12 GOVERNOR & AIR CLEANER

### GOVERNOR — FUNCTION & CENTRIFUGAL TYPE (IFOS 2019, 2020)

**Governor :** a device that keeps the engine speed ***nearly constant under varying load*** by automatically adjusting the fuel (rack) or throttle. As load increases the engine tends to slow; the governor increases fuel to restore speed, and reduces it when load falls.

**Centrifugal governor : working —** rotating ***flyweights*** driven by the engine fly outward with speed against a spring; their movement, through a sleeve and linkage, moves the fuel-pump rack (or throttle). If load rises and speed drops, the weights fall inward → more fuel → speed restored; if speed rises, the weights fly out → less fuel. Thus speed is held nearly constant.

**Governor hunting (OPSC 2018) :** continuous over-correction — the speed oscillates above and below the set value because the governor is too sensitive/unstable.

**Tractor vs car governor (AP·PSC 2012) :** a tractor engine works at nearly constant set speed under widely varying draft load, so it needs a governor that controls speed automatically over the whole range; a car engine speed is controlled directly by the driver's accelerator and usually has only a maximum-speed (limiting) governor.

**OIL-BATH AIR CLEANER (IFOS 2020, 2016)**

Air must be cleaned of dust before entering the engine (dust causes rapid cylinder/ring wear). In an ***oil-bath air cleaner***, incoming air is drawn down onto the surface of an oil reservoir; its direction reverses sharply, so the heavier dust particles, by inertia, strike and stick in the oil. The air then passes up through a ***wire-mesh/oil-wetted filter*** (which traps finer dust and returns oil) to the intake. The trapped dust settles in the oil, which is cleaned/refilled periodically. Simple, cheap and effective in dusty field conditions.

**PREVIOUS YEAR QUESTIONS**

- Explain the working principle of a centrifugal governor with neat sketch. How is the speed maintained constant under varying load conditions in an IC engine? [IFoS 2019 | P2/1(b) | 8M]
- What is the purpose of the air-cleaning system? Write about the working of the oil-bath type air-cleaning system of a farm tractor.[IFoS 2020 | P2/3(a) | 10M]
- Describe the working of an oil-bath type air cleaner. [IFoS 2016 | P2/2(c) | 10M]
- Describe the working principle of the centrifugal governor used in tractors. Explain governor hunting. [OPSC·CSE (Main) 2018-19 | Paper-II Q.2(a) | 20M]
- Why does a tractor engine have a governor? How does a tractor engine differ from a car engine with respect to the governor? [AP·PSC RFO (Mains) 2012 | Q.1(G) | 4M]

***FIGURE 2.10 — Centrifugal governor & oil-bath air cleaner***

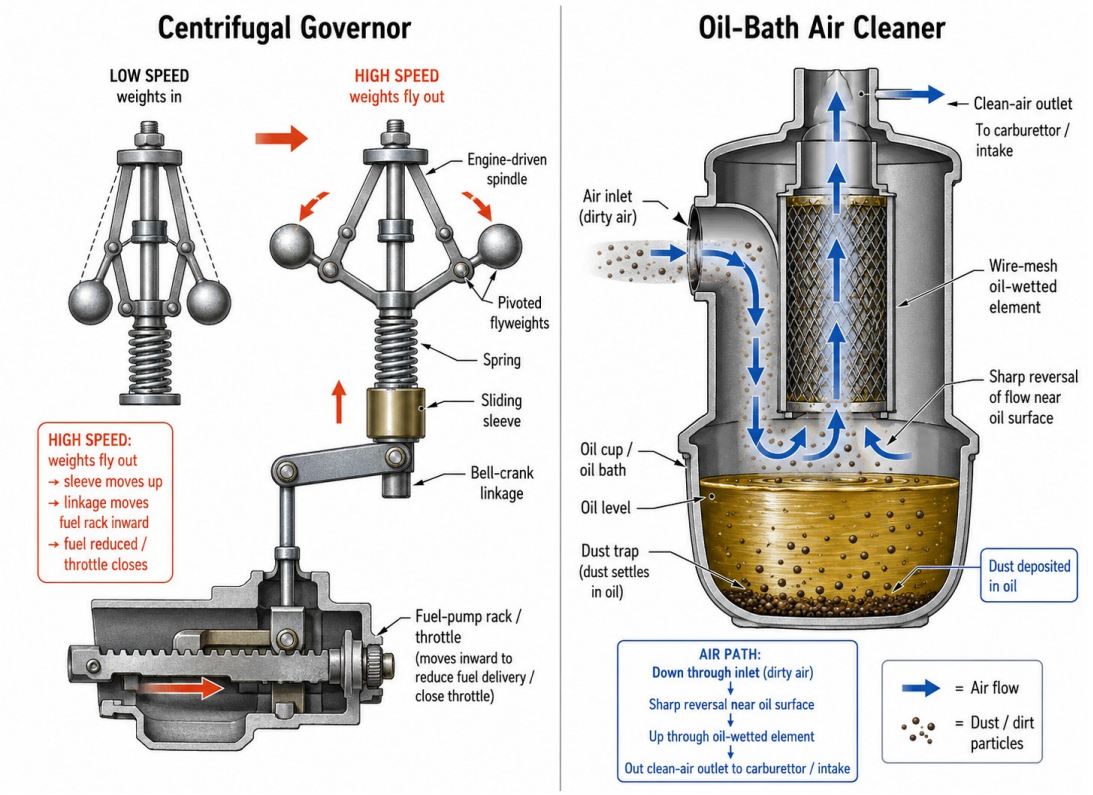



*Fig. 2.10 Centrifugal governor (left) and oil-bath air cleaner (right).*


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## 13 VALVE TIMING, FIRING ORDER & ENGINE COMPONENTS

### VALVE MECHANISM & VALVE-TIMING DIAGRAM (IFOS 2019, 2023)

Valves are opened by the ***camshaft → tappet → push-rod → rocker arm*** and closed by springs; the camshaft runs at half crankshaft speed (4-stroke) via timing gears/chain. A ***valve-timing diagram*** plots, on a circle representing crank angles, the exact instants of inlet-valve opening (IVO, a little before TDC) and closing (IVC, after BDC), and exhaust-valve opening (EVO, before BDC) and closing (EVC, after TDC). The early/late timing and the ***valve overlap*** (both valves open around TDC) improve breathing (volumetric efficiency) and scavenging.

### FIRING ORDER & FIRING INTERVAL (OPSC-FOREST 2023)

**Firing order :** the sequence in which the cylinders fire, chosen for even torque and balance and to avoid overloading adjacent bearings — e.g. ***1-3-4-2 (or 1-2-4-3) for a 4-cylinder*** and ***1-5-3-6-2-4 for a 6-cylinder*** engine.

**Firing interval :** the crank-angle between successive firings = 720°/number of cylinders (4-stroke): 180° for a 4-cylinder, 120° for a 6-cylinder.

| Component | Function |
|---|---|
| Flywheel | stores energy during the power stroke and releases it during the idle strokes → smooth, uniform rotation |
| Timing gears | drive the camshaft (and FIP) at the correct speed & phase relative to the crankshaft, timing valve & injection events |
| Crankshaft & connecting rod | convert the piston's reciprocating motion into rotary motion |
| Camshaft | operates the valves (and often the FIP) in the correct sequence |
| Piston, rings & cylinder | form the moving gas seal that transmits gas pressure to the crank |

**PREVIOUS YEAR QUESTIONS**

- What do you mean by valve-timing diagram of a four-stroke IC engine? Describe the occurrence of events in a four-cylinder four-stroke engine in a tabular form, having standard firing order.
  [IFoS 2019 | P2/2(b) | 15M]
- Write short notes on: (i) Compression ratio [§2] (ii) Timing gears of IC engine … [harvesting & biogas parts in their chapters]. [IFoS 2023 | P2/1(c) | 8M]
- Differentiate between firing interval and firing order. What should be the firing interval and firing order of a 6-cylinder 4-stroke engine? What do you understand from a valve-timing diagram?
  [OPSC·Forest (Main) 2023-24 | Paper-II Q.2(a) | 20M]
- Describe the constructional features and working principle of the valve train of an IC engine. Draw the valve-timing diagram of a spark-ignition (SI) engine.
  [OPSC·CSE (Main) 2022-23 | Paper-II Q.2(a),(b) | 12M+12M]
- Write a short note on: Valve-timing diagram of a 4-stroke cycle IC engine.
  [IFoS 2025 | P2/2(a)(v) | part of 15M]

***FIGURE 2.11 — Valve-timing diagram & valve train***

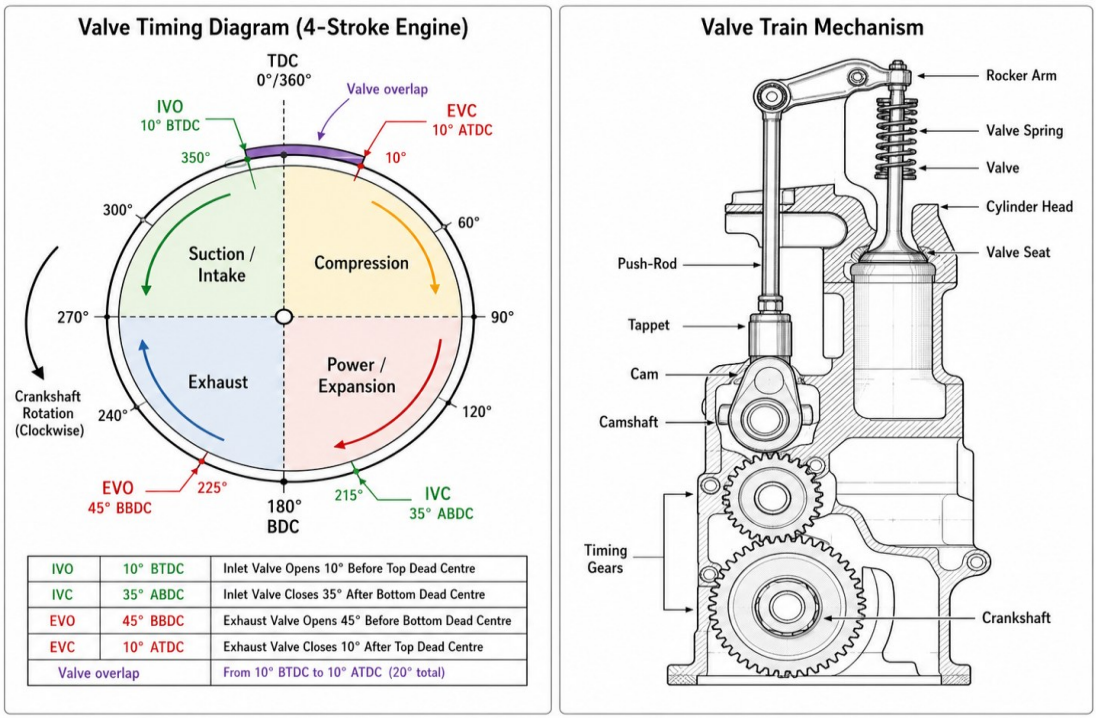



*Fig. 2.11 Valve-timing diagram (left) and the valve train driven by timing gears (right).*

**FORMULA SHEET — CHAPTER 2**

| Quantity | Formula |
|---|---|
| Swept volume | $V_s = (\pi/4)D^2L$ |
| Compression ratio | $r = (V_s+V_c)/V_c = 1 + V_s/V_c$ |
| Indicated power | $IP = p_m \cdot L \cdot A \cdot N \cdot k$ (N = rpm/2, 4-stroke) |
| Brake power | $BP = 2\pi NT/60$ |
| Friction power | FP = IP − BP |
| Mechanical efficiency | $\eta_{mech} = BP/IP$ |
| Thermal efficiency | $\eta_{ith} = IP/(\dot{m}_f \cdot CV)$ ; $\eta_{bth} = BP/(\dot{m}_f \cdot CV)$ |
| Relative efficiency | $\eta_{rel} = \eta_{thermal} / \eta_{air\text{-}standard}$ |
| Volumetric efficiency | $\eta_{vol}$ = air inducted / swept volume |
| Specific fuel consumption | SFC = fuel-rate/power ; BSFC = fuel/BP |
| Otto efficiency | $\eta = 1 - 1/r^{(\gamma-1)}$ |
| Diesel efficiency | $\eta = 1 - (1/r^{(\gamma-1)}) \cdot [(\rho^{\gamma-1})/(\gamma(\rho-1))]$ |
| Dual efficiency | $\eta = 1 - (1/r^{(\gamma-1)}) \cdot [(\alpha\rho^{\gamma-1})/((\alpha-1)+\gamma\alpha(\rho-1))]$ |
| Cut-off ratio (x% of stroke) | $\rho = 1 + x \cdot (r-1)$ |
| Injection duration | $t = (angle/360) \times (60/rpm)$ |
| Fuel per cycle/cyl | = BSFC·BP / (cycles/h × k) |
| Firing interval (4-stroke) | = 720°/no. of cylinders |

**SUMMARY**

- An IC engine burns fuel inside the cylinder (vs EC engine, combustion outside); higher efficiency, compact, quick-starting.


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- Classify by ignition (SI/CI), cycle (2-/4-stroke), cooling, cylinders, fuel and aspiration; SI uses a spark & petrol, CI self-ignition & diesel (r 14-20 vs 6-10).
- 4-stroke: suction-compression-power-exhaust in 2 revolutions (SI compresses air-fuel + spark; CI compresses air + injects fuel). 2-stroke: 1 cycle/revolution via ports, ~double power but less efficient.
- Geometry: $V_s=(\pi/4)D^2L$, $r=(V_s+V_c)/V_c$. Air-standard cycles: Otto $\eta=1-1/r^{(\gamma-1)}$; Diesel & Dual less at same r (bracket>1) but run higher r; equal r → Otto>Dual>Diesel, equal peak pressure → Diesel>Dual>Otto.
- Performance: $IP=p_mLANk$, $BP=2\pi NT/60$, $\eta_{mech}=BP/IP$; relative efficiency (actual/air-standard) is preferred; SFC=fuel/power.
- Combustion faults: detonation (SI end-gas auto-ignites), pre-ignition, diesel knock (long delay); octane rates SI anti-knock, cetane rates CI ignition quality (inverse).
- SI fuel supply via a float-type carburettor (venturi suction draws fuel from the main jet; throttle controls quantity).
- CI fuel supply via feed pump → FIP (meters & pressurises fuel, governor-controlled) → injector; correct fuel viscosity is vital; modern engines use CRDI with ECU control.
- Ignition: battery-coil (points collapse the coil field → high-voltage secondary → distributor) or self-generating magneto.
- Cooling (air or water): thermo-siphon (natural) or forced-feed (pump); thermostat holds working temperature; pressurised cap raises coolant boiling point; coolant = water + glycol + inhibitors.
- Lubrication reduces friction/wear, cools, seals, cleans and cushions; splash or forced-feed; multigrade oil (e.g. 20W-40) protects cold and hot; oil rings control oil film.
- Governor holds speed constant under varying load (centrifugal flyweights vary the fuel rack; hunting = over-correction); oil-bath air cleaner traps dust by inertia in oil.
- Valve-timing diagram shows IVO/IVC/EVO/EVC & overlap; firing order (e.g. 1-3-4-2) with interval 720°/cylinders gives balance; flywheel smooths, timing gears phase the camshaft/FIP.

**LAST-NIGHT REVISION**

| Must-remember | Value / formula |
|---|---|
| IC vs EC | combustion inside vs outside cylinder |
| Compression ratio | petrol 6-10 \| diesel 14-20 |
| Swept volume | $V_s = (\pi/4)D^2L$ ; $r = 1+V_s/V_c$ |
| 4-stroke | suction-compression-power-exhaust / 2 rev |
| 2- vs 4-stroke power | 2-stroke ≈ 2× (1 power stroke/rev) |
| Otto η | $1 - 1/r^{(\gamma-1)}$ |
| Diesel η | $1 - (1/r^{(\gamma-1)})[(\rho^{\gamma-1})/(\gamma(\rho-1))]$ |
| Cycle comparison | equal r: Otto>Dual>Diesel ; equal p_max: Diesel>Dual>Otto |
| IP / BP | $IP=p_mLANk$ ; $BP=2\pi NT/60$ ; $\eta_{mech}=BP/IP$ |
| Relative efficiency | actual thermal / air-standard (preferred) |
| Octane vs cetane | SI anti-knock vs CI ignition quality (inverse) |
| Carburettor | venturi suction draws fuel from main jet (SI) |
| FIP | meters + pressurises + times diesel; viscosity critical |
| Ignition | battery-coil (points+distributor) or magneto |
| Cooling | thermo-siphon / forced-feed ; thermostat holds temp |
| Multigrade oil | e.g. 20W-40 — flows cold, protects hot |
| Governor | centrifugal flyweights hold speed; hunting = over-correction |
| Firing order / interval | 4-cyl 1-3-4-2 ; interval 720°/cylinders |

CHAPTER

# 3

# TRACTORS, POWER TILLERS & HYDRAULICS

*Classification · Power train (clutch, gearbox, differential, final drive, PTO) · Hydraulic 3-point linkage · Wheels & front-wheel geometry · Stability · Traction aids · Power tillers*

**SYLLABUS (Paper II | Farm Power & Machinery) :** Tractor classification & types — general-purpose, special-purpose, utility, crawler vs wheeled, 2WD vs 4WD, mini/compact. Power transmission train — clutch (single/dual/multi-plate), gear box (sliding-mesh, constant-mesh, synchromesh), differential (with lock), final drives, PTO shaft. Hydraulic system — hydraulic lift, draft control, draft sensing, position control, three-point linkage (lower link, top link), hitch. Tractor wheels & geometry — wheelbase, track width, tyre inflation (front vs rear), drive-wheel lugs, front-wheel adjustments (caster, camber, king-pin, toe-in). Tractor stability — overturn during turning, longitudinal/lateral stability, safe turning radius. Power tillers. Brakes & controls — independent brake pedals, differential brake. Traction aids – cage wheel, dual wheel, ballast, tyre chains. (Selection/calibration/capacity/cost → Ch.1; tractive theory → Ch.4.)

## Chapter Outline

1. **Tractor Classification & Types**
2. **Power Transmission Train — Overview**
3. **Clutch**
4. **Gear Box**
5. **Differential, Final Drive & PTO**
6. **Hydraulic System & Three-Point Linkage**
7. **Wheels & Front-Wheel Geometry**
8. **Tractor Stability**
9. **Brakes, Traction Aids & the Tractor Governor**

**MIND-MAP — *Chapter 3 concept map***

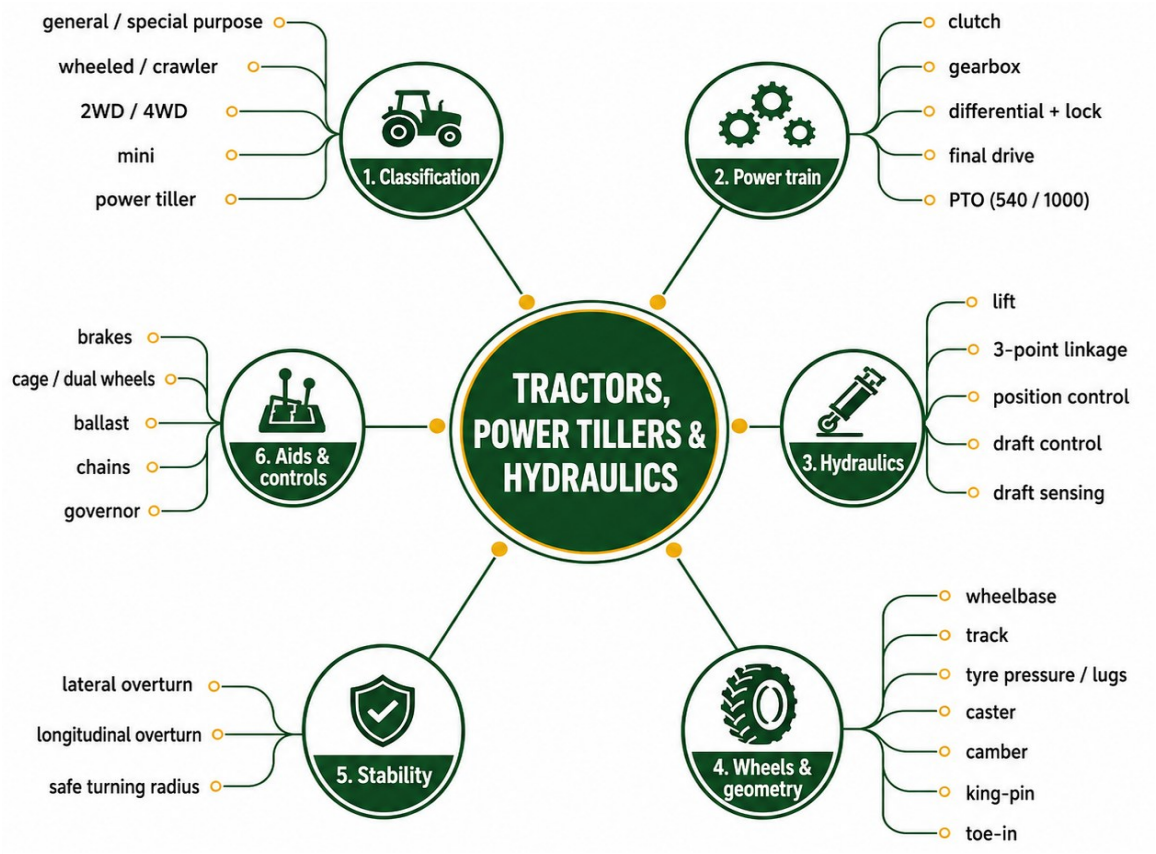



*Fig. 3.0 Concept map of Chapter 3 — tractor systems, hydraulics and stability.*

## 1 TRACTOR CLASSIFICATION & TYPES

***Tractor*** — a self-propelled ***prime mover*** that provides mobile power at the drawbar (to pull implements), at the PTO (to drive rotary machines) and through its hydraulics (to lift and control mounted implements).

| Basis | Types |
|---|---|
| By use | general-purpose \| row-crop \| special-purpose (orchard, industrial) \| utility |
| By construction | wheeled (2WD / 4WD) \| crawler (track-type) |
| By size / power | mini/compact (<20 hp) \| medium (20-45 hp) \| heavy (>45 hp) |
| By drive | two-wheel drive (2WD) \| four-wheel drive (4WD) |

| Basis | Wheeled tractor | Crawler (track) tractor |
|---|---|---|
| Traction/flotation | lower; slips in wet/loose soil | high; large track contact area |
| Speed & road use | faster; road-legal | slow; not for roads |
| Cost & maintenance | cheaper, simpler | costly, higher maintenance |
| Steering | front-wheel steering | by braking one track (no differential-lock need) |
| Use | general farming | heavy earthwork, very soft/steep land |

**POWER TILLER (WALKING TRACTOR)**

A ***single-axle, walk-behind*** power unit of 5-12 hp; the operator walks behind holding the handle. Its two wheels drive rotary or trailed tools; ideal for ***small, terraced and wet (puddled) fields*** — puddling, tillage, transport and stationary work (pump/thresher via a belt) — where a four-wheel tractor is uneconomic or cannot manoeuvre.

**PREVIOUS YEAR QUESTIONS**

What do you understand by a farm tractor? Explain the different types of tractors used for various purposes on Indian farms. What is a power tiller?

[UK·PSC RFO (Mains) 2012 | Q.5(i) | 10M]

***FIGURE 3.1 — Tractor types & power tiller***




*Fig. 3.1 Wheeled (2WD/4WD), crawler tractors and the walking-type power tiller.*

## 2 POWER TRANSMISSION TRAIN — OVERVIEW

The transmission (power train) carries the engine's power to the drive wheels and the PTO, and along the way ***changes the torque and speed*** to suit the widely varying field draft and speed — because the engine itself runs at nearly constant speed.

### THE POWER FLOW (ENGINE → WHEELS)

***Engine → Clutch → Gear box → Differential → Final drive → Rear (drive) wheels***. The ***clutch*** connects/disconnects the engine; the ***gear box*** selects the speed/torque ratio; the ***differential*** splits drive to the two wheels and lets them turn at different speeds on a bend; the ***final drive*** gives the last big reduction (high wheel torque). A branch drives the **PTO**, and the engine also drives the hydraulic pump.

### FUNCTIONS OF THE TRANSMISSION SYSTEM

Transmit power from engine to wheels/PTO (Power take off); provide a range of ***speed & torque ratios*** and a reverse; disconnect the engine for starting/stopping/gear change; distribute drive to both wheels (differential); and give the final speed reduction and ground clearance.

### POWER OUTLETS & AVAILABILITY (OPSC 2015)

| Power outlet | Approx. availability | Use |
|---|---|---|
| Engine (rated) | 100% | reference |
| PTO / belt pulley | ~85% | rotary machines — thresher, rotavator, pump |
| Drawbar | ~50-60% (soil-dependent) | pulling tillage/transport implements |
| Hydraulic | as required | lifting & controlling mounted implements |


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Losses down the train arise from transmission friction, rolling resistance and wheel slip — which is why drawbar power is much less than engine power (and least on soft soil).

**PREVIOUS YEAR QUESTIONS**

- With a line diagram of each stroke, explain the working of a 4-stroke spark-ignition engine. [IFoS 2021 | P2/3(a) | 15M]
- How is power transmitted from the engine to the traction wheels and PTO shaft of a two-wheel-drive tractor? Explain with a schematic diagram. [IFoS 2018 | P2/3(b) | 10M]
- Draw a neat schematic diagram of a tractor power train and discuss the significance of each member of the power train. [IFoS 2016 | P2/2(b) | 10M]
- With a flow chart, explain the working of the tractor power train by mentioning the function of each component. [IFoS 2020 | P2/2(b·ii) | 10M]
- Explain the power transmission system of a tractor with a neat diagram. [OPSC·CSE (Main) 2017-18 | Paper-II Q.2(a) | 20M]
- What is the importance of the power-transmission system in a tractor? Describe the working of the power-transmission train with a labelled diagram. Describe the various power outlets of a tractor and the percentage of power availability at these points. [OPSC·CSE (Main) 2015-16 | Paper-II Q.3(a) | 20M]
- What do you mean by transmission system of a tractor? What are the functions of the transmission system? [OPSC·Forest (Main) 2019-20 | Paper-II Q.2(a) | 20M]
- Describe the role of the clutch, gearbox and differential in transmitting power from the engine to the wheels of a tractor. [OPSC·CSE (Main) 2023-24 | Paper-II Q.4(b) | 15M]

***FIGURE 3.2 — Tractor power train (block diagram)***

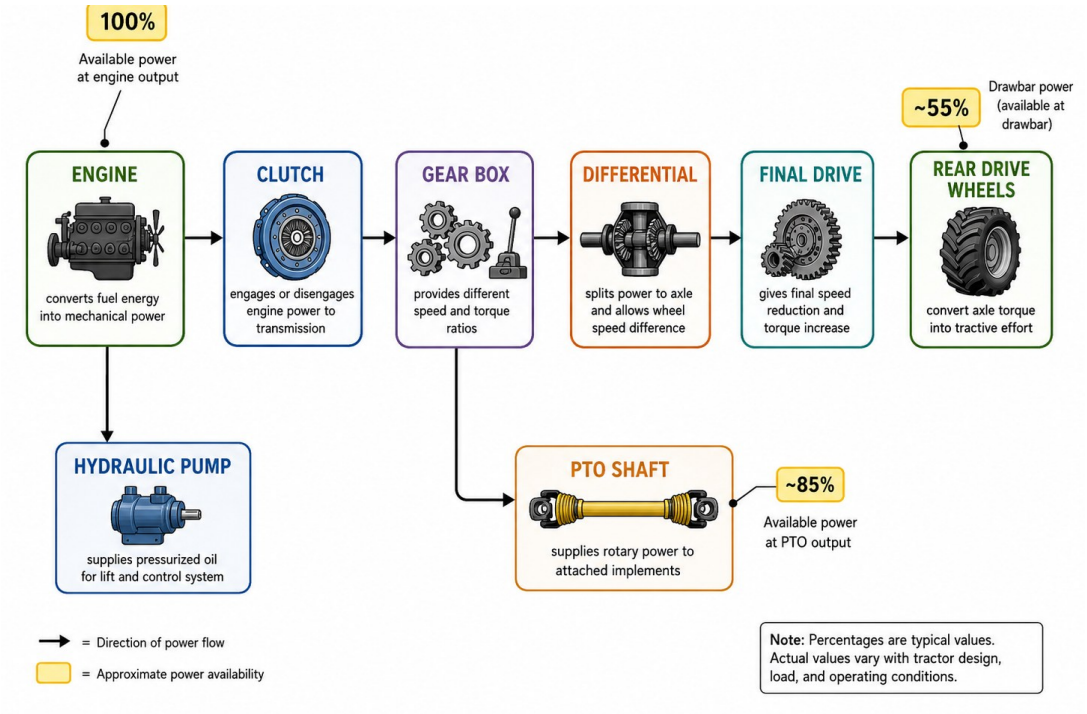



*Fig. 3.2 Power flow from engine through clutch, gearbox, differential and final drive to the wheels, with the PTO branch.*

## 3 CLUTCH

**Clutch** — a device that ***connects and disconnects the engine from the transmission*** smoothly — needed to start the tractor from rest, change gears, and stop the machine without stalling the engine. It transmits power by ***friction*** between a driven plate and the engine flywheel.

**Working Principle — How It Engages & Disengages**

**Engaged (normal running) :** strong ***clutch springs press the pressure plate***, clamping the friction disc hard against the spinning flywheel. The disc — splined to the gearbox (clutch) shaft — is gripped between flywheel and pressure plate and so turns with the engine, transmitting torque by ***friction (T = n·μ·W·R)***.

**Disengaged (pedal pressed) :** the linkage pushes the ***release bearing*** to draw the pressure plate back against the springs; the disc is set free and no torque reaches the transmission — letting the tractor start from rest, change gear or stop without stalling the engine.

**Types & Essential Features**

**Single-plate (dry) :** one friction disc between flywheel and pressure plate; common on tractors.

**Dual / double-plate :** two driven plates — often to drive the transmission and a live PTO independently.

**Multi-plate :** several plates in a stack (may run wet in oil) for ***heavy torque in limited space***.

**Essential features (AP·PSC 2012) :** positive drive when engaged, gradual/smooth take-up, ability to dissipate heat, light pedal effort, dynamic balance, freedom from grab/slip, and durability.

**Single-Plate Vs Dual-Plate Clutch (Ifos 2016)**

| Point | Single-plate clutch | Dual / double-plate clutch |
|---|---|---|
| Driven plates | one friction disc | two friction discs (an extra plate & pressure member) |
| Torque capacity | lower — one pair of friction faces | higher — more friction area for the same diameter |
| PTO drive | PTO stops when the clutch pedal is pressed | second plate can drive a live/independent PTO on its own |
| Control | single-stage engagement | often two-stage (transmission first, then PTO) |
| Typical use | most utility/general-purpose tractors | tractors needing an independent PTO or higher torque |

Torque per surface: $T = \mu \cdot W \cdot R$  Single plate (2 surfaces): $T = 2\mu WR$  n surfaces: $T = n \cdot \mu \cdot W \cdot R$

*μ friction coefficient; W axial force; R mean friction radius. Uniform wear: $R = (r_o + r_i)/2$, $W = 2\pi \cdot p_{max} \cdot r_i \cdot (r_o - r_i)$. Uniform pressure: $R = (2/3)(r_o^3 - r_i^3)/(r_o^2 - r_i^2)$, $W = p \cdot \pi(r_o^2 - r_i^2)$.*

◆ ***WORKED NUMERICAL — Number of plates of a multi-plate clutch*** **[IFoS 2019 | P2/4(a) | 10M]**

**Problem.** *A multi-plate clutch is designed for a vehicle whose engine develops a maximum torque of 13 N·m at 3500 rpm. The external diameter of the facings is 100 mm, the inner diameter 0.2 times the external, maximum pressure 80 kPa and μ = 0.3. Calculate the number of plates (assume uniform wear).*

**Given.** T = 13 N·m; $r_o$ = 50 mm = 0.05 m; $r_i$ = 0.2×100 = 20 mm ⇒ 0.01 m; $p_{max}$ = 80 kPa; μ = 0.3; uniform wear.

**Axial force.** $W = 2\pi \cdot p_{max} \cdot r_i \cdot (r_o - r_i) = 2\pi \times 80\,000 \times 0.01 \times 0.04 = 201.1$ N

**Mean radius.** $R = (r_o + r_i)/2 = (0.05 + 0.01)/2 = 0.03$ m

**Torque per surface.** $= \mu \cdot W \cdot R = 0.3 \times 201.1 \times 0.03 = 1.81$ N·m

**Number of surfaces.** $n = T/(\mu WR) = 13/1.81 = 7.18$ ⇒ 8 friction surfaces

**Result. 8 friction surfaces ⇒ provide about 9 plates (5 on one shaft + 4 on the other).**

**PREVIOUS YEAR QUESTIONS**


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- Explain the working principle and uses of the tractor power-train component: Clutch.
  [IFoS 2023 | P2/3(b)(i) | part of 15M]
- Why does a tractor need a clutch? What are the essential features of a good clutch?
  [AP·PSC RFO (Mains) 2012 | Q.2(B) | 5M]
- Differentiate between single-plate clutch system and dual-plate clutch system. [other pairs — naturally-aspirated vs turbocharged (Ch.2), centrifugal vs gear pump, wheelbase vs track (§7) — in their sections].
  [IFoS 2016 | P2/1(a)(iii) | part of 8M]

***FIGURE 3.3 — Single-plate & multi-plate clutch***

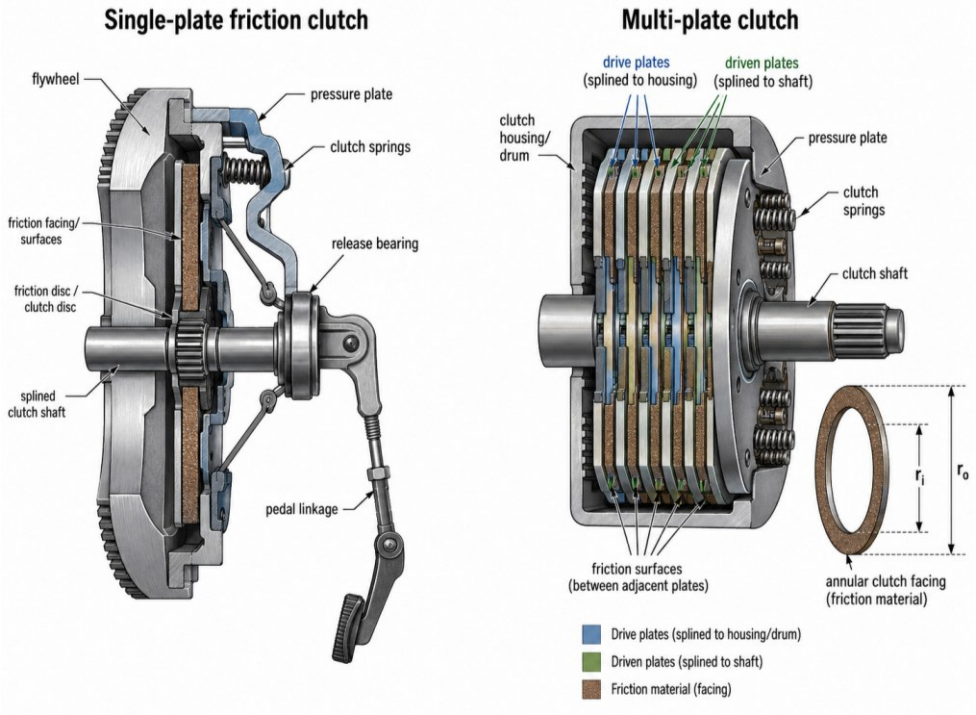



*Fig. 3.3 Single-plate (left) and multi-plate (right) friction clutches.*

## 4 GEAR BOX

***Gear box (transmission) :*** provides a range of ***speed and torque ratios*** between the engine and the wheels, plus a reverse and a neutral. It is needed because the engine runs at a nearly ***constant speed*** while the field demands widely varying ***travel speed and draft*** — low gear gives high torque (heavy tillage), high gear gives high speed (transport).

**TYPES OF GEAR BOX**

| Type | How gears engage | Feature |
|---|---|---|
| Sliding-mesh | spur gears slid along the splined shaft to mesh | simplest, cheapest; noisy; needs double-declutching; commonest on tractors |
| Constant-mesh | gears always meshed; dog clutches lock the chosen gear to the shaft | quieter, stronger (helical gears); easier shift |
| Synchromesh | constant-mesh + synchronizing cones equalise speeds before engagement | smoothest, clash-free; cars & higher-end tractors |

The gearbox also ***multiplies engine torque*** in the low gears (torque out = torque in × gear ratio), letting a modest engine develop the large drawbar pull tillage needs.

**WORKING OF THE SLIDING-MESH GEAR BOX**

Different-sized spur gears are ***fixed to the lay (counter) shaft***, while their matching gears ***slide along the splines of the main shaft***. To take a ratio the driver ***declutches*** and moves a shift fork so the chosen main-shaft gear slides into mesh with its lay-shaft gear — a small gear driving a large one gives ***low speed / high torque***, a large driving a small gives ***high speed / low torque***. **Reverse** is obtained by introducing an extra ***idler gear*** that reverses the output rotation. Because the meshing gears must be brought to matching speed, this box needs ***double-declutching*** and is noisy — hence constant-mesh and synchromesh boxes on higher-end machines.

**PREVIOUS YEAR QUESTIONS**

- Explain the working principle and uses of the following components of the tractor power train: (ii) Gear Box. [The full question also covers clutch, differential, final drives & PTO — each answered in its own section.]

  [IFoS 2023 | P2/3(b)(ii) | part of 15M]

- With a neat diagram, explain the working of a sliding-mesh type gear box. How does anthropometric data help in the design of agricultural machinery?

  [OPSC·Forest (Main) 2023-24 | Paper-II Q.2(b) | 20M]

***Anthropometric data (2nd part — cross-ref: Ergonomics & Machine-Design chapter) : body-dimension and strength statistics of the operator population*** — reach, grip, seat height, leg room, and the force a person can apply. Designers use these percentile figures to size ***seats, pedals, levers, steering and controls*** so the machine fits the operator — reducing fatigue and hazard and improving output (ergonomic design). Full treatment is in the farm-machinery design/ergonomics chapter.

## 5 DIFFERENTIAL, FINAL DRIVE & PTO

**DIFFERENTIAL — WHY A TRACTOR NEEDS ONE**

On a turn the ***outer wheel travels farther than the inner*** in the same time. If both drive wheels were on one rigid axle they would fight (scuff, skid, stress the train). The ***differential*** (bevel crown-wheel driven by the pinion, carrying spider/side gears) lets the two wheels turn at ***different speeds*** while still driving both.

**DIFFERENTIAL — WORKING PRINCIPLE**

The gearbox output shaft's ***bevel pinion drives the crown wheel***, which carries the ***differential cage***. Inside the cage, small ***spider (pinion) gears*** mesh with the two ***side (sun) gears*** splined to the half-axles.

**Going straight :** both wheels meet equal resistance, so the spider gears do not spin on their own pins; cage, spiders and side gears revolve together as one solid unit and both wheels turn at crown-wheel speed.

**On a turn :** the inner wheel meets more resistance and slows, so the spider gears now ***rotate on their pins***, rolling around the slower side gear and driving the outer side gear faster by exactly the same amount.

Hence the sum $N(inner) + N(outer) = 2 \times N(crown\ wheel)$ always holds — power reaches both wheels while they turn at different speeds.

**USES OF THE DIFFERENTIAL**


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Lets the tractor ***turn without tyre scrub, skid or transmission wind-up***; divides drive equally to both wheels when going straight; and reduces stress and wear on the axles and tyres.

***Differential lock*** : ***locks the two axle shafts together*** so both wheels turn at the same speed. Engaged when one wheel spins in mud/loose soil (the differential would otherwise send all drive to the slipping wheel); the lock restores traction to the gripping wheel. Released for normal turning.

**FINAL DRIVE — WORKING PRINCIPLE & USES**

**Working :** a fixed-ratio reduction on each half-axle, after the differential: a ***bull-and-pinion (spur) pair***, an ***epicyclic/planetary set***, or a ***chain-and-sprocket***. It makes the last and largest speed reduction, so wheel torque is multiplied by its gear ratio right at the wheel (torque out = torque in × ratio).

**Uses :** supplies the high torque a tractor needs for drawbar pull; brings wheel speed down to the working field range; ***raises the axle centre to give ground clearance***; and lets the gearbox and differential stay small and light, since the bulk of the reduction is taken here.

**POWER TAKE-OFF (PTO) — WORKING PRINCIPLE & USES**

**Working :** a ***splined stub shaft*** driven from the transmission (transmission-PTO) or straight from the engine (live / independent-PTO) through a gear set, turning at the standard **540 rpm or 1000 rpm**; the implement's telescopic universal-joint shaft slides onto the splines.

**Uses :** delivers rotary power to ***threshers, rotavators, sprayer pumps, mowers, balers and post-hole diggers***, and to stationary machines via a belt or shaft.

**Types :** transmission PTO (stops with the clutch), live PTO (two-stage clutch), independent PTO (own clutch — runs regardless of travel).

**PREVIOUS YEAR QUESTIONS**

- Explain the working principle and uses of the following components of the tractor power train: (iii) Differential (iv) Final Drives (v) Power Take-off.

  [IFoS 2023 | P2/3(b)(iii,iv,v) | part of 15M]

- With the help of a diagram and labelled parts, explain the need and working principle of the differential system of a tractor.

  [UK·PSC RFO (Mains) 2012 | Q.7(ii) | 10M]

- Write the function of the differential unit of a tractor. [Multi-chapter question — timing gear, flywheel, fluted roller & straw-walker sub-parts are in their own chapters.]

  [IFoS 2024 | P2/2(c)(iv) | part of 15M]

- Why is a differential lock provided in a tractor? [One part of a 4-part 'describe in brief' Q — rear-tyre pressure §7, independent brakes §9, drive-wheel lugs §7.]

  [IFoS 2021 | P2/1(b)(ii) | part of 8M]

- Elaborate the function of the differential with a suitable sketch. What are the advantages of the differential lock? [Engine torque / fuel-impulse sub-parts of this Q → Ch.2.]

  [OPSC·CSE (Main) 2018-19 | Paper-II Q.2(c) | part | 20M]

***FIGURE 3.4 — Differential & final drive***

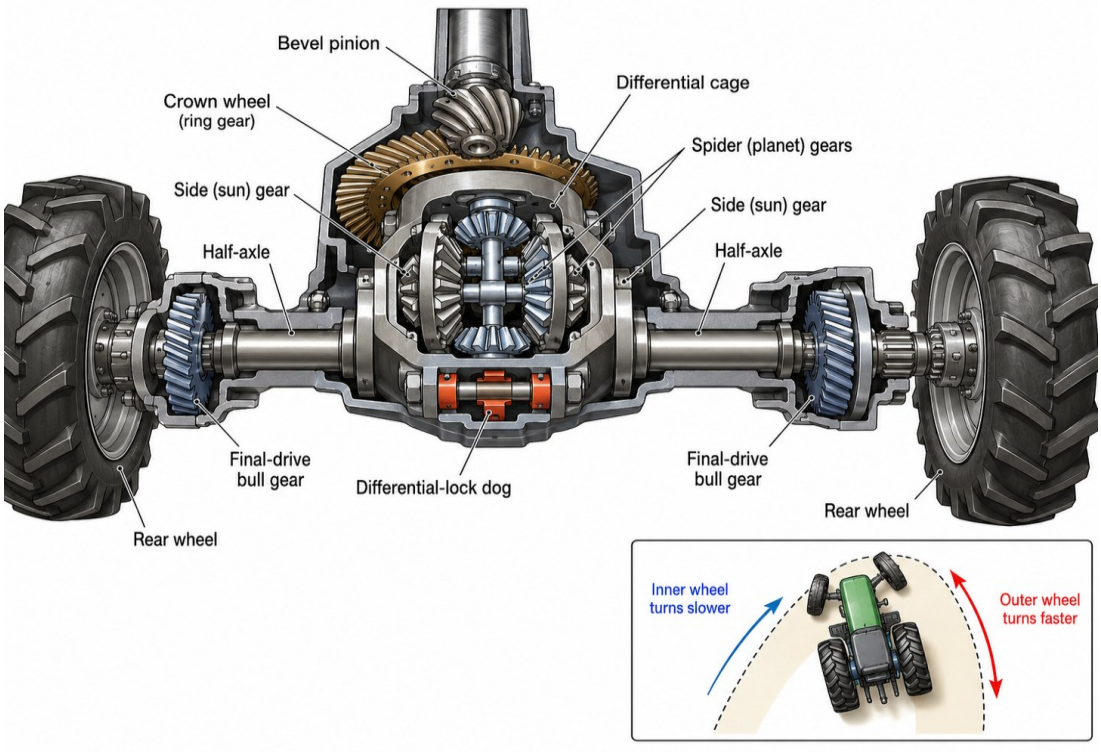



*Fig. 3.4 Differential (crown wheel, pinion, spider & side gears), differential lock and final drive.*

## 6 HYDRAULIC SYSTEM & THREE-POINT LINKAGE

The tractor hydraulic system ***raises, lowers and controls mounted implements*** and provides remote power (tipping trailers, etc.). An engine-driven ***pump (gear pump)*** sends oil through a ***control valve*** to the ***lift cylinder***; the piston turns the ***rockshaft***, whose lift arms raise the linkage. Lowering releases oil back to the sump.

**THREE-POINT LINKAGE (3PL)**

Two **lower links** (carry the draft/pull and the weight) and one **top link** (sets the implement's pitch/tilt). Their lines converge to a virtual hitch point that transfers implement weight onto the rear wheels for extra traction. Sized by ***category (I, II, III)*** to tractor power.

**CONTROL MODES — POSITION VS DRAFT (A FAVOURITE 'WHY' QUESTION)**

| Mode | What is held constant | Use |
|---|---|---|
| Position control | implement HEIGHT (fixed rockshaft position) | shallow/gauge work, transport, seeding at set depth |
| Draft control | the DRAFT (pull) — depth varies automatically | ploughing in variable soil; saves fuel, prevents overload & wheel-spin |
| Draft sensing | mechanism (top-link/lower-link spring or torsion bar) that senses draft and signals the valve | the sensor that makes draft control work |

**ADDC (Automatic Depth-and-Draft Control)** blends the two — holding draft but limiting depth swing — for uniform work in patchy soil.


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**PREVIOUS YEAR QUESTIONS**

- What do you understand by draft sensing in the hydraulics of a tractor? Discuss, with the help of a suitable diagram, the automatic position-control system on tractors.

  [IFoS 2019 | P2/2(c) | 15M]

- Differentiate between draft control and position control hydraulic systems. [Multi-chapter 'differentiate' Q — 2-/4-stroke engine, spraying/dusting and seed-drill/transplanter pairs are in their own chapters.]

  [IFoS 2020 | P2/1(b)(ii) | part of 8M]

***FIGURE 3.5 — Hydraulic lift & three-point linkage***

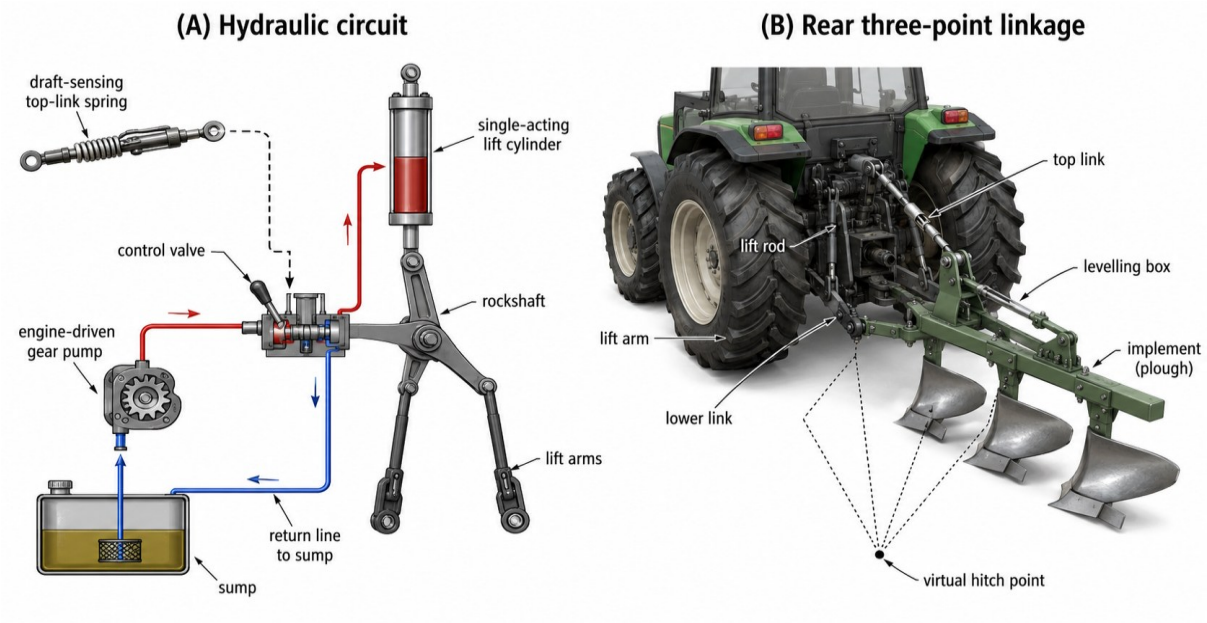



*Fig. 3.5 Tractor hydraulic lift circuit (A) and the three-point linkage with draft sensing (B).*

## 7 WHEELS & FRONT-WHEEL GEOMETRY

| Term | Meaning |
|---|---|
| Wheelbase | distance between the front and rear axles (along the tractor) |
| Track / tread width | distance between the two wheels of the SAME axle (across) — adjustable for row-crop work |

**FRONT VS REAR WHEELS — THE 'WHY' BOXES**

***Why rear tyres are large, lugged & run at LOW pressure :*** Large diameter + deep ***lugs*** bite the soil for traction; low inflation gives a ***large contact patch*** (more grip, less soil compaction, softer ride) and lets the tyre carry the tractor's weight for pull. Front tyres are small, smooth and at ***higher pressure*** — they mainly ***steer*** and carry less weight, so higher pressure means less rolling resistance and sharper steering.

**FRONT-WHEEL GEOMETRY (STEERING GEOMETRY)**

***Front-wheel alignment : the set of angles given to the front wheels and the steering axis*** — camber, king-pin inclination, caster and toe-in — that together keep steering ***light, stable and self-centring*** and stop the tyres from scrubbing or wearing unevenly.

| Adjustment | What it is | Why |
|---|---|---|
| Camber | top of wheel tilted OUT from vertical | puts load near the king-pin, reduces bearing load, |

| | | |
|---|---|---|
| | (~1-3°) | eases steering |
| King-pin inclination | steering axis tilted INWARD (top in) | self-centring (wheels return to straight), reduces steering effort & wander |
| Caster | steering axis tilted fore/aft (top back) | directional stability & self-return after a turn |
| Toe-in | front wheels closer together at the FRONT (6-10 mm) | cancels the tendency to roll outward, keeps wheels parallel when moving, prevents tyre scrub/wear |

**ACKERMAN STEERING**

Correct steering (Ackerman): $\cot \phi - \cot \theta = w / l$

*ϑ inner-wheel angle, φ outer-wheel angle, w = king-pin distance (track), l = wheelbase. All wheels then roll about one common turning centre — no tyre scrub.*

**PREVIOUS YEAR QUESTIONS**

- What are the different adjustments in the front wheels of tractors? Discuss with the help of a suitable diagram. [IFoS 2019 | P2/3(c) | 15M]
- Why do the rear wheels of general-purpose tractors have tyre inflation pressure less than the front wheels? [IFoS 2021 | P2/1(b)(i) | part of 8M]
- Why are drive-wheel tyres provided with lugs in general-purpose tractors? [IFoS 2021 | P2/1(b)(iv) | part of 8M]
- Justify: why is the size of the rear wheels of a tractor larger than the front wheels? [IFoS 2020 | P2/1(c)(i) | part of 8M]
- Answer: (i) Why do general-purpose tractors have larger rear and smaller front wheels? (iii) Why do tractor rear wheels have lesser inflation pressure than the front wheels? [IFoS 2016 | P2/2(d)(i,iii) | part of 10M]
- Differentiate between wheelbase and track width of a tractor. [Other pairs of this 'differentiate' Q – aspirated/turbo & centrifugal/gear pump → Ch.2, single/dual clutch → § 3.] [IFoS 2016 | P2/1(a)(iv) | part of 8M]

***FIGURE 3.6 — Front-wheel geometry***

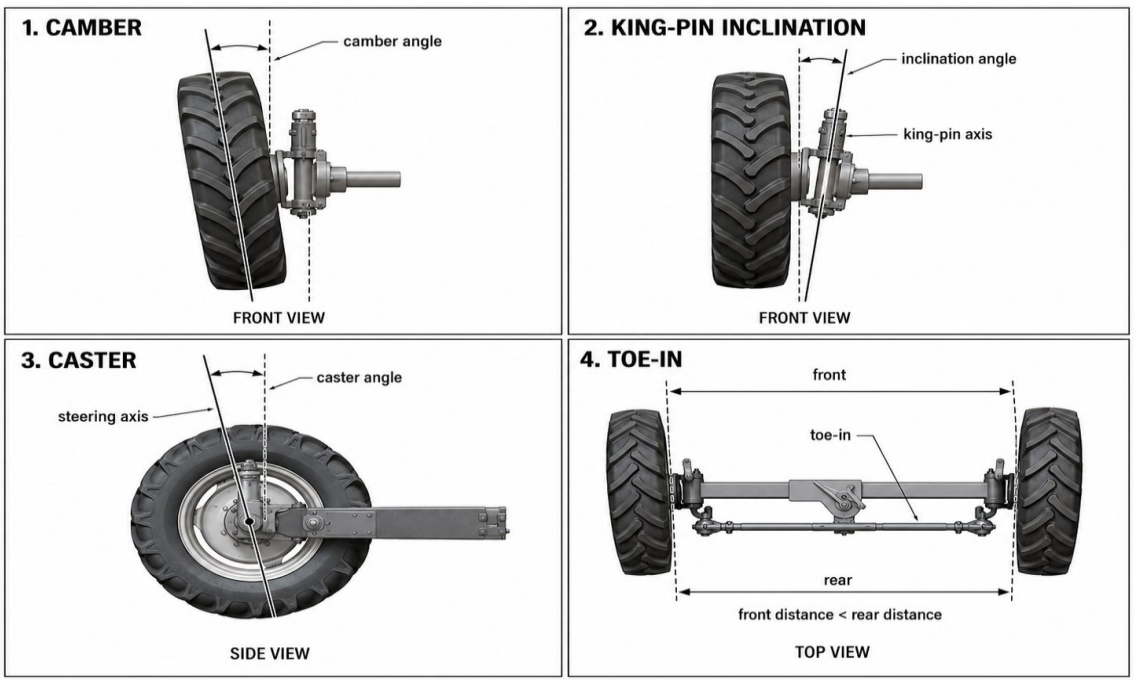



*Fig. 3.6 Front-wheel adjustments — camber, king-pin inclination, caster and toe-in.*


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## 8 TRACTOR STABILITY

A tractor can overturn ***sideways (lateral)*** — chiefly on a fast turn or a side-slope — or ***rearward (longitudinal)*** when pulling a heavy load hitched too high or climbing steeply. Stability is governed by the ***centre-of-gravity (CG) height, the track/wheelbase, and speed***.

### LATERAL OVERTURN ON A TURN — THE MECHANICS

Rounding a curve of radius R at speed v, the centrifugal force $(W/g)(v^2/R)$ acts at CG height h and tends to tip the tractor about the ***outer wheels***. Overturn just begins when its moment equals the restoring moment of the weight about that line:

At the point of overturn: $(W/g)(v^2/R)\cdot h = W\cdot(t/2) \Rightarrow v = \sqrt{(g \mid R \mid (t/2) / h)}$ ; safe turning radius $R = v^2\cdot h / (g \mid (t/2))$

*W weight, g 9.81 m/s², v speed, R turn radius, t track width, h CG height. Note W cancels — overturn speed is independent of weight; it depends on track, CG height and radius.*

◆ ***WORKED NUMERICAL — Speed at which a tractor overturns on a turn*** **[IFoS 2021 | P2/4(c) | 15M]**

**Problem.** *A tractor weighing 2 t has its CG 1 m ahead of the rear-axle line and 0.75 m above the ground; wheelbase 2.20 m and rear-wheel spacing (track) 1.6 m. Find the speed at which it will overturn while turning on a circle of 4 m radius.*

**Given.** t = 1.6 m ⇒ t/2 = 0.8 m; h = 0.75 m; R = 4 m; g = 9.81 m/s². (Weight, wheelbase & CG-position are for the longitudinal check / distractors — weight cancels in the side-overturn condition.)

**Condition.** side overturn about the outer wheels: $v = \sqrt{(g \mid R \mid (t/2) / h)}$

**Substitute.** $v = \sqrt{(9.81 \times 4 \times 0.8 / 0.75)} = \sqrt{(31.392 / 0.75)} = \sqrt{41.856}$

**Speed.** v = 6.47 m/s

**Convert.** 6.47 × 3.6 = 23.3 km/h

**Result. The tractor overturns at about 6.47 m/s ≈ 23.3 km/h on the 4 m turn.**

◆ ***WORKED NUMERICAL — Safe turning radius against side overturn*** **[OPSC·CSE (Main) 2015-16 | Paper-II Q.1(c) | 20M]**

**Problem.** *A tractor of 3000 kg travels at 25 km/h. Its track width is 1.8 m and CG height 0.8 m. Find the minimum (safe) radius of turn so that it does not overturn sideways.*

**Given.** v = 25 km/h = 25/3.6 = 6.944 m/s; t/2 = 0.9 m; h = 0.8 m; g = 9.81 m/s². (Mass cancels.)

**Condition.** $R = v^2\cdot h / (g \mid (t/2))$

**Substitute.** $R = (6.944^2 \times 0.8) / (9.81 \times 0.9) = (48.23 \times 0.8) / 8.829 = 38.58 / 8.829$

**Result. R = 4.37 m — turning sharper than this radius at 25 km/h risks side overturn.**

### LONGITUDINAL (REARWARD) STABILITY

A rear pull applied ***above the drawbar*** (e.g. hitched to the axle) creates a moment that lifts the front — the tractor can flip backward about the rear-axle line. Safeguards: hitch loads ***only at the drawbar (low)***, add front ballast, and start moving gently. This is why implements must never be hitched high on the axle.

◆ ***WORKED NUMERICAL — Drawbar power from draft and speed*** **[OPSC·CSE (Main) 2020-21 | Paper-II Q.3(a)(i) | 8M]**

**Problem.** *Draft (dynamometer) = 1200 kgf; the tractor moves 50 m in 30 s while ploughing. Calculate the drawbar horse-power developed and the forward speed (km/h). [The same question's other part — functions of the differential, final drives and PTO — is answered in §5. Fuller tractive theory: slip, tractive efficiency → Ch.4.]*

**Speed.** S = 50/30 = 1.667 m/s = 1.667 × 3.6 = 6.0 km/h

**Formula (metric).** DBP(hp) = D(kgf) × S(km/h) / 270

**Substitute.** DBP = 1200 × 6.0 / 270 = 7200 / 270 = 26.7 hp

**Check (SI).** P = D·S = (1200 × 9.81 N)(1.667 m/s) = 19 620 W ≈ 19.6 kW = 26.3 hp ✓

**Result. Forward speed 6 km/h; drawbar power ≈ 26.7 hp (≈ 19.6 kW).**

***FIGURE 3.7 — Tractor overturn mechanics***

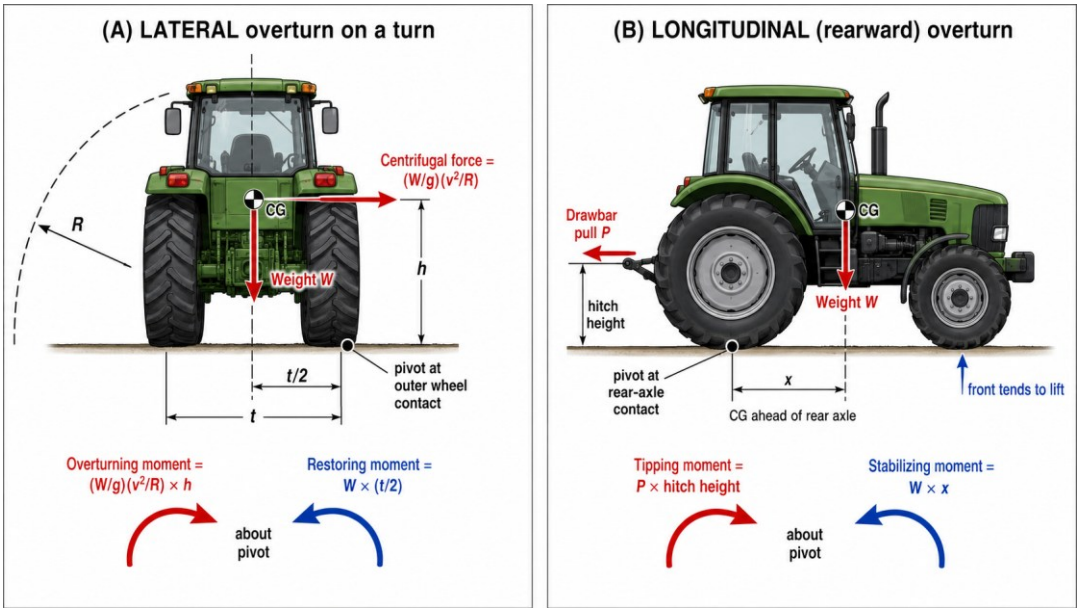



*Fig. 3.7 Side overturn on a turn (A) and rearward overturn under pull (B).*

## 9 BRAKES, TRACTION AIDS & THE TRACTOR GOVERNOR

### BRAKES — INDEPENDENT (SPLIT) PEDALS

***Independent rear-wheel brakes :*** Two **separate pedals**, one per rear wheel. Braking a single rear wheel pivots the tractor about it, giving a ***short turning radius at the headland*** (a 'turning brake'). A latch locks the two pedals together for equal, straight-line braking on the road. Types: internal-expanding shoe, disc, or oil-immersed (wet) brakes.

### TRACTION AIDS (IFOS 2019)

Devices that raise grip and cut wheel slip in loose or wet soil: **cage / strake wheels** (open steel wheels for puddled paddy fields), **dual wheels** (two tyres per side — spread load, more contact), **ballasting** (cast-iron weights or water in the tyres to add traction weight), and **tyre chains / lugs / strakes**. Purpose: increase tractive effort, reduce slip and prevent sinkage.

### THE TRACTOR GOVERNOR — TYPE, WORKING PRINCIPLE & OPERATION (IFOS 2025)

***Governor (tractor) : a speed-regulating device*** that automatically holds the engine at the operator's set speed as the field load varies, by adjusting the fuel delivered to the engine.

**Type used in Indian tractors :** a ***mechanical (centrifugal) fly-weight governor*** of the **variable-speed (all-speed) type**, because field load swings constantly and the operator must be able to preset and hold ANY working speed (unlike a constant-speed genset engine).

**Working principle & operation :** two ***fly-weights*** spin on an engine-driven spindle; their ***centrifugal force*** is opposed by a ***governor spring*** whose tension the operator sets with the hand throttle. **When load rises** the engine slows, the weights fly ***inward***, and the sleeve-linkage moves the fuel-pump rack to ***inject more fuel*** —


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restoring speed. **When load falls** the engine speeds up, the weights fly ***outward*** and ***cut the fuel*** back. The engine settles where centrifugal force balances spring tension — holding the chosen speed.

***FIGURE 3.8 — Tractor centrifugal variable-speed governor***

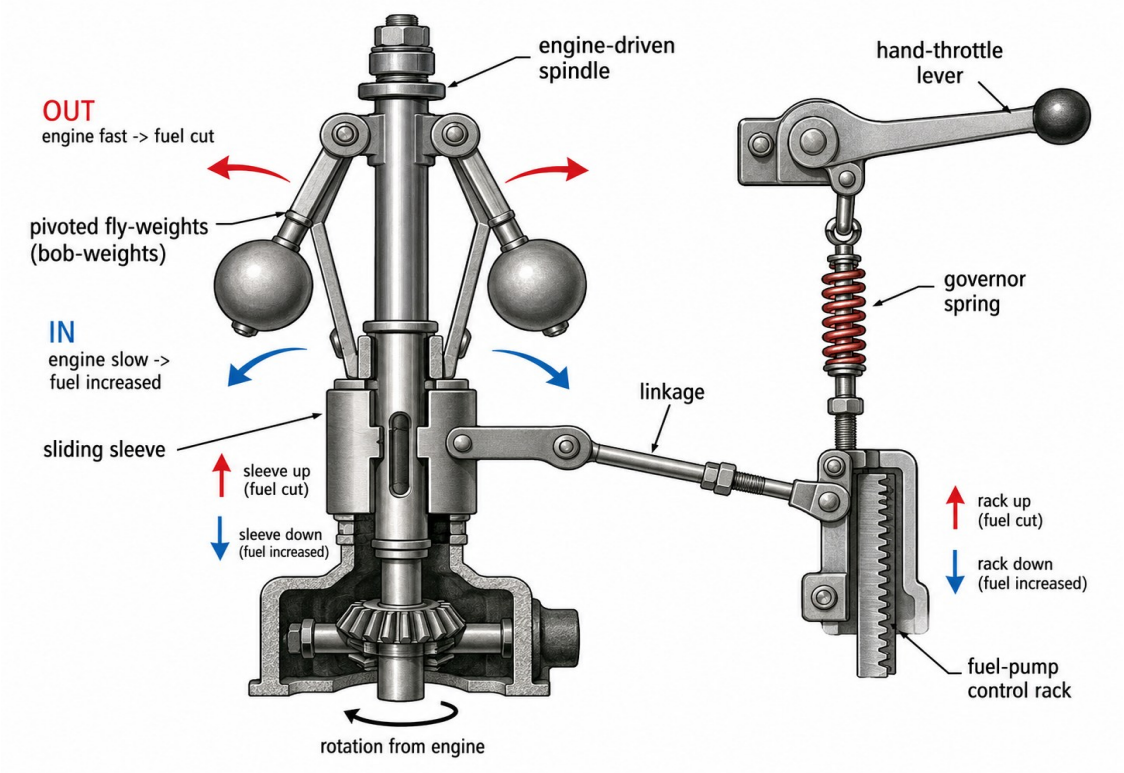



*Fig. 3.8 Centrifugal variable-speed governor — fly-weights versus spring position the fuel rack to hold the set engine speed.*

**PREVIOUS YEAR QUESTIONS**

- What type of governor is generally used in tractors manufactured in India? Explain its working principle and operation with the help of a suitable diagram.

  [IFoS 2025 | P2/3(a) | 15M]

- What is the purpose of traction aids in wheeled tractors? Discuss the different types of traction aids used in a wheeled tractor.

  [IFoS 2019 | P2/2(a) | 10M]

- Why do tractors have independent brake pedals? [One part of the 4-part 'describe in brief' Q — the other parts are answered in §5 and §7.]

  [IFoS 2021 | P2/1(b)(iii) | part of 8M]

**FORMULA SHEET — CHAPTER 3**

Clutch torque: $T = n \cdot \mu \cdot W \cdot R$ (single plate, 2 surfaces: $T = 2\mu WR$)

*Uniform wear: $R = (r_o + r_i)/2$, $W = 2\pi \cdot p_{max} \cdot r_i \cdot (r_o - r_i)$. Uniform pressure: $R = (2/3)(r_o^3 - r_i^3)/(r_o^2 - r_i^2)$, $W = p \cdot \pi(r_o^2 - r_i^2)$.*

Lateral overturn on a turn: $v = \sqrt{(g \mid R \mid (t/2) / h)}$ ; safe radius $R = v^2 \cdot h / (g \mid (t/2))$

*Weight cancels; depends on track t, CG height h, radius R.*

Drawbar power: DBP(hp) = D(kgf)·S(km/h) / 270 ; DBP(kW) = D(kN)·S(m/s)

*Fuller tractive theory (slip, tractive efficiency, weight transfer) → Chapter 4.*

Ackerman steering: $\cot \phi - \cot \theta = w / l$ | PTO speeds: 540 & 1000 rpm | Power availability: engine 100% → PTO ~85% → drawbar ~50-60%

## CHAPTER SUMMARY

A ***tractor*** is a mobile prime mover giving power at the ***drawbar, PTO and hydraulics***; it may be wheeled (2WD/4WD) or crawler, with the ***power tiller*** serving small, wet and terraced fields. The **power train** carries engine power to the wheels — Engine → Clutch → Gear box → Differential → Final drive → Wheels, with a PTO branch — matching the near-constant engine speed to variable field draft. The ***clutch*** (single/dual/multi-plate) engages and disengages the engine; the ***gear box*** (sliding/constant/synchromesh) sets speed-torque ratios; the ***differential*** lets the wheels turn at different speeds on a bend (the ***lock*** restores traction when one slips); the ***final drive*** gives the last big reduction. The **hydraulic 3-point linkage** lifts and controls implements, with ***position control*** holding height and ***draft control*** holding pull. Front-wheel ***camber, king-pin inclination, caster and toe-in*** make steering light and stable, and rear tyres run large, lugged and at low pressure for traction. **Stability** fails by lateral overturn on fast turns ($v = \sqrt{(gR(t/2)/h)}$, weight-independent) or rearward overturn under a high hitch; ***traction aids*** (cage/dual wheels, ballast, chains) and the ***governor*** (constant set speed under load) complete the machine.

## LAST-NIGHT REVISION – 60 SECOND RECALL

- ***Power train order*** : Engine → Clutch → Gear box → Differential → Final drive → Wheels (+ PTO branch, + engine-driven hydraulic pump).
- ***Power availability*** : engine 100% → PTO ~85% → drawbar ~50-60% (losses: transmission, rolling resistance, slip).
- ***Clutch torque*** : $T = n \cdot \mu \cdot W \cdot R$; uniform wear $R = (r_o + r_i)/2$, $W = 2\pi \cdot p_{max} \cdot r_i \cdot (r_o - r_i)$. IFoS-2019 clutch → 8 surfaces ≈ 9 plates.
- ***Gear boxes*** : sliding-mesh (simple, noisy, double-declutch) | constant-mesh (dog clutch, quieter) | synchromesh (cones, clash-free).
- ***Differential*** : different wheel speeds on a turn; lock = equal drive when one wheel slips.
- ***PTO*** : splined shaft, 540 & 1000 rpm; transmission / live / independent.
- ***Hydraulics*** : position control = constant height; draft control = constant pull (depth auto-varies); draft sensing via top link; 3PL = 2 lower + 1 top link.
- ***Front geometry*** : camber (out, eases steering), king-pin (in, self-centring), caster (fore/aft, directional), toe-in 6-10 mm (no scrub).
- ***Tyres*** : rear large/lugged/low-pressure (traction); front small/smooth/high-pressure (steer).
- ***Stability*** : overturn speed $v = \sqrt{(gR(t/2)/h)}$ — weight cancels; IFoS-2021 → 23.3 km/h; OPSC-2015 safe R = 4.37 m; rearward overturn from high hitch → hitch low + front ballast.
- ***Traction aids*** : cage/strake wheels, dual wheels, ballasting, tyre chains — more grip, less slip.
- ***Drawbar HP*** : DBP = D·S/270 (kgf, km/h); OPSC-2020 → 26.7 hp at 6 km/h.


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CHAPTER

# 4

# TILLAGE IMPLEMENTS & TRACTION THEORY

*Plough · harrow · cultivator · rotavator · MB & disc geometry · implement attachment · traction theory · soil cutting*

**SYLLABUS :** Tillage implements — mould board plough, disc plough, harrow, cultivator, ridger, sub-soiler, rotavator, etc.; theory of soil cutting and pulverization; traction theory. (UPSC IFoS, Agricultural Engineering, Paper II, Section A — Farm Power & Machinery.) Chapter 4 covers tillage classification and objectives; MB plough components, suction, mouldboard types, centre of resistance & centre of pull; disc plough/harrow geometry — disc, tilt and gang angles, single vs double action, offset vs tandem, penetration factors; cultivator, rotavator, sub-soiler, spike- & spring-tooth harrows, ridger, puddler; implement attachment — trailed, semi-mounted, mounted; traction theory — drawbar pull/power, tractive efficiency, coefficient of traction, unit/specific draft, rolling resistance, wheel slip vs skid, weight transfer; theory of soil cutting and pulverization; and field-capacity & draft numericals.

## Chapter Outline


1. **Scope & Introduction to Tillage**
2. **Classification of Tillage & Objectives**
3. **Mould Board (MB) Plough**
4. **Disc Plough**
5. **Harrows — Disc, Spike-tooth & Spring-tooth**
6. **Cultivators, Rotavator, Sub-soiler, Ridger, Puddler & Indigenous Plough**
7. **Implement Attachment Systems — Trailed, Semi-mounted, Mounted**
8. **Forces on Tillage Tools; Centre of Resistance & Centre of Pull**
9. **Theory of Soil Cutting & Pulverization; Draft**
10. **Traction Theory — Fundamentals**
11. **Traction — Soil Shear, Prediction & Improvement**
12. **Weight Transfer, Centre of Gravity & Tractor Stability**
13. **Solved Numericals Bank (all PYQ numericals, fully worked)**
14. **Formula Sheet | Summary | Last-Night Revision**

***MIND-MAP — Chapter 4 concept map***

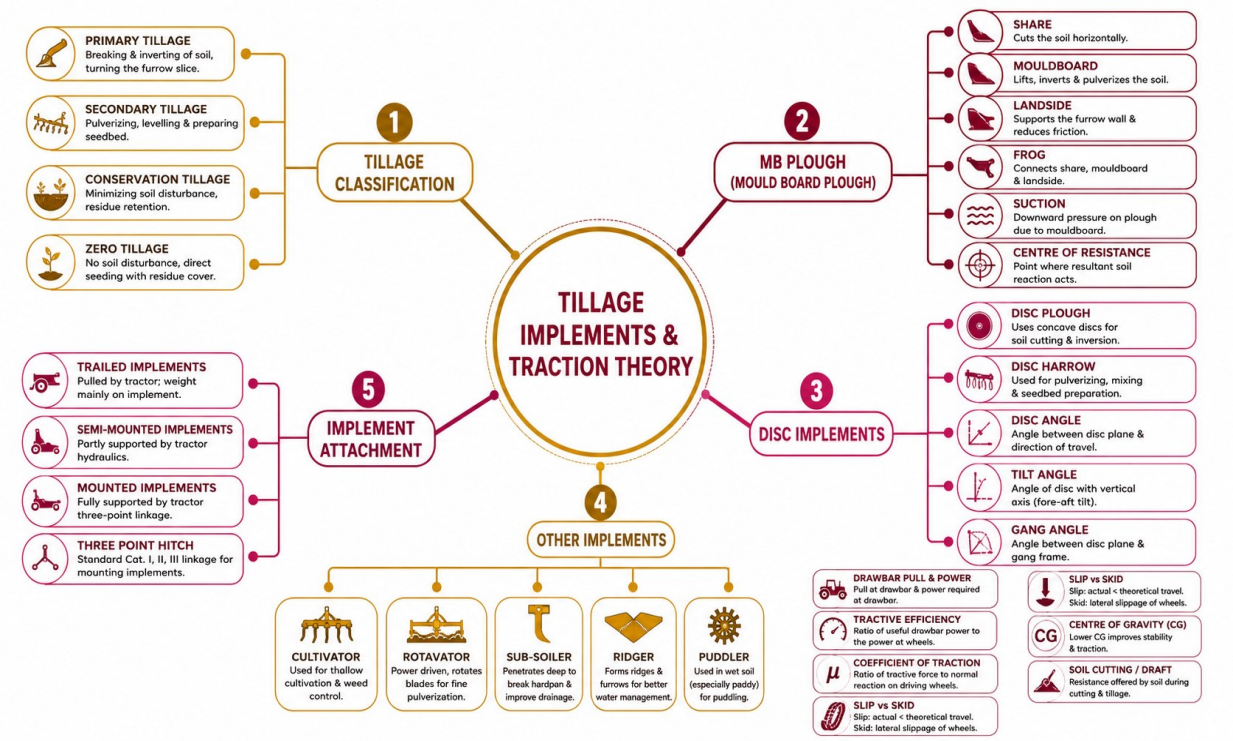



*Fig. 4.0 Chapter-4 concept map — how tillage implements and traction theory interlink.*

## 1 SCOPE & INTRODUCTION TO TILLAGE

This chapter deals with the ***implements that prepare the seedbed*** and with the ***mechanics by which a tractor converts engine power into useful pull***. In the IFoS Agricultural Engineering paper these two themes recur every year: tillage classification, the mould-board and disc plough, harrows and cultivators on the implement side; and drawbar pull, tractive efficiency, wheel slip and weight transfer on the traction side. Roughly two-fifths of the marks in this area come from derivations and numerical

### 1.1 What is Tillage?

> **Tillage** : *the mechanical manipulation of soil to provide a favourable environment for seed germination, seedling emergence and crop growth. It loosens and pulverises the soil, inverts and mixes it, and manages residues and weeds.*

> **Tilth** : *the resulting physical condition of the soil in relation to plant growth — an aggregate of factors such as size distribution of clods, degree of aeration, moisture retention and drainage. A soil in good tilth is loose, friable and well-granulated.*

Tillage is usually limited to the ***arable layer*** (about the top 10–30 cm) where organic matter is concentrated and root activity occurs. The energy the soil absorbs during tillage does two useful things — it ***cuts and lifts*** the furrow slice and it ***pulverises*** the clods; the rest is dissipated as friction and is, from the agronomic view, wasted.

### 1.2 Objectives of Tillage

- ***Seedbed preparation*** : to obtain a fine, firm seedbed that gives good seed–soil contact and uniform germination.
- ***Weed control*** : to uproot, bury or cut weeds and destroy their regenerative parts.


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- ***Soil aeration & warming*** : to admit air and heat into deeper layers, aiding microbial activity and root respiration.
- ***Moisture management*** : to increase infiltration and, through a soil mulch, reduce evaporation losses; also to improve drainage.
- ***Residue & manure incorporation*** : to bury crop residues, stubble and green manures so they decompose in the root zone.
- ***Pest control*** : to expose soil-borne insects, larvae and rodents to sun and predators.
- ***Root-zone loosening*** : to break hard pans and reduce bulk density so roots penetrate freely.

**PREVIOUS YEAR QUESTIONS**

- Define tillage. What do you understand by primary tillage and secondary tillage? Classify implements on the basis of how they are attached to the tractor.

[IFoS 2018 | P2/1(a) | 8M]

**MODEL Q** Open with the one-line definition of tillage, then split into primary vs secondary (§2.2) with one example implement each, and finish with the trailed / semi-mounted / mounted classification (§7). A labelled line — 'define → classify tillage → classify implements'***

## 2 CLASSIFICATION OF TILLAGE & OBJECTIVES

### 2.1 Primary and Secondary Tillage

***Primary tillage :*** *the first, deeper cut into the soil after harvest. It is comparatively rough, opens and inverts the soil to 15–30 cm, and is done with high-draft implements — mould-board plough, disc plough, sub-soiler, chisel plough.*

***Secondary tillage :*** *the lighter, shallower operations that follow primary tillage to pulverise clods, level the surface, conserve moisture and prepare the final seedbed — done with harrows, cultivators, rollers and pulverisers.*

**OBJECTIVES OF PRIMARY TILLAGE**

to shatter and invert the furrow slice; bury weeds and residues; open a hard soil for aeration and moisture entry; and break the plough pan.It leaves the surface cloddy and rough.

**OBJECTIVES OF SECONDARY TILLAGE**

to break clods into a fine tilth; firm and level the seedbed; conserve moisture through a soil mulch; destroy freshly-germinated weeds; and incorporate fertilisers or pesticides near the surface.

**PREVIOUS YEAR QUESTIONS**

- Write about the objectives of primary and secondary tillage.

[IFoS 2020 | P2/2(b·i) | 5M]

- What is secondary tillage system? Write its objectives. Explain utility of spike tooth and spring tooth harrows.

[IFoS 2017 | P2/1(e) | 8M]

(The spike- and spring-tooth harrows demanded by the 2017 question are treated in §5.3.)

**SPECIAL PRIMARY-TILLAGE OPERATIONS**

- ***Sub-soiling*** : deep loosening (40–75 cm) to shatter a plough-pan or hard-pan without inverting topsoil — improves drainage and deep-root penetration; done every few years, not annually.
- ***Deep ploughing*** : occasional ploughing well below normal depth to bury heavy trash, expose pests and open compacted layers.
- ***Listing / bedding*** : primary tillage that simultaneously opens furrows and throws up ridges/beds (with a lister/ridger) for row-crop planting and in-situ moisture harvesting.

Thus tillage is chosen by ***purpose and soil***: inversion (MB plough) to bury weeds and residue; non-inversion loosening (chisel, sub-soiler, sweep) to conserve residue and break pans; and rotary tillage to make a seedbed in a single pass. The classification in §2.2 organises these by how much soil and residue each disturbs.

| Basis | Primary tillage | Secondary tillage |
|---|---|---|
| Purpose | Open, invert, break the soil | Pulverise, level, firm the seedbed |
| Depth | 15-30 cm (deep) | 5-15 cm (shallow) |
| Draft/power | High | Lower |
| Finish | Cloddy, rough | Fine, level tilth |
| Implements | MB plough, disc plough, sub-soiler, chisel | Disc/spike/spring harrow, cultivator, roller, plank |

## 2.2 Conventional, Conservation, Minimum & Zero Tillage

Modern classification groups tillage by ***how much soil and residue it disturbs***:

- ***Conventional tillage*** : the traditional sequence — one primary operation (ploughing) followed by two or more secondary operations (harrowing, planking). It inverts the soil fully and leaves ***< 15 % residue cover***. High energy and high erosion risk.
- ***Conservation tillage*** : any system that leaves ***≥ 30 % of crop residue*** on the surface after planting, to reduce soil and water erosion. Includes mulch tillage, strip/zone tillage and no-till.
- ***Minimum tillage*** : the minimum soil manipulation necessary for crop production — fewer passes, saving energy and time.
- ***Zero / no-till*** : the crop is sown directly into untilled soil through the residue with a special drill; only a narrow slot is opened. Weed control shifts to herbicides.
- ***Strip / rotary / mulch tillage*** : strip: only the seed row is tilled; rotary: a powered rotavator does primary + secondary in one pass; mulch (stubble-mulch): sweeps undercut the soil leaving residue on top.

| Feature | Conventional tillage | Conservation tillage |
|---|---|---|
| Residue cover | < 15 % (soil fully inverted) | ≥ 30 % retained on surface |
| No. of passes | Many (plough + 2-3 harrowings) | Few / single; direct-seeding in no-till |
| Primary implement | MB or disc plough (inversion) | Chisel, sweep, or none (no-till drill) |
| Energy & fuel | High | Low |
| Soil & water erosion | High risk | Strongly reduced |
| Weed control | Mechanical (burial) | Chiefly herbicides |
| Soil moisture / organic C | Lost faster | Conserved; builds organic matter |

**PREVIOUS YEAR QUESTIONS**

Write the difference between: Conventional tillage and Conservation tillage. [IFoS 2024 | P2/1(c·i) | 2M]


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**MODEL Q** For the 2-mark version give just the residue-cover line (< 15 % vs ≥ 30 %) plus one consequence (erosion / energy). The full table above is the 8–10-mark treatment.***

***Fig. 4.1 Tillage classification tree***

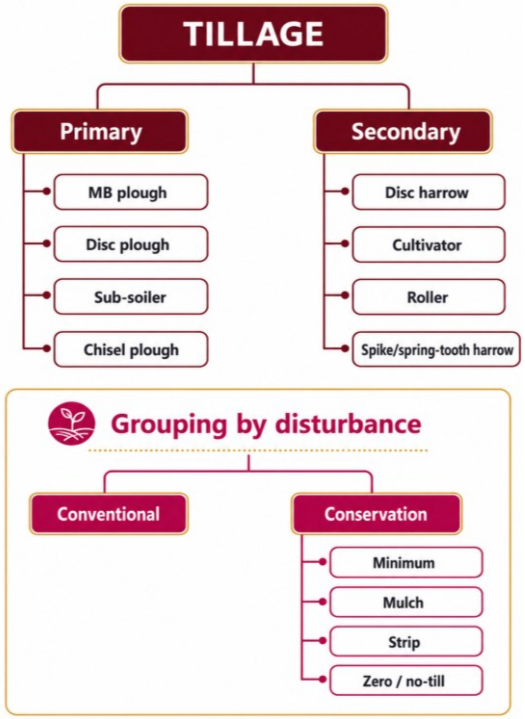



*Fig. 4.1 Classification of tillage operations and representative implements.*

## 3 MOULD BOARD (MB) PLOUGH

The mould-board plough is the classic ***primary tillage, soil-inverting*** implement. Its bottom cuts a rectangular furrow slice, lifts it, and turns it over — burying weeds and residue while pulverising the soil. It is the single most-examined implement in this paper, so learn its parts, its two suctions and its force system thoroughly.

### 3.1 Principle & the Plough Bottom

The working part is the ***plough bottom***, a three-sided wedge that simultaneously cuts the slice horizontally (share edge), cuts it vertically (shin / landside edge) and lifts-and-turns it (mould-board). The three surfaces meet at the ***point***. A plough may have one bottom or several (2-, 3-, 4-bottom) mounted on a common frame.

**FUNCTIONS OF THE MB PLOUGH**

- ***Cutting*** : cuts a furrow slice of chosen width and depth.
- ***Lifting & inversion*** : raises the slice up the mould-board and inverts it (up to 135°) to bury trash.
- ***Pulverisation*** : shatters the slice as it is bent and dropped.
- ***Trash burial*** : covers weeds, stubble and manure under the inverted slice.

### 3.2 Components & their Functions

**WORKING BOTTOM**

- ***Share*** : the cutting edge that slices the furrow horizontally and penetrates the soil. Its ***cutting edge***, ***wing***, ***gunnel*** and ***point*** are its parts. Share types: ***slip share*** (one-piece, re-sharpenable), ***slip-nose share***, ***shin share*** and ***bar-point share*** (for hard/stony soils).

- ***Mould board*** : the curved surface that receives the slice from the share and inverts + pulverises it. It continues the share's lift into a turning action.
- ***Landside*** : the flat plate on the furrow-wall side that ***absorbs the side thrust*** of the soil and steadies the plough. The rear/bottom part that bears on the furrow sole is the ***heel***.
- ***Frog (standard)*** : the wedge-shaped block to which share, mould-board and landside are all bolted; it is the backbone of the bottom, connected to the beam.

**ACCESSORIES**

- ***Coulter*** : cuts the soil and trash vertically ***ahead of the share***, giving a clean furrow wall. Types: ***disc coulter*** (rolling) and ***knife / stalk coulter*** (fixed).
- ***Jointer (skimmer)*** : a miniature mould-board fitted above the share that pares off the top 4–5 cm of the furrow slice with the trash and drops it into the furrow bottom — improving burial.
- ***Gauge / furrow wheel*** : controls depth and takes part of the side and vertical thrust; the rolling landside of a mounted plough.
- ***Clevis / hitch*** : the point of attachment to the tractor drawbar; its setting fixes the line of pull (see suction, §3.3, and hitching, §7).

| Type of mould board | Characteristic | Best suited to |
|---|---|---|
| General-purpose | Medium curvature; moderate pulverisation + good inversion | Most soils, general work |
| Stubble (digger) | Short, sharply-curved; strong pulverisation, quick turning | Stubble / trashy soils, shallow work |
| Sod / breaker | Long, gently-curved; complete inversion, little pulverisation | Grassland / sod, deep work |
| Slat | Open (slatted) surface; reduces sticking | Sticky / clay soils |
| Deep-digger | Long high-lift form | Deep ploughing |

**PREVIOUS YEAR QUESTIONS**

- What are the functions of M.B. plough? Write in brief about its components and accessories.
  [UK-PSC ACF/RFO 2025 | Q.5(i) | 10M]
- Explain the functions of various parts of a mould board plough with the help of a neat labelled diagram. Also, indicate various forces acting on it and mention their significance.
  [UK-PSC RFO 2012 | Q.5(ii) | 10M]
- What are various types of mould boards in a mould board plough? Explain their suitability for different soil conditions.
  [UK-PSC RFO 2012 | Q.7(iv) | 10M]


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▣ *Fig. 4.2 MB plough — labelled assembly*

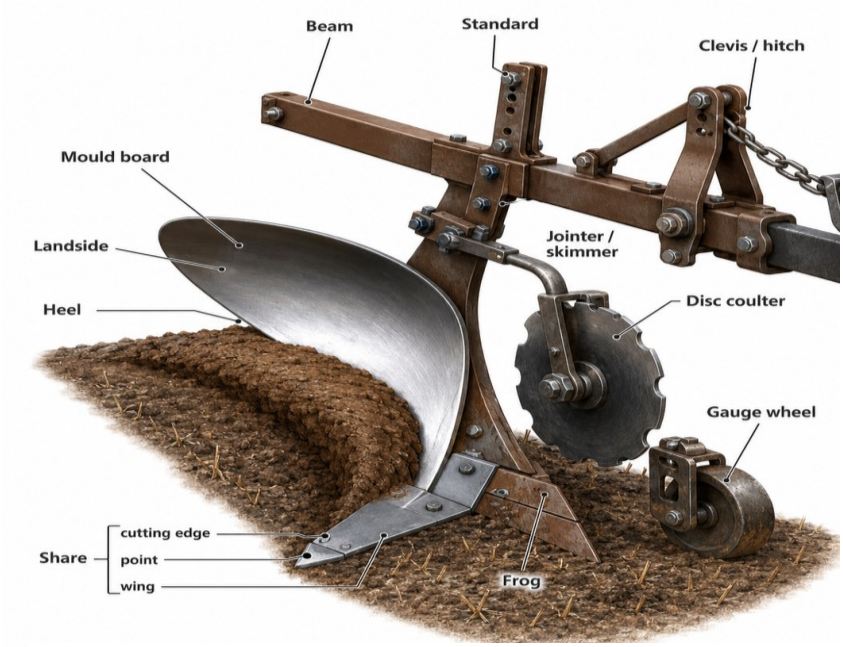



*Fig. 4.2 Principal parts of a mould-board plough bottom and its accessories.*

**THE PLOUGH BOTTOM AS A THREE-SIDED WEDGE**

Geometrically the bottom is a ***wedge acting in three planes*** at once. Three angles define how it works: the ***horizontal angle*** of the share edge to the furrow wall sets the width of cut and the sliding of soil along the edge; the ***vertical angle*** (lift/approach angle of the share to the furrow bottom, ~45° on the share planes) governs penetration and how the slice climbs; and the ***curvature of the mould-board*** fixes the degree of inversion versus pulverisation. A long, gently-curved surface inverts cleanly (sod type); a short, sharply-curved one pulverises hard (stubble/digger type).

**SCOURING**

For the slice to slide instead of sticking, the soil–metal friction must be overcome — this is ***scouring***. Scouring fails in sticky clays and in soils of low abrasiveness; remedies are a highly-polished or hard-chromed surface, a slat mould-board, or a low-friction coating (PTFE reduces the friction angle markedly).

**MATERIAL OF CONSTRUCTION**

- ***Share*** : high-carbon or ***chilled cast / boron steel***, hardened at the cutting edge for wear resistance while the body stays tough; must be re-sharpenable.
- ***Mould-board*** : three-layer ***soft-centre steel*** (hard–soft–hard) — hard faces resist abrasion, the soft core resists shock; surface polished for scouring.
- ***Landside & frog*** : tough mild/medium-carbon steel or cast iron — strength and shock resistance rather than a cutting edge.

## 3.3 Suction of the MB Plough

**Vertical suction (down suction) :** *the maximum clearance under the landside/share when the plough rests on a level surface — the small gap between the furrow sole and the rear of the share wing. It makes the share bite into the soil and hold depth. Typical value 3–5 mm (larger for hard soils).*

**Horizontal suction (land suction / side suction) :** *the clearance at the landside end, i.e. the offset of the*

*share point towards the unploughed land, which makes the plough cut full width and hold the furrow wall. Typical value 5–13 mm.*

Vertical suction governs ***penetration/depth***, horizontal suction governs ***width of cut and side steadiness***. Worn shares lose suction, so the plough rides up and cuts narrow.

**PREVIOUS YEAR QUESTIONS**

- Distinguish between Vertical suction and Horizontal suction of MB plough.

[IFoS 2022 | P2/2(a·ii) | part]

- Distinguish between Coulter and Jointer in a plough.

[IFoS 2022 | P2/2(a·iii) | part]

| Basis | Vertical (down) suction | Horizontal (land) suction |
|---|---|---|
| **Plane** | Vertical clearance under share | Horizontal offset toward land |
| **Controls** | Depth / penetration | Width of cut & side hold |
| **Typical value** | 3-5 mm | 5-13 mm |
| **Effect if lost (worn)** | Plough rides up; shallow | Cuts narrow; wanders |

## 3.4 Types by Attachment & Action; Size

- ***By action*** : one-way (fixed) plough turns all slices one way, forming back- and dead-furrows; ***two-way / reversible / turn-wrest*** plough has right- and left-hand bottoms used alternately, turning all slices the same way and leaving a level, furrowless field — ideal for irrigated and terraced land.
- ***By attachment*** : trailed, semi-mounted, mounted (see §7).
- ***Size*** : the size of an MB plough = ***width of one bottom (furrow width)***; e.g. a '35 cm 3-bottom plough' cuts 3 × 35 = 105 cm total width.

## 3.5 Field Adjustments & Care

### ADJUSTMENTS FOR EFFECTIVE OPERATION

- ***Levelling*** : top link (fore-and-aft level) and the right lower-link levelling box (side level) are set so all bottoms cut equal depth.
- ***Depth*** : set by top-link length / gauge wheel; deeper cut needs more down suction and power.
- ***Width of front furrow*** : adjusted by the cross-shaft / offset so the front bottom cuts full width; guided by running the right rear wheel in the previous furrow.
- ***Vertical & horizontal suction*** : restored by re-sharpening or replacing shares.

### CARE & MAINTENANCE

- ***During operation*** : tighten all nuts/bolts after the first 2 h and every 50 h; keep shares sharp; never reverse or turn with the plough in the ground.
- ***Storage*** : wash off soil, coat bright surfaces with used oil/grease to prevent rust, replace worn shares, store under cover.

**PREVIOUS YEAR QUESTIONS**

- Write about different adjustments of standard disc plough and mould board plough for effective field operation.

[IFoS 2024 | P2/3(a) | 10M]


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Write about the care and maintenance during operation and storage of Disc plough and disc harrow.
[IFoS 2022 | P2/4(b·i) | part]

## 3.6 Ploughing Methods & Furrow Terminology

How a one-way plough is worked across a field decides the finish and the number of idle turns. Learn the terms - they recur in the indigenous-plough and layout questions.

**FURROW TERMINOLOGY**

- ***Furrow slice*** : the ribbon of soil cut, lifted and inverted by one bottom.
- ***Back furrow*** : the ***ridge*** formed when two slices are turned towards each other at the start of a land (gathering).
- ***Dead furrow*** : the ***open trench*** left when slices are turned away from each other at the finish of a land (casting).
- ***Crown & headland*** : crown = the high centre of a gathered land; headland = the unploughed strip at the field ends, kept for turning and ploughed last.

**METHODS OF PLOUGHING**

- ***Gathering (casting inward)*** : ploughing round a central back-furrow, working inward-to-outward; builds a crown.
- ***Casting (gathering outward)*** : ploughing round the outside inward, throwing soil outward; leaves a dead furrow at the centre.
- ***Continuous / lands method*** : the field is divided into ***lands***; alternate lands are gathered and cast so back- and dead-furrows balance out, minimising idle running.
- ***Round-and-round (spiral)*** : ploughing continuously round the boundary inward — few turns, but sharp corners are awkward; suited to square/rectangular fields.
- ***One-way (with a reversible plough)*** : a two-way/turn-wrest plough turns every slice the same way, so no back- or dead-furrows form and the surface stays level — best for irrigated and terraced land.

***Fig. 4.9 Ploughing methods & furrow terms***

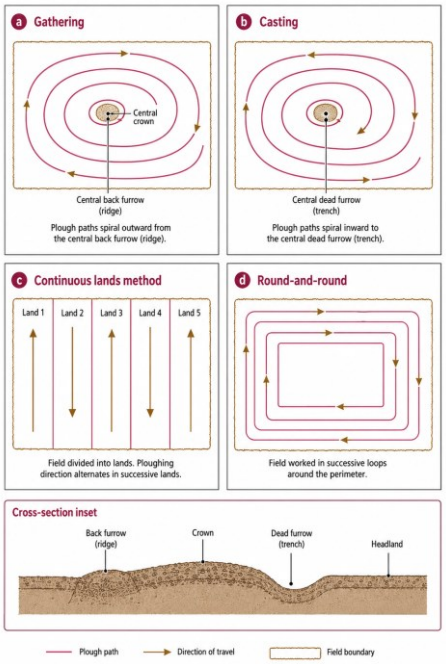



*Fig. 4.9 Gathering, casting, lands and round-and-round ploughing; furrow terminology.*

## 4 DISC PLOUGH

A disc plough does the same primary-tillage job as an MB plough but with a ***revolving concave steel disc*** instead of a fixed wedge. It ***rolls*** through the soil, so it works hard, dry, sticky, stony or trashy land where an MB share would jam, stick or break.

### 4.1 Principle, Types & Components

- ***Standard disc plough*** : individually-mounted large concave discs (60–90 cm dia), each set at a disc angle and a tilt angle; used for general primary tillage.
- ***Vertical disc plough (harrow plough)*** : discs mounted on a common gang shaft, nearly vertical; lighter, for shallower work and seedbed preparation.

**MAIN PARTS**

- ***Disc*** : concave, hardened-steel cutting element; its ***radius of curvature*** sets the concavity.
- ***Disc bearing / hub, standard & beam*** : carry each disc and fix it to the frame.
- ***Scraper*** : removes soil sticking to the concave face, keeping the disc rolling and turning the slice.
- ***Furrow wheel & rear furrow wheel*** : resist the large side thrust characteristic of disc ploughs.

$$R = t/2 + D^2 / (8t)$$

*Radius of curvature of a disc: R = radius (cm); D = disc diameter (cm); t = concavity, i.e. max. depth of the concave face measured on a straight-edge across the disc (cm).*

**DERIVATION — RADIUS OF CURVATURE OF A DISC**

Treat the disc as a spherical cap. If D is the disc diameter and t the concavity (the maximum depth of the hollow measured across the rim with a straight-edge), then the disc rim is a chord of the generating sphere of radius R. By the intersecting-chords (geometry of a circle) theorem, the product of the two segments of the vertical diameter equals the product of the two segments of the chord:

$$t(2R - t) = (D/2)(D/2)$$

*Intersecting chords: the concavity chord segment t and its complement (2R − t) equal the square of the half-chord (D/2).*

Expanding: $2Rt - t^2 = D^2/4$. For a shallow cap $t^2$ is very small compared with $2Rt$ and $D^2/4$, so it is neglected; then $2Rt \approx D^2/4$, giving $R \approx D^2/8t$. Retaining the half-thickness term gives the working form:

$$R = t/2 + D^2 / (8t)$$

*R = radius of curvature (cm); D = disc diameter (cm); t = concavity (cm). Smaller t (flatter disc) → larger R → less inversion and lower draft; larger t (deeper cup) → smaller R → more inversion and pulverisation but higher draft.*

### 4.2 Disc Angle, Tilt Angle & Concavity

***Disc angle :*** *the angle between the plane (face) of the disc and the direction of travel. It governs width of cut and penetration; usual range 42°–45°. Larger disc angle → wider cut, more penetration.*

***Tilt angle :*** *the angle between the plane of the disc and the vertical. It controls penetration and the degree of soil inversion; usual range 15°–25°. Smaller tilt (more upright disc) → deeper penetration.*

***Concavity :*** *the depth of the hollow of the disc; greater concavity gives more soil inversion and pulverisation but higher draft.*

**PREVIOUS YEAR QUESTIONS**

Distinguish between Disc angle and Tilt angle of a disc plough.

[IFoS 2022 | P2/2(a·v) | part]


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What is the difference between disc angle and tilt angle?

[AP-PSC RFO 2012 | Q.2(C) | 5M]

| Basis | Disc angle | Tilt angle |
|---|---|---|
| Measured between | Disc face & direction of travel | Disc face & the vertical |
| Typical range | 42°-45° | 15°-25° |
| Primarily controls | Width of cut & penetration | Penetration & inversion |
| Increase it → | Wider cut, more bite | Disc leans over → shallower bite (a smaller tilt angle gives deeper penetration) |

**FACTORS AFFECTING PENETRATION OF A DISC PLOUGH**

- ***Disc & tilt angles*** : a larger disc angle and a smaller tilt angle (more upright disc) increase penetration.
- ***Weight on the disc*** : added weights/ballast are usually needed because a rolling disc has no share-suction bite.
- ***Disc sharpness & diameter*** : a sharp edge and larger, more concave disc penetrate better.
- ***Soil condition & scraper action*** : hard/dry soil resists; a clean scraper keeps the disc rolling and cutting.

## 4.3 Disc Plough vs MB Plough; Advantages & Limitations

| Basis | Mould-board plough | Disc plough |
|---|---|---|
| Working action | Fixed wedge - slides & inverts | Revolving disc - rolls & partly inverts |
| Soil suited | Normal, moist, clean soils | Hard, dry, sticky, stony, trashy, root-infested |
| Soil inversion | Complete (good burial) | Partial (poorer burial) |
| Draft | Higher per unit width in hard soil; jams | Rolls over obstacles; lower risk of breakage |
| Penetration | By suction (share bite) | By disc weight + angles; needs extra weight |
| Side thrust | Taken by landside | Large; taken by furrow wheels |
| Scouring in sticky soil | Poor (sticks) | Better (disc + scraper) |

- ***Advantages of disc plough***: works hard/dry/stony/trashy land; rolls over obstacles without breakage; no need for frequent sharpening; can work in soils where an MB plough will not scour.
- ***Limitations***: does not invert or bury trash as completely; leaves a rougher surface; large side thrust needs furrow wheels; needs added weight to penetrate.

**PREVIOUS YEAR QUESTIONS**

How a disc plough differs with mould board plough in principle? [AP-PSC RFO 2012 | Q.1(I) | 4M]

Name the different implements used as Primary tillage and Secondary tillage. How a disc plough differs with mould board plough in principle? What are the advantages and disadvantages of disc plough?

[OPSC-Forest 2019–20 | P2/Q.1(b) | 20M]

**ADJUSTMENTS & MAINTENANCE (DISC PLOUGH)**

- ***Adjustments*** : disc angle (42–45°), tilt angle (15–25°), width of cut via cross-shaft, levelling, bearing/castle-nut, and scraper clearance; to plough deeper, reduce the tilt angle so the disc stands more upright.
- ***Maintenance*** : clean and grease hubs (2 h / 50 h / 300 h schedule); replace discs worn below ~550–600 mm; coat with oil for storage.

## 5 HARROWS — DISC, SPIKE-TOOTH & SPRING-TOOTH

Harrows are the chief ***secondary tillage*** implements. They pulverise clods, level and firm the seedbed, cover seed and destroy young weeds after the plough has done the primary work.

### 5.1 Disc Harrow — Types & Arrangement

A disc harrow carries ***gangs*** of concave discs on a common shaft, set at a ***gang angle*** to the direction of travel so each disc cuts, lifts and throws the soil sideways.

> ***Gang angle :*** *the angle between the gang axle and a line perpendicular to the direction of travel; increasing it makes the discs cut deeper and throw more soil. It is the disc-harrow analogue of the plough's disc angle, adjustable 0°–50°. It is the primary penetration/aggression control.*

**BY NUMBER OF GANGS / ACTION**

- ***Single-action*** : two gangs in one line throwing soil in opposite directions (one left, one right); leaves a small ridge/furrow at the centre. One pass covers the width once.
- ***Double-action*** : two sets of gangs one behind the other; the ***rear gangs throw soil opposite to the front gangs***, so the whole width is worked twice and levelled. The two standard double-action layouts are ***tandem*** and ***offset***.

**TANDEM VS OFFSET (BOTH DOUBLE-ACTION)**

- ***Tandem disc harrow*** : four gangs in an X / symmetrical arrangement — front two throw soil outward, rear two throw it inward; works directly behind the tractor, leaving a level surface.
- ***Offset disc harrow*** : two gangs in line but set to ***one side of the tractor*** (offset), so it can work under low branches in orchards and cut heavy trash; side-draft is balanced by the gang setting.

**PREVIOUS YEAR QUESTIONS**

- What types of disc harrow fall under the category of 'Double Action' disc harrow? Explain their working with a line sketch.
  [IFoS 2025 | P2/3(b·i) | 5M]
- Draw neat figures showing arrangement of discs in a single action, tandem and offset disc harrows. Describe how the depth of penetration is controlled in these harrows.
  [UK-PSC RFO 2015 | Q.6(iii) | 10M]
- Differentiate between Offset and Tandem disc harrow. [IFoS 2016 | P2/1(b·ii) | part]

| Basis | Tandem disc harrow | Offset disc harrow |
|---|---|---|
| Gang layout | 4 gangs in symmetric X | 2 gangs in line, set to one side |
| Position vs tractor | Directly behind | Offset to one side |
| Soil throw | Front out, rear in - self-levelling | Balanced by gang angle |
| Special use | General seedbed levelling | Orchards (under branches), heavy trash |

**FACTORS AFFECTING PENETRATION OF A DISC HARROW**

- ***Gang angle*** : larger gang angle → deeper penetration.
- ***Weight on gangs*** : added weight boxes / ballast increase penetration.
- ***Disc diameter & concavity*** : larger, more concave discs bite deeper.
- ***Sharpness of disc edge*** : sharp edges penetrate; blunt edges ride up.
- ***Soil condition*** : hard/dry soil resists; tilled/moist soil allows deeper cut.


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- ***Angle of approach / hitch setting & speed*** : affect how aggressively discs enter.

**PREVIOUS YEAR QUESTIONS**

What are the different factors affecting the penetration of disc harrow? Define gang angle and its adjustment.

[IFoS 2022 | P2/1(c) | 8M]

***Fig. 4.3 Disc-harrow arrangements***

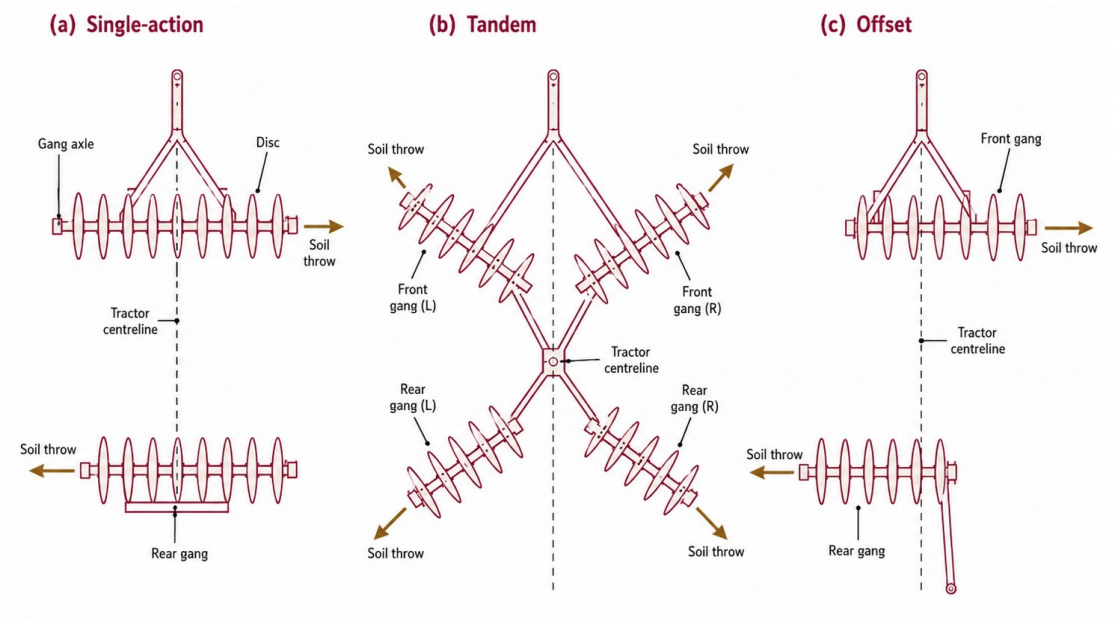



*Fig. 4.3 Single-action, tandem and offset disc-harrow gang arrangements.*

## 5.2 Spike-tooth & Spring-tooth Harrows

- ***Spike-tooth harrow*** : a rectangular frame carrying many short, straight ***rigid spikes*** pointing down. It smooths and firms the seedbed, breaks small clods, covers broadcast seed and destroys tiny weeds in the 'white-thread' stage. Tooth slant is adjustable for aggressiveness. Best on mellow soils.
- ***Spring-tooth harrow*** : curved ***flexible spring-steel teeth*** that vibrate as they work, so they spring over stones and roots without breaking. It penetrates harder ground than the spike-tooth type, drags out roots and rhizomes of perennial weeds, and loosens without inverting. Best on stony / root-infested soils.

| Basis | Spike-tooth harrow | Spring-tooth harrow |
|---|---|---|
| Teeth | Short, straight, rigid | Curved, flexible spring steel |
| Action | Smooths, firms, covers seed | Deeper loosening; drags out roots |
| Obstacles | May catch / break | Springs over stones & roots |
| Best soil | Mellow, clean seedbeds | Stony, root-infested, harder soil |

**PREVIOUS YEAR QUESTIONS**

What is secondary tillage system? Write its objectives. Explain utility of spike tooth and spring tooth harrows. [IFoS 2017 | P2/1(e) | 8M]

Other harrows: the ***blade harrow (bakhar / guntaka)*** : a blade that undercuts and levels without inversion, popular in dry-farming; and the ***patela / plank*** for final levelling and clod-crushing.

**OTHER SECONDARY-TILLAGE & LEVELLING IMPLEMENTS**

- ***Blade harrow (bakhar / guntaka)*** : a wide horizontal blade on a frame that ***undercuts and shaves*** the top 5–8 cm, killing weeds and forming a soil mulch without inversion — the mainstay of dryland (rainfed) farming for moisture conservation.
- ***Roller / clod-crusher (Cambridge, plain, ring)*** : firms a loose seedbed and crushes clods to improve seed–soil contact; ring/Cambridge rollers leave a ridged surface that resists crusting.
- ***Plank / float (patela)*** : a heavy board dragged to level micro-highs, break surface crust and compact lightly before sowing.
- ***Puddler & leveller (wet tillage)*** : for transplanted paddy, the puddler churns saturated soil to a soft, low-percolation mud and the leveller/float finishes it flat for uniform water depth.

The choice among secondary implements follows the required tilth: ***harrow*** for clod-breaking and weeding, ***roller*** for firming, ***plank*** for final levelling — often used in that sequence.

## 6 CULTIVATORS, ROTAVATOR, SUB-SOILER, RIDGER, PUDDLER & INDIGENOUS PLOUGH

### 6.1 Cultivator

***Cultivator :*** *a secondary-tillage / inter-culture implement carrying several tines (shovels/sweeps) that stir and loosen the soil, uproot weeds and prepare a seedbed without inverting the soil.*

- ***Rigid-tine cultivator*** : stiff tines bolted to the frame; for deep, hard work; each tine holds its set depth.
- ***Spring-loaded (spring-tine) cultivator*** : each tine is held by a ***coil/leaf spring*** that lets it trip back over a stone or root and snap back — protecting the tine and giving a vibratory pulverising action. Best on stony land.
- ***Duck-foot / sweep cultivator*** : wide A-shaped sweeps undercut the whole surface to sever weed roots — used for stubble-mulch tillage.

| Basis | Rigid-tine cultivator | Spring-tine cultivator |
|---|---|---|
| Tine mounting | Rigidly bolted | On a trip spring |
| On hitting an obstacle | May bend/break; stops | Springs back, then resets |
| Action | Steady deep tillage | Vibratory; good pulverisation |
| Best soil | Clean, uniform fields | Stony / root-infested soils |

**PREVIOUS YEAR QUESTIONS**

Differentiate: Spring loaded cultivator and Rigid tined cultivator.

[OPSC-Forest 2015–16 | P2/Q.5(a) | part]

### 6.2 Rotavator (Rotary Tiller)

A ***PTO-powered*** implement whose L- or C-shaped blades are mounted on a horizontal rotor. It does primary and secondary tillage in ***one pass***, producing a fine, well-mixed seedbed — ideal for puddling and residue incorporation. Because the rotor is engine-driven, its forward thrust can make the draft ***negative (it pushes the tractor)***, though total power demand is high.

***Bite length ($l = v/n{\cdot}z$) :*** *the distance the machine advances per blade cut; $v$ = forward speed, $n$ = rotor speed (rev/s), $z$ = blades per flange. Shorter bite → finer tilth.*


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**PREVIOUS YEAR QUESTIONS**

Write about the care and maintenance during operation and storage of Rotavator.

[IFoS 2022 | P2/4(b·iii) | part]

- ***Rotavator care*** : check blade wear and bolt tightness; grease the side-drive chain and bearings; clear soil/residue after use; store the rotor off the ground and oil the blades against rust.

### 6.3 Sub-soiler & Chisel Plough

- ***Sub-soiler*** : a heavy, single stout tine that runs 40–75 cm deep to ***shatter the hard-pan*** below normal plough depth, improving drainage and root penetration — without inverting the topsoil. Very high draft.
- ***Chisel plough*** : several curved chisel tines that loosen and aerate deep soil, break pans and leave residue on top — a conservation-tillage tool.

### 6.4 Zero-Till Drill (No-Till Seed Drill)

A zero-till (no-till) seed drill sows seed and places fertiliser directly into untilled soil through the previous crop's residue in a single pass, opening only a narrow slot instead of tilling the whole field. It is the key implement of conservation/zero tillage (§2.2) and the one demanded by the OPSC-CSE 2015-16 forces question.

**SALIENT FEATURES**

- ***Furrow openers*** : inverted-T, disc/coulter or shoe-type openers cut through surface residue and open a narrow slot only in the seed row; the inter-row soil is left undisturbed with its residue cover.
- ***Residue-handling front*** : a serrated disc / residue coulter ahead of each opener slices trash so it does not clog, allowing sowing straight into standing stubble.
- ***Seed + fertiliser placement*** : separate metering places seed and a band of fertiliser at set depth in the same slot; press wheels close and firm the slot for good seed–soil contact.
- ***Minimal soil disturbance*** : only the seed zone is tilled (typically < 25–30 % of the area), so residue stays on the surface as a mulch; weed control shifts to herbicides.

**ADVANTAGES**

- ***Saves fuel, time and labour*** : one pass replaces ploughing + harrowing + sowing, cutting energy use and operations sharply.
- ***Conserves soil moisture & checks erosion*** : the retained residue mulch reduces evaporation and protects the surface from wind and water erosion.
- ***Timely sowing*** : enables sowing immediately after harvest (e.g. wheat after rice), avoiding the delay of conventional tillage.
- ***Builds soil health*** : undisturbed soil and surface residue raise organic matter, improve structure and encourage earthworm/microbial activity over time.
- ***Lower cost of cultivation*** : fewer field operations and less machinery wear reduce per-hectare costs.

### 6.5 Ridger, Puddler, Roller & Leveller

- ***Ridger (bund former)*** : a double mould-board (right + left) that splits the soil both ways to throw up ridges and open furrows for row crops (potato, sugarcane) and irrigation.
- ***Puddler*** : blades/discs that churn wet soil into a soft, impervious mud for transplanted paddy — reducing percolation and controlling weeds.
- ***Roller / clod-crusher*** : firms and levels the seedbed and crushes clods after harrowing.
- ***Leveller / plank (patela)*** : final smoothing and levelling before sowing.

## 6.6 Indigenous (Desi) Plough

The traditional bullock-drawn ***indigenous plough*** is a ***wedge/soil-stirring*** tool: it ***opens a V-shaped furrow and stirs the soil without inverting*** it. Chief parts — ***body, share (iron point), beam, handle and sole***. It leaves an unploughed strip between passes, so the field is cross-ploughed. Cheap and simple, but no inversion, shallow depth and uneven work.

**PREVIOUS YEAR QUESTIONS**

- Explain the working of indigenous plough used in your state with details of line sketch, parts, ploughing procedure/pattern, furrow cross section, methods of layout of land, soil deformation, adjustments, field capacity and power requirement.

[OPSC-CSE 2020–21 | P2/Q.2(a) | 20M]

| Basis | Indigenous (soil-stirring) plough | Soil-turning (MB) plough |
|---|---|---|
| Action | Stirs; V-furrow, no inversion | Cuts & inverts the slice |
| Weed/trash burial | Poor | Good |
| Draft power | Light (bullock) | Heavy (tractor/animal pair) |
| Depth & finish | Shallow, uneven | Deeper, uniform |

**PREVIOUS YEAR QUESTIONS**

- Differentiate between Indigenous and Soil turning ploughs.

[IFoS 2016 | P2/1(b·i) | part]

***Fig. 4.4 Indigenous plough & ploughing pattern***

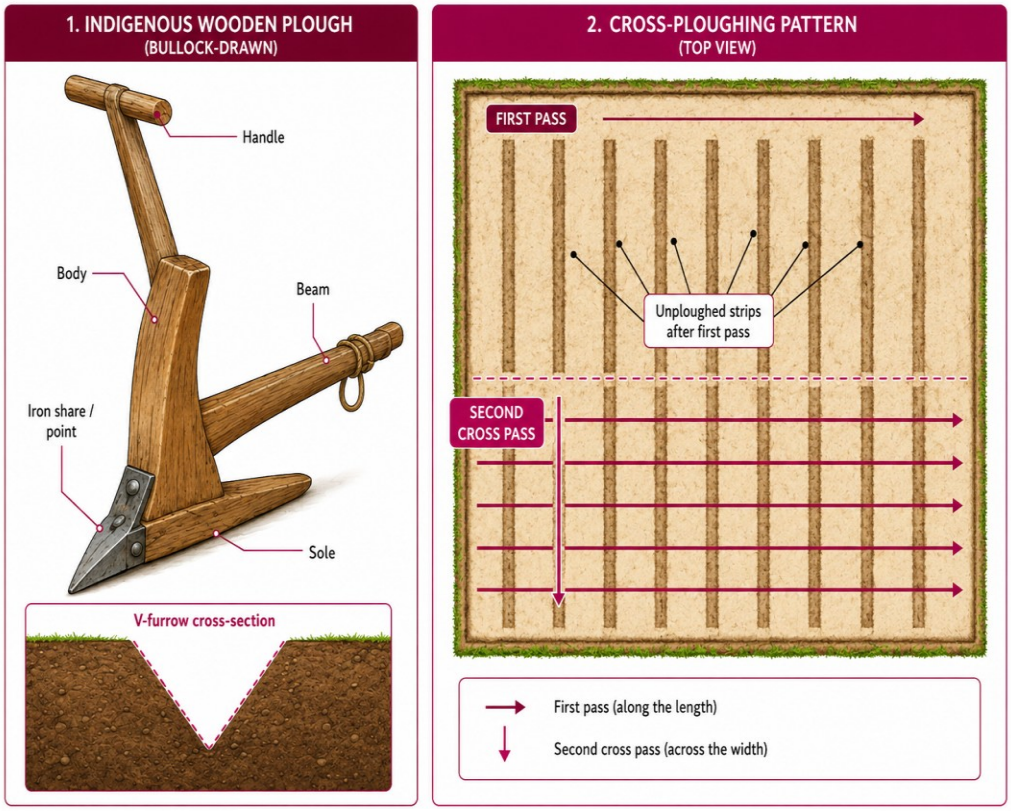



*Fig. 4.4 Indigenous plough parts, V-furrow section, and cross-*


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### 6.7 Indigenous Plough — Field Layout, Pattern & Performance

The OPSC 20-mark question asks for the ***complete field treatment*** of the indigenous plough — layout, ploughing pattern, furrow section, soil deformation, adjustments, field capacity and power. Answer it as follows.

- ***Furrow cross-section*** : a shallow **V (triangular) groove** 8–12 cm deep; the soil is merely pushed aside and stirred, not inverted, so a small unploughed ridge is left between adjacent passes.
- ***Soil deformation*** : the wedge-shaped body loosens and shatters the soil by ***lateral compression and shear***; because there is no mould-board there is no turning or burial of trash.
- ***Ploughing pattern / layout*** : worked by ***cross-ploughing*** : the field is ploughed twice, the second pass at right angles to the first, so the unploughed strips of the first pass are cut by the second. Land is laid out in narrow lands or ploughed round-and-round; no back- or dead-furrows are formed as the plough is symmetrical.
- ***Adjustments*** : depth is set by the angle of the beam to the ground (raising the beam-end lowers the share, increasing depth) and by the operator's downward pressure on the handle; width by spacing successive passes.

**FIELD CAPACITY & POWER (ORDER-OF-MAGNITUDE)**

Effective width ≈ furrow width less the overlap; with a bullock pair at ~2–3 km/h and 60–70 % field efficiency, field capacity is only about **0·02–0·05 *ha/h***, and the power delivered by a bullock pair is roughly **0·7–1·0 *hp*** (see worked example N10, §13). Two cross-passes therefore make it slow but cheap.

◆ *Source: Farm Machinery & Equipment-I, Lessons 11, 13–14, 19–20; Sahay, §13 (ploughs, cultivators, other implements).*

## 7 IMPLEMENT ATTACHMENT SYSTEMS — TRAILED, SEMI-MOUNTED, MOUNTED

Implements are classified by ***how they are attached to and supported by the tractor***. This is a very frequently-asked bookwork question, so learn the three-way split with one clear discriminator: ***who carries the weight*** — the implement's own wheels, the tractor, or both.

### 7.1 The Three Classes

- ***Trailed (pull-type)*** : the implement is ***fully carried on its own wheels*** and simply pulled from a single hitch point on the drawbar. The tractor takes ***no vertical load***. Turned at headland by its own wheels; long turning radius. Example: trailed disc harrow, trailed MB plough.
- ***Mounted*** : the implement is ***attached to the tractor's three-point linkage*** and ***carried entirely by the tractor*** when raised — it has no transport wheels. Highly manoeuvrable, short turns, good weight transfer for traction. Example: mounted MB/disc plough, mounted cultivator.
- ***Semi-mounted*** : a ***compromise***: the front is attached to the linkage/hitch (carried by the tractor) while the rear rests on ***one castor/furrow wheel of its own***. Weight is shared. Used for large multi-bottom ploughs too heavy to fully mount. Turned partly by the linkage, partly by the rear wheel.

| Basis | Trailed | Semi-mounted | Mounted |
|---|---|---|---|
| Weight carried by | Own wheels | Shared (tractor + 1 wheel) | Tractor (3-pt linkage) |
| Transport wheels | Full set | One (rear castor/furrow) | None |
| Manoeuvrability | Low (long turns) | Medium | High (short turns) |
| Weight transfer to tractor | None | Partial | Full - aids traction |
| Typical use | Large/simple implements | Large multi-bottom ploughs | Most modern implements |

**PREVIOUS YEAR QUESTIONS**

- Classify implements on the basis of how they are attached to a wheel-type Agricultural Tractor and discuss each. [IFoS 2024 | P2/4(c) | 10M]
- Define tillage. What do you understand by primary tillage and secondary tillage? Classify implements on the basis of how they are attached to the tractor. [IFoS 2018 | P2/1(a) | 8M]
- Define tillage. State its objectives. Classify implements on the basis how they are attached to the tractors. [MH-PSC Forest 2024 | Q.5(a) | 8M]
- Distinguish between Trailed type and Mounted type implement. [IFoS 2022 | P2/2(a·iv) | part]

## 7.2 The Three-Point Hitch

Modern mounted implements attach through the ***three-point linkage*** — two lower draft links and one upper (top) link. The three links, converging forward, define a ***virtual hitch point*** (instantaneous centre) ahead of the tractor where the effective line of pull passes; placing it correctly gives automatic weight transfer and stable draft.

- ***Hitch categories*** : standardised by tractor power — Category I, II, III, IV — fixing pin sizes and link spacing.
- ***Draft vs position control*** : the hydraulics can hold a set depth (position control) or a set draft (draft control), sensing the pull in the top link and raising the implement slightly when draft rises — this transfers weight to the rear wheels and cuts wheel slip.
- ***Free vs restrained link*** : adjustable check-chains restrain sideways sway of the lower links during work and transport.

***Fig. 4.5 Three-point hitch & virtual hitch point***

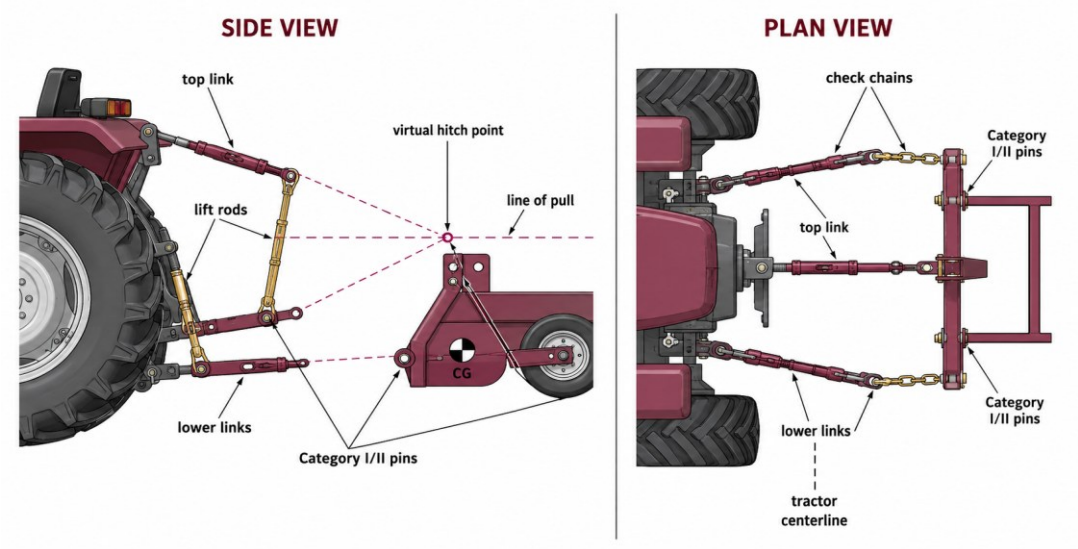



*Fig. 4.5 Three-point linkage geometry and the virtual (instantaneous) hitch point.*

**HITCHING PRINCIPLES — VERTICAL & HORIZONTAL**

- ***Horizontal hitching*** : in the horizontal plane the line of pull (drawbar to implement) must pass through the implement's centre of resistance, or the implement yaws and side-drafts (see §8.2).
- ***Vertical hitching*** : in the vertical plane the line of pull should, when projected, pass near the tractor's centre of pull; a properly-set hitch height gives the useful weight transfer of §12 without lifting the front.
- ***Single vs multiple hitch points*** : trailed implements use one drawbar point; mounted implements use the three linkage points, which additionally control the implement's attitude (depth and roll).


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## 8 FORCES ON TILLAGE TOOLS; CENTRE OF RESISTANCE & CENTRE OF PULL

When a tillage tool moves through soil, the soil pushes back on it with a distributed reaction. Resolving this reaction into components, and locating where it effectively acts, lets us design the hitch so the implement runs straight and steady. This underpins the 'forces on MB plough' and 'centre of resistance vs centre of pull' questions.

### 8.1 The Soil-Reaction Force System

The total soil reaction **R** on a plough bottom is resolved into three mutually perpendicular components (A. W. Clyde's analysis):

- ***Longitudinal (L)*** : the horizontal component along the direction of travel — this is the ***draft*** that the tractor must overcome.
- ***Vertical (V)*** : the up/down component; a downward V (from suction) helps penetration, an upward V lifts the plough.
- ***Side / lateral (S)*** : the horizontal component across the direction of travel — the ***side thrust*** taken by the landside (MB) or furrow wheels (disc).

Clyde further split all forces into ***useful*** (those doing the cutting/turning) and ***parasitic*** (friction and side forces that only add to draft). The line of action of the resultant of L, V and S passes through the centre of resistance.

$$R = \sqrt{(L^2 + V^2 + S^2)}$$

*Resultant soil reaction R (N); L = longitudinal (draft) component; V = vertical component; S = side component. For a well-balanced plough the side and vertical components are kept small.*

***Fig. 4.11 Forces on a mould-board plough***

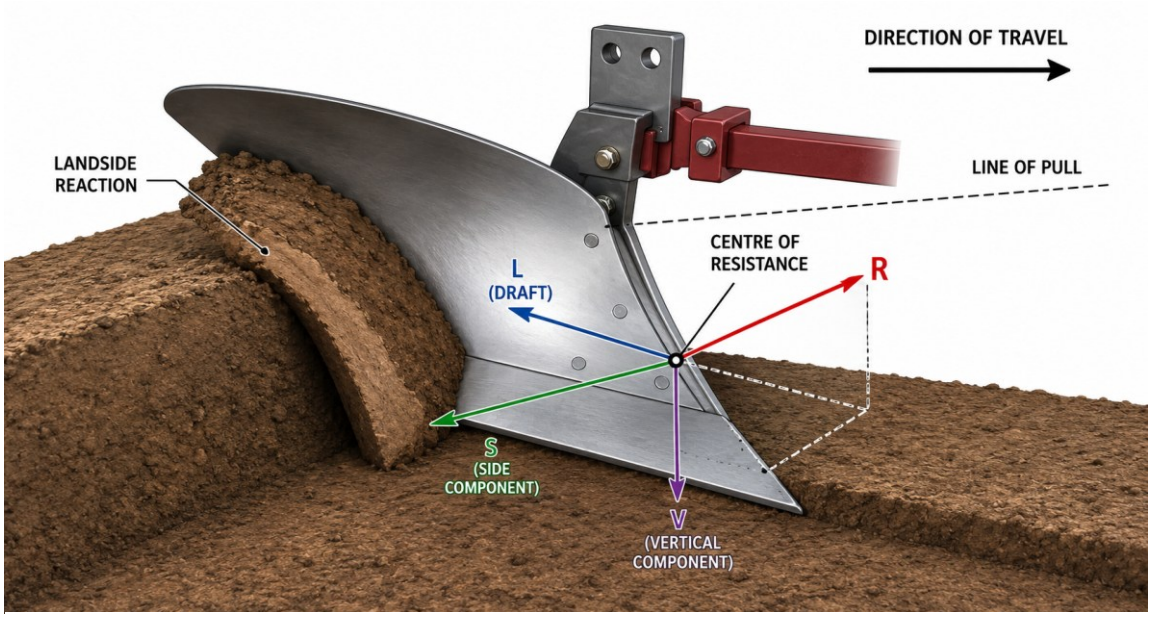



*Fig. 4.11 Soil reaction on a plough bottom resolved into L, V and S components.*

**RESOLVING THE SOIL REACTION — COMPONENT RELATIONS**

Let R be the resultant soil force and θ, ϕ the angles its line of action makes with the direction of travel in the horizontal and vertical planes. The three working components are:

$$L = R\cos\theta\cos\phi \quad ; \quad S = R\sin\theta\cos\phi \quad ; \quad V = R\sin\phi$$

*L = longitudinal (draft) component; S = side component; V = vertical component; ϑ = horizontal angle, φ = vertical angle of the resultant R. The draft the tractor overcomes is L (plus implement rolling resistance).*

The pull P supplied by the tractor must balance L for steady motion, so P = L = R cosθ cosϕ. Because S and V do no useful forward work, they are ***parasitic*** — they only load the landside/wheels and add friction. Good plough design keeps θ and ϕ small so that most of R goes into useful cutting.

**HITCHING TO AVOID SIDE DRAFT**

For a multi-bottom plough the centre of resistance is at the mid-width of the cut. If the tractor's centre of pull is offset from this line by a horizontal distance, the plough is dragged sideways (side draft). The hitch is therefore set with a lateral ***offset e*** so the line of pull, projected forward from the drawbar, passes through the centre of resistance — cancelling the side moment and letting the plough run straight with minimum draft.

## 8.2 Centre of Resistance & Centre of Pull

***Centre of resistance :*** *the point on the implement through which the resultant of all soil forces acts. For a single bottom it lies roughly at the centroid of the furrow cross-section; for a multi-bottom plough it is at the centroid of all the bottoms — i.e. at the middle of the total width of cut.*

***Centre of pull (line of pull) :*** *the line along which the tractor's pull effectively acts. For straight, side-draft-free running the line of pull must pass through the centre of resistance (and, at the tractor end, through the centre of pull of the drive wheels).*

If the hitch is set so these do not align, the plough experiences ***side draft***, tends to run in or out of the land, and wastes power. The horizontal offset needed to line them up is the basis of the hitching calculation.

**PREVIOUS YEAR QUESTIONS**

- Differentiate between Centre of resistance and Centre of pull. [IFoS 2016 | P2/1(b·iv) | part]
- What are the various forces acting upon the mould board plough used for tillage operation? Elaborate graphically. [OPSC-CSE 2018–19 | P2/Q.3(a) | 20M]
- Explain the forces acting upon a tillage tool. Explain the working and importance of the tractor drawn tillage tool which is very efficient and can prepare seed bed in single run. State the salient features and advantages of Zero till Drill. [OPSC-CSE 2015–16 | P2/Q.1(b) | 20M]

| Basis | Centre of resistance | Centre of pull |
|---|---|---|
| Belongs to | The implement (soil side) | The tractor (power side) |
| Definition | Point where resultant soil force acts | Line/point along which tractor pull acts |
| Location | Centroid of furrow cross-section(s) | Set by drawbar / hitch geometry |
| Design rule | Line of pull must pass through it | Aligned with centre of resistance → no side draft |

## 8.3 Worked Example — Vertical Soil Reaction

◆ **WORKED NUMERICAL — *Vertical soil reaction on an implement*** **[IFoS 2016 | P2/1(d·iv) | part]**

**Problem.** *Calculate the vertical soil reaction on an implement weighing 350 kg, when a pull of 6·5 kN is exerted on it at an angle of 15° with the ground surface.*

**Given.** Weight W = 350 kg; pull P = 6·5 kN at θ = 15° above the horizontal (ground).

**Find.** Vertical soil reaction Rv.

**Formula (first principles).** Vertical equilibrium of the implement: soil reaction + upward pull component = weight, so $R_v = W - P\cdot\sin\theta$.

**Substitution.** W = 350 × 9·81 = 3433·5 N; P·sinθ = 6500 × sin15° = 6500 × 0·2588 = 1682·2 N.


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Rv = 3433·5 − 1682·2 = 1751·3 N.

**Result. Vertical soil reaction ≈ 1·75 kN (downward on the soil / upward on the implement).**

**Check.** Units N − N = N ✓; the pull lifts the implement, so the soil need only support the remaining 1·75 kN of the 3·43 kN weight — physically reasonable.

## 9 THEORY OF SOIL CUTTING & PULVERIZATION; DRAFT

This section explains ***how soil fails*** when a tool cuts it, and defines the ***draft, unit draft and specific draft*** that dominate the numerical. Master the definitions and the draft–speed relation here; the arithmetic is drilled in §13.

### 9.1 Soil as an Engineering Material

Soil resists a tool through three properties: ***cohesion*** (c, the shear strength at zero normal load — dominant in clays), ***internal friction*** (ϕ, resistance between soil particles — dominant in sands) and ***adhesion*** (soil sticking to the tool). Coulomb's law of soil shear combines the first two:

$$\tau = c + \sigma \cdot \tan \phi$$

*Soil shear strength τ (kPa); c = cohesion (kPa); σ = normal stress on the failure plane (kPa); φ = angle of internal friction. For a pure clay (φ ≈ 0): τ = c; for a dry sand (c ≈ 0): τ = σ·tan φ.*

As a tool advances, soil ahead of it is stressed until it ***fails in shear*** along a rupture surface, rises up the tool face and is pulverized by bending and by impact when it falls. Below a ***critical depth*** the soil flows sideways rather than rupturing forward, so tools are kept above it for efficient cutting.

**HOW THE SOIL FAILS AHEAD OF THE TOOL**

Ahead of an advancing tine, the soil is compressed until it fails and rises as a series of ***crescent-shaped blocks*** along curved rupture surfaces (the shear planes). This is ***brittle/shear failure*** in dry, cohesive soil and gives good pulverization; in wet plastic soil the block ***flows*** and smears instead of shattering. Above a ***critical depth*** the failure runs forward and upward to the surface (efficient cutting); below it the soil merely flows sideways (compaction, little pulverization), so tools are kept above the critical depth.

***Fig. 4.7 Soil failure & pulverization ahead of a tillage tool***

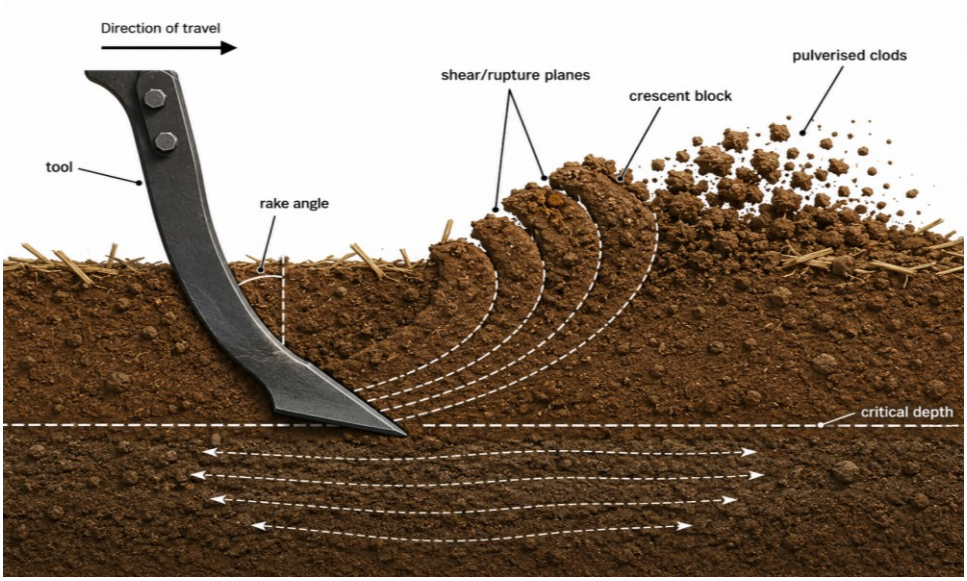



*Fig. 4.7 Crescent-block shear failure and the critical depth in soil cutting.*

Pulverization is completed by two actions after failure: ***bending*** of the slice as it climbs the curved surface, and ***impact*** when it falls back. The energy going into useful pulverization, as a fraction of total draft energy, is the ***energy-utilisation factor***; the remainder is friction and acceleration loss.

## 9.2 Draft, Unit Draft & Specific Draft

**Draft (D) :** *the force required to pull an implement, measured in the direction of travel. It is the longitudinal (L) component of the soil reaction plus rolling resistance of the implement. Units: N or kN (kgf in older papers).*

**Unit draft :** *draft per unit cross-sectional area of the furrow slice: unit draft = D / (w × d), where w = width and d = depth of cut. Units: N/cm² or kg/cm². It measures how hard a given soil is to cut and lets ploughs of different sizes be compared.*

**Specific draft :** *the draft per unit cross-sectional area — numerically the same quantity as unit draft, usually quoted in N/cm². Typical specific-draft values (Kepner): sandy soils 1·4–2, loams 2–5, clay 4–8, gumbo/heavy clay 10–14 N/cm².*

$$\text{Unit (specific) draft} = D / (w \mid d)$$

*D = total draft (N); w = width of cut (cm); d = depth of cut (cm). For an n-bottom plough w = n × (furrow width).*

Note the distinction sometimes drawn: ***unit draft*** per unit ***width*** (kN/m) versus ***specific draft*** per unit ***area*** (N/cm²). In IFoS numerical 'unit draft in kg/cm²' always means draft ÷ (width × depth).

## 9.3 Effect of Speed on Draft

Draft rises with the ***square of speed*** because faster soil must be accelerated and thrown farther. For a mould-board plough, Kepner-Bainer-Barger give:

$$D_s = D_r\ (0{\cdot}83 + 0{\cdot}0073\ S^2)$$

*$D_s$ = draft at speed S (km/h); D_r = reference draft at 4·83 km/h; S in km/h. (In mph form: 0·83 + 0·0189 S².) A sub-soiler is far less speed-sensitive: $D_s/D_r = 0{\cdot}944 + 0{\cdot}0024\ S^2$.*

Consequence: raising speed from ~4·8 to ~9·6 km/h increases MB-plough draft by roughly 50 %, disc-plough draft 40-90 %, but sub-soiler draft only ~15 %. Power (= draft × speed) therefore rises even faster than draft.

**PREVIOUS YEAR QUESTIONS**

Describe the critical design features of primary tillage equipment that contribute to their efficiency.

[OPSC-CSE 2023–24 | P2/Q.9(b) | 15M]

**MODEL Q** A 'design features of primary tillage equipment' answer should cover: share/point geometry & suction (penetration), mould-board curvature (inversion vs pulverisation), material & scouring, cutting angles, and keeping the line of pull through the centre of resistance to minimise draft — then link each to reduced specific draft.***

## 9.4 Field Capacity & Field Efficiency

**Theoretical field capacity (TFC) ;** *the rate of work if the implement worked at full rated width and speed with no time lost: TFC = w·V/10 (w in m, V in km/h → ha/h). It is an upper limit.*

**Effective (actual) field capacity (EFC) :** *the actual rate of covering the field, including all time losses — turning, overlap, filling, blockages: EFC = TFC × field efficiency.*

**Field efficiency (ηf) :** *the ratio EFC/TFC, i.e. the fraction of the theoretical capacity actually achieved.*


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*Typical values: MB plough 70–90 %, disc harrow 70–85 %, cultivator 80–90 %, planter 55–70 %.*

TFC = w·V/10 ; EFC = TFC·ηf ; ηf = productive time / (productive + lost time)

*w = working width (m); V = speed (km/h); result in ha/h. Time-loss form: ηf = T / (T + t_loss). Area A takes time = A/EFC.*

**CAUSES OF LOST FIELD EFFICIENCY**

- ***Turning at headlands*** : idle time and part-width passes at row ends.
- ***Overlap*** : covering already-worked ground to avoid skips reduces effective width.
- ***Servicing & blockages*** : refilling seed/fertilizer, clearing trash, adjustments and breakdowns.
- ***Speed variation*** : slowing in heavy patches or for safety cuts the achieved speed below rated.

### 9.5 Worked Example — Field Capacity, Unit Draft & Drawbar Power

◆ **WORKED NUMERICAL — 3-bottom MB plough — FC, unit draft, drawbar power** [IFoS 2020 | P2/3(b) | 15M]

**Problem.** *A 3-bottom 35 cm mould board plough is working at a depth of 20 cm. It requires a draft force of 18 kN working at a speed of 3 km/h. If the field efficiency is 70 %, calculate the actual field capacity of the plough. Also calculate the unit draft and drawbar horsepower. (Take g = 10 m/s².)*

**Given.** bottoms n = 3; furrow width = 35 cm → total w = 105 cm = 1·05 m; depth d = 20 cm; draft D = 18 kN; speed S = 3 km/h; field efficiency ηf = 70 %.

**Find.** actual field capacity, unit draft, drawbar power/hp.

**(a) Theoretical field capacity.** TFC = (w × S)/10 (w in m, S in km/h → ha/h) = (1·05 × 3)/10 = 0·315 ha/h.

**Actual field capacity.** AFC = TFC × ηf = 0·315 × 0·70 = **0·221 ha/h.**

**(b) Unit draft.** area = w × d = 105 × 20 = 2100 cm²; unit draft = D/area = 18000 N / 2100 cm² = **8·57 N/cm².**

**(c) Drawbar power.** S = 3 km/h = 3/3·6 = 0·833 m/s; P = D × S = 18000 × 0·833 = 15000 W = 15 kW.

Drawbar hp = 15 / 0·746 = **≈ 20·1 hp.**

**Result. AFC ≈ 0·221 ha/h; unit draft ≈ 8·57 N/cm²; drawbar power = 15 kW (≈ 20 hp).**

**Check.** units: (m·km h⁻¹)/10 → ha/h ✓; N/cm² ✓; N·m/s = W ✓. Unit draft 8·6 N/cm² sits in the clay-loam band, consistent with 18 kN over a 105 × 20 cm slice.

## 10 TRACTION THEORY — FUNDAMENTALS

Traction is the ***single highest-yield topic*** in this chapter — drawbar pull, tractive efficiency, slip and weight transfer recur almost every year, in both theory and numericals. Build the vocabulary here; the models and numericals follow in §11–§13.

### 10.1 Traction & the Basic Quantities

***Traction*** : *the propelling (tractive) force developed by a wheel or track at its contact with the soil, by which a tractor pulls a load. It is the soil's shear reaction to the driving torque.*

***Tractive effort / gross traction (F)*** : *the total horizontal force the driving wheels develop at the soil from the axle torque, before deducting motion losses.*

***Drawbar pull (P)*** : *the net horizontal force available at the drawbar* to pull an implement: P = F − R, *where R is the rolling (motion) resistance of the tractor itself.*

***Rolling (motion) resistance (R)*** : *the force resisting forward motion from soil compaction, tyre flexing*

*and bulldozing. On soft soil it can be a large fraction of the weight.*

P = F – R ; Drawbar power DBP = P × V

*P = drawbar pull (kN); F = gross tractive effort (kN); R = rolling resistance (kN); V = actual forward speed (m/s); DBP in kW. In hp: DBP(hp) = P(kgf) × V(m/s) / 75.*

**Coefficient of traction (μ) :** *the ratio of tractive force to the dynamic weight on the driving wheels:* μ = F / W *(gross) or drawbar-pull/weight (net). It measures how effectively weight is turned into pull; higher on firm soil, lower on loose sand.*

**Rim pull :** *the tractive force at the tyre rim corresponding to the engine torque delivered to the wheel — the force available before soil slip and rolling losses.*

**ROLLING (MOTION) RESISTANCE IN MORE DETAIL**

Rolling resistance R absorbs part of the axle power before any pull is delivered. On soft soil its main cause is the energy spent ***compacting and bulldozing*** soil ahead of the wheel; on firm ground it is mainly tyre flexing. It is expressed as a ***coefficient of rolling resistance*** ρ = R/W:

| Surface | Coeff. of rolling resistance ρ = R/W |
|---|---|
| Concrete / hard road | 0·02 - 0·04 |
| Firm, dry field / stubble | 0·05 - 0·08 |
| Tilled / soft soil | 0·10 - 0·20 |
| Loose sand / wet soil | 0·20 - 0·30+ |

Because P = F - R, a high ρ (soft soil) eats directly into drawbar pull - which is why flotation (bigger tyres, lower pressure, tracks) matters as much as raw traction.

**DRIVEN WHEEL VS TOWED WHEEL**

- ***Driven (powered) wheel*** : torque T at the axle produces a tractive force F = T/r at the soil (r = rolling radius); it develops pull but must slip to do so.
- ***Towed (unpowered) wheel*** : carries load but delivers no tractive force; it only shows rolling resistance and, if braked, skids. The difference F between a driven and a towed wheel at the same load is the net traction the axle adds.

F = T / r μ = F / W (rim pull corresponds to engine torque at the wheel rim)

*T = axle torque (N·m); r = rolling radius (m); F = tractive force (N); W = dynamic wheel load (N); μ = coefficient of traction. Rim pull is the tractive force the delivered engine torque could give before soil slip and rolling loss.*

## 10.2 Wheel Slip vs Wheel Skid

**Wheel slip :** *of a driven (powered) wheel: the wheel turns faster than the tractor advances, so the soil is sheared backward. Slip = the loss of forward travel relative to the distance the wheel should have rolled. Some slip (≈ 8–15 %) is needed to develop pull; excessive slip wastes power and digs in.*

**Wheel skid :** *of a towed or braked wheel: the wheel turns slower than the tractor advances (it is dragged), i.e. it travels farther than its rotation implies. Skid is effectively negative slip; in the limit a locked wheel skids 100 %.*

Slip $s = (V_t - V_a)/V_t \times 100\ \%$ ; $V_t = \pi D N$

*s = wheel slip (%); $V_t$ = theoretical speed (no slip) = π D N; $V_a$ = actual forward speed; D = rolling diameter of the wheel (m); N = wheel rotational speed (rev/s). By distances (same revolutions): $s = (L_o - L)/L_o \times 100$, $L_o$ = no-load run, L = loaded run.*


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| Basis | Wheel slip | Wheel skid |
|---|---|---|
| Occurs on | Driven / powered wheel | Towed / braked wheel |
| Wheel vs travel | Wheel turns faster than travel | Wheel turns slower than travel |
| Sign | Positive | Negative slip |
| Soil shear | Sheared backward (pull developed) | Dragged / scuffed forward |
| Limit case | 100 % = spinning on the spot | 100 % = locked wheel sliding |

**PREVIOUS YEAR QUESTIONS**

- Distinguish between Wheel slip and Wheel skid.

  [IFoS 2022 | P2/2(a·i) | part]

- Write short notes on: Tractive efficiency (Traction Theory).

  [IFoS 2020 | P2/4(c·i) | 3M]

- What is traction? Explain with proper equations/expressions how the traction can be improved under (i) sandy soil, and (ii) clayey soil conditions.

  [IFoS 2018 | P2/1(d) | 8M]

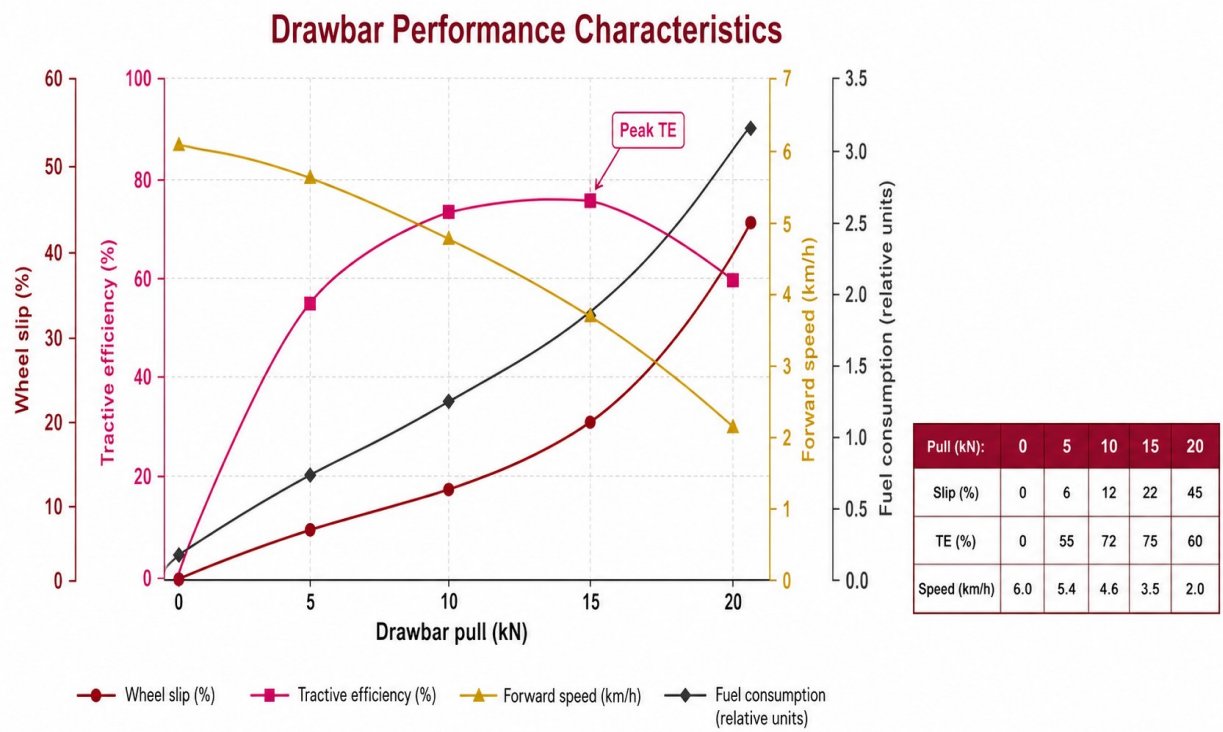
## 10.3 Tractive Efficiency

**Tractive efficiency (TE) :** *the ratio of drawbar (output) power to axle (input) power — the fraction of the power delivered to the wheels that reaches the drawbar. It falls with both slip and rolling resistance.*

TE = DBP / axle-power = (P/F)(V_a/V_t) = (P/F)(1 − s)

*TE = tractive efficiency; P = drawbar pull; F = gross tractive effort; s = slip (fraction). Peak TE (≈ 0·7–0·8 on firm soil) occurs at moderate slip; too little slip → low pull, too much → low speed.*

***Fig. 4.6 Tractor drawbar performance***




| Pull (kN): | 0 | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|
| Slip (%) | 0 | 6 | 12 | 22 | 45 |
| TE (%) | 0 | 55 | 72 | 75 | 60 |
| Speed (km/h) | 6.0 | 5.4 | 4.6 | 3.5 | 2.0 |

*Fig. 4.6 Drawbar pull vs slip, speed, tractive efficiency and fuel consumption.*

**PREVIOUS YEAR QUESTIONS**

Graphically illustrate the tractor drawbar performance in terms of drawbar pull and fuel consumption.
[OPSC-CSE 2022–23 | P2/Q.3(a) | 10M]

## 11 TRACTION — SOIL SHEAR, PREDICTION & IMPROVEMENT

### 11.1 Soil-Thrust (Maximum Traction) Equation

The maximum tractive force a wheel/track can develop equals the ***shear strength of the soil integrated over the contact area*** (Coulomb–Micklethwaite):

$$H_{max} = c \cdot A + W \cdot \tan \phi$$

*$H_{max}$ = maximum soil thrust / gross traction (kN); c = soil cohesion (kPa); A = ground-contact area ($m^2$); W = dynamic weight (normal load) on the running gear (kN); φ = angle of internal friction. Gross traction coefficient = $H_{max} / W$.*

This one equation answers the 2018 'improve traction in sandy vs clayey soil' question:

- ***Clayey (cohesive) soil*** : ϕ ≈ 0, so H ≈ c·A. Traction depends on ***contact area*** — improve it by using ***larger/wider tyres, tracks, dual wheels or cage wheels*** to increase A. Added weight helps little.
- ***Sandy (frictional) soil*** : c ≈ 0, so H ≈ W·tan ϕ. Traction depends on ***weight*** — improve it by ***ballasting (added/liquid-filled wheel weights) and by lugs/strakes*** that mobilise internal friction.

### 11.2 Traction Prediction — Cone Index (Wismer–Luth)

Empirical prediction uses the ***cone index*** (CI, soil strength from a cone penetrometer) combined into a dimensionless ***wheel numeric***:

$$C_n = CI \cdot b \cdot d / W$$

*$C_n$ = wheel numeric; CI = cone index (kPa); b = tyre width, d = tyre diameter (m); W = wheel load (kN).*

$$\text{Towed force: } R/W = 1{\cdot}2/C_n + 0{\cdot}04 \quad ; \quad \text{Net pull: } P/W = 0{\cdot}75(1 - e^{(-0{\cdot}3\, C_n\, s)}) - (1{\cdot}2/C_n + 0{\cdot}04)$$

*s = slip (fraction). Gross traction ratio $0{\cdot}75(1 - e^{(-0{\cdot}3\, C_n\, s)})$; higher $C_n$ (stronger soil, wider tyre, lighter load) → higher pull and lower motion resistance.*

The theoretical (Bekker) approach models pressure–sinkage $p = (k_c/b + k_\varphi)\, z^n$ and shear $\tau = (c + \sigma \tan \varphi)(1 - e^{(-j/K)})$; it explains why sinkage and slip erode traction on soft ground.

**BEKKER PRESSURE–SINKAGE AND SHEAR (THEORETICAL BASIS)**

Bekker modelled the soil under a running wheel in two parts. Vertical support comes from a ***pressure–sinkage*** law, and horizontal thrust from a ***shear–displacement*** law:

$$p = (k_c/b + k_\phi)\, z^n \qquad \tau = (c + \sigma \tan \phi)(1 - e^{(-j/K)})$$

*p = contact pressure; z = sinkage; b = smaller contact dimension; $k_c$, $k_\varphi$ = cohesive & frictional sinkage moduli; n = sinkage exponent. τ = shear stress developed at soil displacement j (= i·x, slip × distance); K = shear-deformation modulus. Thrust rises with slip until it saturates at $H_{max} = cA + W \tan\varphi$.*

The exponential shows why ***some slip is essential*** — at zero slip j = 0 and τ = 0, so no thrust; thrust builds as slip increases and then saturates. Excess slip beyond saturation only increases sinkage and motion resistance, which is why tractive efficiency peaks at a moderate slip.

**WISMER–LUTH PREDICTION — WORKED RELATIONS**

For a pneumatic tyre the empirical Wismer-Luth equations predict performance from the wheel numeric $C_n$. Gross traction ratio, motion-resistance ratio and net-pull ratio are:


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$GT/W = 0{\cdot}75(1 - e^{(-0{\cdot}3\,C_n\,s)})$ $MR/W = 1{\cdot}2/C_n + 0{\cdot}04$ $NP/W = GT/W - MR/W$

*$C_n = CI{\cdot}b{\cdot}d/W$ (cone index × tyre width × diameter ÷ wheel load); s = slip (fraction). Tractive efficiency then $TE = (NP/GT)(1 - s)$. Higher $C_n$ (firmer soil, bigger tyre, lighter load) raises pull and lowers resistance.*

Example read-off: on firm soil with $C_n = 30$ and $s = 0{\cdot}15$, $GT/W = 0{\cdot}75(1 - e^{(-0{\cdot}3{\cdot}30{\cdot}0{\cdot}15)}) = 0{\cdot}75(1 - e^{(-1{\cdot}35)}) = 0{\cdot}75{\times}0{\cdot}741 = 0{\cdot}556$; $MR/W = 1{\cdot}2/30 + 0{\cdot}04 = 0{\cdot}08$; so $NP/W = 0{\cdot}476$ - i.e. nearly half the wheel load is available as drawbar pull.

### 11.3 Traction Improvement — Practical Methods

- ***Ballasting*** : add cast-iron weights or liquid-fill ($CaCl_2$ solution) in the tyres to raise Won frictional soils — but not beyond the point where slip is already low, or rolling resistance rises.
- ***Tyre selection & inflation*** : larger diameter and width lower ground pressure and sinkage; lug (R-1) treads grip; correct (lower) inflation on soft soil spreads the contact patch.
- ***Dual & cage wheels, tracks*** : increase contact area A — decisive on cohesive/wet soils and paddy.
- ***Strakes / lugs / chains*** : penetrate loose soil to reach firmer strata and mobilise shear.
- ***Weight transfer & 4WD*** : draft-control and hitch geometry shift weight onto the drive wheels (see §12); 4WD spreads the tractive demand over all four wheels, cutting slip.

**PREVIOUS YEAR QUESTIONS**

Discuss in brief about traction theory and weight transfer in agricultural tractors. Explain how traction can be increased.

[UK-PSC ACF/RFO 2025 | Q.5(iv) | 10M]

**MODEL Q** For 'improve traction' always anchor on $H = cA + W{\cdot}\tan\phi$: sandy → add weight (W term); clayey → add area (A term); then list the practical aids (ballast, duals/tracks, lugs, 4WD, weight transfer). Quoting the equation earns the theory marks.***

### 11.4 Types of Traction Devices

| Device | Principle & merit | Best use |
|---|---|---|
| Pneumatic tyre (2WD) | Flexible lugged tyre; good on firm soil; simple | General field & transport |
| 4-wheel drive | Tractive demand shared by all four wheels → less slip | Heavy draft, wet/soft soil |
| Crawler track | Very large contact area → low ground pressure, high pull | Soft, wet, sloping land; earth-moving |
| Cage / lug wheel | Open steel cage grips puddled soil, sheds mud | Wetland paddy / puddling |
| Half-track / strakes | Add grip/flotation to a wheeled tractor | Occasional soft-ground work |

A track develops higher pull than a tyre at equal weight because its long, wide contact mobilises more soil shear (larger A in $H = cA + W\tan\phi$) and sinks less; a wheeled tractor recovers some of this advantage through 4WD, ballast and correct tyre selection.

## 12 WEIGHT TRANSFER, CENTRE OF GRAVITY & TRACTOR STABILITY

When a tractor pulls an implement, the drawbar pull and the implement weight ***redistribute the load on the axles*** — lightening the front, loading the rear. Understanding this ***weight transfer*** explains traction, stability and the CG numericals asked almost every year.

## 12.1 Centre of Gravity of a Tractor

The ***centre of gravity (CG)*** is the point through which the whole weight acts. For a 2WD farm tractor 55–80 % of the static weight rests on the ***rear (drive) axle***, and the CG lies low and rearward. Its horizontal position is found by weighing the front axle reaction and taking moments; its height by weighing with the front raised a known angle.

Horizontal CG: $x_1 = R_f \mid L / W$

*$x_1$ = horizontal distance of CG from the REAR axle (m); $R_f$ = static front-axle reaction (kN); L = wheelbase (m); W = total weight (kN). (Take moments about the rear-wheel ground contact.)*

Derivation: taking moments about the rear-axle contact, the front reaction $R_f$ acting at wheelbase L balances the weight W acting at $x_1$ from the rear: $R_f \cdot L = W \cdot x_1 \rightarrow x_1 = R_f \cdot L/W$. The rear reaction is $R_r = W - R_f$.

## 12.2 Static Equilibrium & Weight Transfer on Pulling

Model the tractor as a rigid body on level ground with weight W at the CG, front reaction $R_1$, rear reaction $R_2$, and a drawbar pull P at height y and horizontal distance from the rear axle. Equilibrium gives:

$\Sigma V = 0 : R_1 + R_2 = W \qquad \Sigma M(\text{rear}) = 0 : R_1 \cdot L = W \cdot x_1 - P \cdot y$

*$R_1$ = front reaction, $R_2$ = rear reaction, W = weight, $x_1$ = CG distance ahead of rear axle, L = wheelbase, P = drawbar pull, y = height of line of pull above ground. Solving: $R_1 = (W \cdot x_1 - P \cdot y)/L$.*

Weight transferred to rear: $\Delta R = P \cdot y / L \rightarrow R_2 = W - R_1 = W - (W \cdot x_1 - P \cdot y)/L$

*$\Delta R$ = load shifted from front to rear axle when pulling. A higher hitch (larger y) or higher pull P transfers more weight to the drive wheels — improving traction but risking front-end lift.*

Front-end lift (rearward overturning) impends when $R_1 \rightarrow 0$, i.e. when $\mathbf{P \cdot y = W \cdot x_1}$. This is the limiting stability condition and the reason hitching above the drawbar is dangerous.

**PREVIOUS YEAR QUESTIONS**

- Derive an expression for the weight transfer in a tractor pulling an attached implement.
  [OPSC-CSE 2022–23 | P2/Q.13(a) | 10M]
- Discuss the kinematic principles of tractor-implement combination and illustrate the various forces acting on a tractor pulling an implement. Derive the weight transfer within the tractor in rest condition and when the implement is attached and pulled.
  [OPSC-CSE 2024–25 | P2/Q.2 | 15M]

**FULL DERIVATION — WEIGHT TRANSFER, REST VS PULLING**

Consider the tractor as a rigid body (Fig 4.8). Let W = weight at the CG, which is at horizontal distance $x_1$ ahead of the rear-axle contact and height h; wheelbase L; front and rear ground reactions $R_1$ and $R_2$. A drawbar pull P acts at angle α, at height y above the ground and horizontal distance e behind the rear axle.

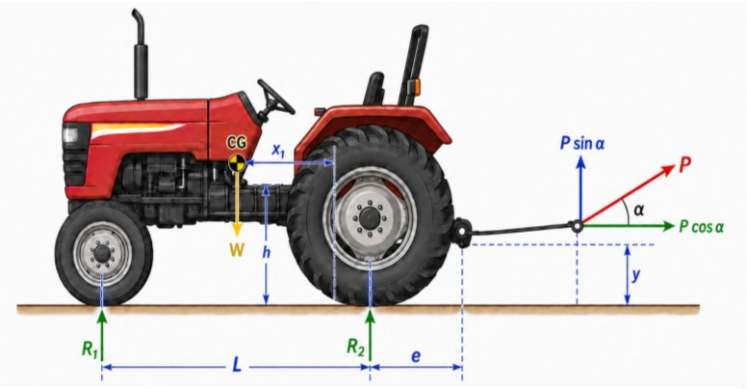



*Fig. 4.8 Forces on a tractor at rest and while pulling an implement.*

***Fig. 4.8 Free-body diagram — tractor pulling an implement***

Rest condition (P = 0). Taking moments about the rear contact: $R_1 \cdot L = W \cdot x_1$, so $R_1 = W \cdot x_1/L$ and $R_2 = W - R_1 = W(L - x_1)/L$. This is the static split (rear-heavy for a 2WD).


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Pulling condition. Resolve P into horizontal P·cosα and vertical P·sinα. Taking moments about the rear contact (anticlockwise positive):

$$R_1 \cdot L + P\cos\alpha \mid y = W \cdot x_1 + P\sin\alpha \mid e$$

*Moment balance about the rear-wheel contact. The horizontal pull component (P cosα) at height y tends to lift the front; the vertical component (P sinα) at distance e adds a moment depending on hitch position.*

Solving for the front reaction and hence the transfer $\Delta R = R_1(\text{rest}) - R_1(\text{pull})$:

$$R_1 = [W \cdot x_1 + P\sin\alpha \cdot e - P\cos\alpha \cdot y] / L \qquad \Delta R = (P\cos\alpha \cdot y - P\sin\alpha \cdot e) / L$$

*ΔR = load lifted off the front (and added to the rear). For a horizontal pull (α = 0) this reduces to ΔR = P·y/L — the classic result: pull × hitch-height ÷ wheelbase.*

Rear reaction while pulling: $R_2 = W - R_1 = W(L - x_1)/L + \Delta R$. The drive wheels thus gain ΔR, which raises the available traction ($H = cA + R_2 \tan\phi$). Front-lift/rearward overturning impends when $R_1 \rightarrow 0$.

## 12.3 Kinematic Principles & Stability

- ***Kinematic principle***: for a fully-mounted implement the tractor–implement acts as one rigid body; the converging three links define a virtual hitch point, and the effective line of pull runs from the implement's center of resistance through that point — governing how weight transfers.
- ***Longitudinal stability***: rearward overturning about the rear axle when P·y or a raised implement moves the CG behind the rear wheels — guard by front ballast and low hitching.
- ***Lateral (side) stability***: side-slope overturning about the downhill wheels. The tractor tips when the vertical through the CG falls outside the downhill wheel track; a lower CG and wider track raise the safe slope angle. Approximately, overturning impends when tan(slope) = (track/2)/h_CG.
- ***CG & tillage performance***: a rearward, low CG improves drive-wheel grip and reduces slip but too far rearward risks front lift; CG height sets both overturning limits.

**PREVIOUS YEAR QUESTIONS**

- How does the location of a tractor's Center of Gravity (CG) influence the performance of tillage implements?

  [OPSC-CSE 2023–24 | P2/Q.9(a) | 15M]

- Find out tractive force of a tractor and weight transfer to the rear wheel (data: tractor 2500 kg, wheelbase 2·2 m, CG 0·8 m from rear axle, CG height 0·8 m, pull 1500 kg at 30°, angle of cohesion 20°, rear contact area 2000 cm², soil resistance 0·1 kg/cm²).

  [OPSC-CSE 2015–16 | P2/Q.1(d) | 20M]

**DERIVATION — SIDE-SLOPE (LATERAL) OVERTURNING**

On a side slope of angle β the weight W acts vertically through the CG at height h; the wheel track (center-to-center) is b. The tractor is stable while the vertical line through the CG stays inside the downhill wheel. Overturning impends when that line reaches the downhill wheel contact, i.e. when the overturning moment equals the restoring moment:

$$W\sin\beta \mid h = W\cos\beta \mid (b/2) \quad \rightarrow \quad \tan\beta_{max} = (b/2) / h$$

*β_max = maximum safe side-slope angle; b = wheel track (m); h = height of CG (m). A lower CG (smaller h) and a wider track (larger b) raise β_max. This is why a raised mounted implement (which lifts the CG) lowers the safe working slope.*

The same logic gives ***longitudinal (rearward) overturning*** about the rear axle when the CG or an added rear moment passes behind the rear wheels; front ballast restores it. Both limits shrink as the CG rises, so CG height is the master variable for tractor stability.

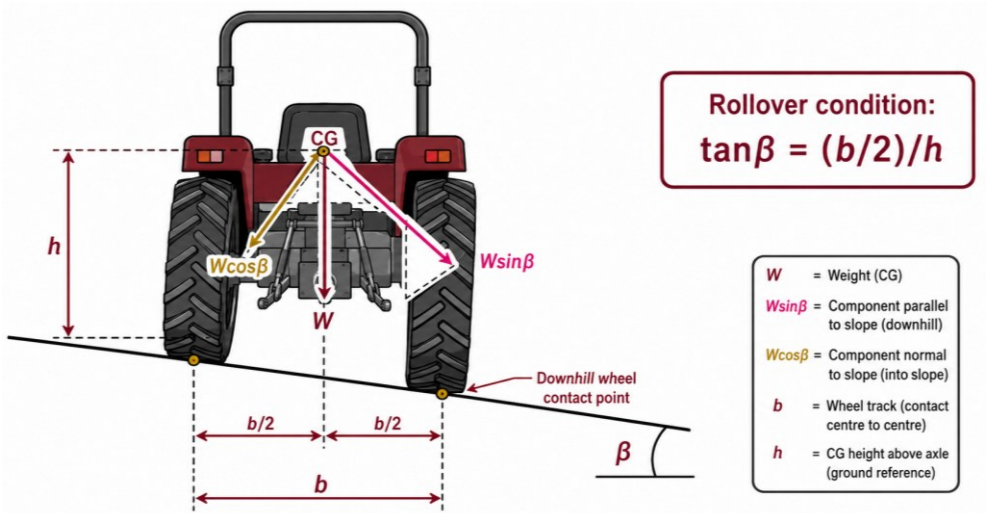



*Fig. 4.10 Geometry of side-slope overturning; safe slope tan θ = (b/2)/h.*

***Fig. 4.10 Side-slope stability of a tractor***

### 12.4 Worked Example — Locating the CG (and 2WD/4WD reasoning)

◆ **WORKED NUMERICAL — CG location, rear reaction & drive type** **[IFoS 2025 | P2/3(b·ii) | 10M]**

**Problem.** *A tractor weighing 28·5 kN with a front wheel reaction of 9·0 kN is in static position on a horizontal surface. The wheelbase is 2·08 m. Calculate the horizontal distance from the rear axle centreline to the centre of gravity. Also calculate the rear wheel reaction and explain, with reason, whether it is a 2-wheel-drive or 4-wheel-drive tractor.*

**Given.** W = 28·5 kN; front reaction R_f = 9·0 kN; wheelbase L = 2·08 m.

**Find.** $x_1$ (CG from rear axle); rear reaction R_r; drive type with reason.

**Formula (moments about rear axle).** $R_f \cdot L = W \cdot x_1 \rightarrow x_1 = R_f \cdot L / W$.

**Substitution.** $x_1 = (9{\cdot}0 \times 2{\cdot}08)/28{\cdot}5 = 18{\cdot}72/28{\cdot}5 =$ **0·657 m from the rear axle.**

**Rear reaction.** $R_r = W - R_f = 28{\cdot}5 - 9{\cdot}0 =$ **19·5 kN.**

**Drive type.** Rear share = 19·5/28·5 = 68·4 % of the weight is on the rear axle (vs 31·6 % front). This strongly rear-biased static loading is characteristic of a **2-wheel-drive (rear-drive) tractor** — the drive wheels are deliberately kept heavily loaded for traction; a 4WD would carry a more even front/rear split.

**Result.** **$x_1$ = 0·657 m ahead of the rear axle; R_r = 19·5 kN; it is a 2WD tractor.**

**Check.** $R_f + R_r = 9{\cdot}0 + 19{\cdot}5 = 28{\cdot}5$ kN = W ✓; $x_1 < L$ and nearer the rear ✓.

## 13 SOLVED NUMERICALS BANK

Every distinct PYQ numerical mapped to Chapter 4 is worked below to the SOP template ***(Given → Find → Formula → Substitution → Result → Check)***. Three others are solved in place: the MB-plough field-capacity/unit-draft problem in §9.5, the vertical-soil-reaction problem in §8.3, and the CG-location problem in §12.4. All answers were recomputed in Python before printing.

◆ **WORKED NUMERICAL — N1 | Actual PTO power to pull a disc harrow** **[IFoS 2025 | P2/1(b·ii) | 4M]**

**Problem.** *A disc harrow with a draft of 18 N is required to be pulled at a speed of 4 km/h in a firm untilled field by a tractor having maximum PTO power rating of 40 kW. Calculate the actual PTO power needed to pull the harrow, if the tractive and transmission coefficient for a 2-wheel-drive tractor*


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*for the untilled firm soil is 0·75.*

**Typo correction.** A draft of 18 N would need ~0·02 kW — physically trivial and inconsistent with a 40 kW tractor. The intended value is 18 kN (a realistic disc-harrow draft). Solved with D = 18 kN and noted.

**Given.** D = 18 kN; V = 4 km/h = 1·111 m/s; overall tractive×transmission coefficient η = 0·75; PTO rating = 40 kW.

**Find.** actual PTO power required.

**Formula.** Drawbar power DBP = D×V;

PTO power = DBP / η.

**Substitution.** DBP = 18 000 × 1·111 = 20 000 W = 20 kW; PTO = 20/0·75 = **26·7 kW.**

**Result. Actual PTO power ≈ 26·7 kW (< 40 kW rating, so the tractor can do it).**

**Check.** N·m/s = W ✓; PTO > DBP as η < 1 ✓.

◆ **WORKED NUMERICAL — N2 | *Drawbar power of a cultivator*** **[IFoS 2024 | P2/2(a) | 10M]**

**Problem.** *The line of pull of a 1·2 m width cultivator is inclined at 20° with horizontal and acting on the vertical plane along the direction of motion. If the pull required by the prime mover at 3 km/h forward speed is 10 kN, determine the drawbar power.*

**Given.** pull P = 10 kN at θ = 20° to horizontal; V = 3 km/h = 0·833 m/s; width 1·2 m (not needed for power).

**Find.** drawbar power.

**Formula.** Only the horizontal component does work along the travel direction: DBP = P·cosθ × V.

**Substitution.** DBP = 10 × cos20° × 0·833 = 10 × 0·9397 × 0·833 = 7·83 kW.

**Result. Drawbar power ≈ 7·83 kW (≈ 10·5 hp).**

**Check.** kN·m/s = kW ✓; using cosθ (not P alone) because pull is inclined ✓.

◆ **WORKED NUMERICAL — N3 | *Track tractor — gross traction coefficient & drawbar power*** **[IFoS 2023 | P2/4(c) | 15M]**

**Problem.** *A track-type tractor with two tracks each 300 mm wide and 1500 mm long weighs 30 kN. While pulling an implement at 3·6 km/h it experiences a rolling resistance of 3 kN. Calculate (i) gross traction coefficient and (ii) drawbar power in kW. Take soil cohesion 8 kPa and angle of internal friction 30°.*

**Given.** 2 tracks, each 0·3 × 1·5 m; W = 30 kN; V = 3·6 km/h = 1·0 m/s; R = 3 kN; c = 8 kPa; ϕ = 30°.

**Find.** (i) gross traction coefficient; (ii) drawbar power.

**Formula.** Contact area A = 2(b×l);

gross thrust H = c·A + W·tanϕ;

GTC = H/W;

net pull P = H − R; DBP = P×V.

**Substitution.** A = 2(0·3×1·5) = 0·90 m²; H = 8×0·90 + 30×tan30° = 7·2 + 30×0·5774 = 7·2 + 17·32 = 24·52 kN.

**(i)** GTC = H/W = 24·52/30 = **0·817.**

**(ii)** P = 24·52 − 3 = 21·52 kN; DBP = 21·52 × 1·0 = **21·5 kW.**

**Result. Gross traction coefficient ≈ 0·82; drawbar power ≈ 21·5 kW.**

**Check.** kPa·m² = kN ✓; H > R ✓; GTC < 1 ✓.

◆ **WORKED NUMERICAL — N4 | *4-bottom trailed MB plough — unit draft, drawbar hp, FC*** **[IFoS 2017 | P2/1(d) | 8M]**

**Problem.** *Total draft of a 4-bottom trailed mould-board plough is 2000 kg when moving at 6 km/h. Calculate (i) the unit draft in kg/cm² if the depth of cut is 20 cm, (ii) drawbar horse-power, (iii) field capacity.*

**Assumption.** Furrow (bottom) width is not stated; take the standard 30 cm bottom → total width w = 4×30 = 120 cm. Flagged for verification.

**Given.** D = 2000 kgf;

V = 6 km/h = 1·667 m/s;

depth d = 20 cm; w = 120 cm.

**(i) Unit draft.** = D/(w×d) = 2000/(120×20) = 2000/2400 = **0·833 kg/cm².**

**(ii) Drawbar hp.** = D×V/75 = 2000×1·667/75 = **44·4 hp.**

**(iii) Field capacity (theoretical).** = w×V/10 = 1·2×6/10 = **0·72 ha/h.**

**Result. Unit draft 0·833 kg/cm²; drawbar power ≈ 44·4 hp; TFC 0·72 ha/h (actual = ×field efficiency).**

**Check.** kgf·m·s$^{-1}$/75 = metric hp ✓; assumption of 30 cm bottom noted.

◆ **WORKED NUMERICAL — N5 | *3-bottom plough — actual field capacity*** **[IFoS 2016 | P2/1(d·i) | part]**

**Problem.** *A three-bottom, 40 cm mould-board plough is working at a depth of 16 cm. Calculate the actual field capacity when the speed of operation is 4·5 km/h and field performance index is 0·75.*

**Given.** w = 3×40 = 120 cm = 1·2 m; V = 4·5 km/h; ηf = 0·75 (depth is not needed for capacity).

**Formula.** TFC = w×V/10;

AFC = TFC×ηf.

**Substitution.** TFC = 1·2×4·5/10 = 0·54 ha/h; AFC = 0·54×0·75 = **0·405 ha/h.**

**Result. Actual field capacity ≈ 0·405 ha/h.**

**Check.** AFC < TFC ✓.

◆ **WORKED NUMERICAL — N6 | *Wheel slip from travel distances*** **[OPSC-CSE 2024–25 | P2/Q.3 | part]**

**Problem.** *When a tractor was tested at no-load and load, the distance covered by the rear wheel (for the same number of revolutions) was 55·8 m and 46·2 m respectively. Calculate the wheel slip.*

**Given.** no-load run $L_o$ = 55·8 m; loaded run L = 46·2 m.

**Formula.** slip s = $(L_o - L)/L_o \times 100$ %.

**Substitution.** s = (55·8 − 46·2)/55·8 × 100 = 9·6/55·8 × 100 = **17·2 %.**

**Result. Wheel slip ≈ 17·2 %.**

**Check.** loaded run < no-load run → positive slip ✓; value in the normal 10–20 % working band ✓.

◆ **WORKED NUMERICAL — N7 | *Cultivator — time, theoretical & effective field capacity*** **[OPSC-CSE 2024–25 | P2/Q.4 | 15M]**

**Problem.** *A tractor with a 3·5 m cultivator cultivates 50 ha at 5·0 km/h. Determine the time taken and the theoretical field capacity. If the operator reports a time loss of 0·75 h per 10 h of field operation, what is the effective field capacity?*

**Given.** w = 3·5 m; V = 5 km/h; area = 50 ha; loss = 0·75 h per 10 h.


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**Theoretical FC.** TFC = w×V/10 = 3·5×5/10 = **1·75 ha/h.**

**Time (theoretical).** t = 50/1·75 = **28·6 h.**

**Field efficiency.** ηf = 10/(10+0·75) = 0·930 = 93·0 %.

**Effective FC.** EFC = TFC×ηf = 1·75×0·930 = **1·63 ha/h; effective time = 50/1·63 = 30·7 h.**

**Result. TFC 1·75 ha/h; theoretical time 28·6 h; effective FC ≈ 1·63 ha/h (≈ 30·7 h).**

**Check.** EFC < TFC ✓; extra time 30·7 − 28·6 ≈ 2·1 h ≈ 7 % loss ✓.

◆ **WORKED NUMERICAL — N8 | *4-bottom plough — centre of resistance & horsepower*** **[OPSC-CSE 2024–25 | P2/Q.14 | 20M]**

**Problem.** *A 4-bottom 30 cm mould-board plough is drawn at 5 km/h. Soil resistance 0·7 kg/cm², working depth 15 cm. Find (a) the centre of resistance from the wing of the first bottom, and (b) the horse-power to pull the plough.*

**Given.** n = 4; furrow width 30 cm; V = 5 km/h = 1·389 m/s;

specific soil resistance 0·7 kg/cm²; d = 15 cm.

**(a) Centre of resistance.** Bottom centres lie at 15, 45, 75, 105 cm from the land wing of the first bottom; their centroid = (15+45+75+105)/4

= **60 cm — i.e. the middle of the 120 cm total width.**

**(b) Draft.** area = n×width×depth = 4×30×15 = 1800 cm²;

D = 0·7×1800 = 1260 kgf.

**Horsepower.** hp = D×V/75

= 1260×1·389/75 = **23·3 hp.**

**Result. Centre of resistance 60 cm from the first-bottom wing; power ≈ 23·3 hp.**

**Check.** CR at mid-width by symmetry ✓; kgf·m·s$^{-1}$/75 = hp ✓.

◆ **WORKED NUMERICAL — N9 | *Wheel slip in a soil bin*** **[OPSC-CSE 2023–24 | P2/Q.6(a) | 15M]**

**Problem.** *Find the slippage of a traction wheel of 600 mm diameter tested in a soil bin: angular speed 10 rpm, input torque 60 N·m, drawbar pull 150 N, normal load 500 N, and wheel forward speed 0·25 m/s.*

**Given.** D = 0·6 m; N = 10 rpm = 10/60 rev/s;

$V_a$ = 0·25 m/s (torque, pull, load not needed for slip).

**Formula.** theoretical speed $V_t = \pi DN$; slip $s = (V_t - V_a)/V_t \times 100$ %.

**Substitution.** $V_t = \pi \times 0{\cdot}6 \times (10/60)$

$= \pi \times 0{\cdot}6 \times 0{\cdot}1667 = 0{\cdot}314$ m/s;

$s = (0{\cdot}314 - 0{\cdot}25)/0{\cdot}314 \times 100 =$ **20·4 %.**

**Result. Wheel slippage ≈ 20·4 %.**

**Check.** $V_a < V_t$ → positive slip ✓.

◆ **WORKED NUMERICAL — N10 | *Bullock plough — power & unit draft*** **[OPSC-CSE 2020–21 | P2/Q.2(b·ii) | 12M]**

**Problem.** *A pair of bullocks pulls a plough at 3 km/h making a furrow 20 cm wide and 11 cm deep; the dynamometer reads an average draft of 85 kgf. Find the horse-power developed and the unit draft.*

**Given.** D = 85 kgf; V = 3 km/h = 0·833 m/s;

furrow 20 cm × 11 cm.

**Horsepower.** hp = D×V/75

= 85×0·833/75

= **0·944 hp.**

**Unit draft.** = D/(w×d)

= 85/(20×11)

= 85/220

= **0·386 kg/cm².**

**Result. Power ≈ 0·944 hp; unit draft ≈ 0·386 kg/cm².**

**Check.** ~0·9 hp for a bullock pair is realistic ✓.

◆ **WORKED NUMERICAL — N11 | *2-bottom plough — unit draft & horsepower*** **[UK-PSC RFO 2012 | Q.8(i) | 10M]**

**Problem.** *A 40 cm mould-board plough bottom makes a 15 cm deep furrow. Compute unit draft and horse-power for a two-bottom plough working at 5 km/h with 1200 kg draft.*

**Given.** n = 2; width 40 cm; d = 15 cm; V = 5 km/h = 1·389 m/s; D = 1200 kgf.

**Unit draft.** = D/(n×w×d)

= 1200/(2×40×15)

= 1200/1200 = **1·0 kg/cm².**

**Horsepower.** = D×V/75

= 1200×1·389/75

= **22·2 hp.**

**Result. Unit draft = 1·0 kg/cm²; power ≈ 22·2 hp.**

**Check.** area 1200 cm² gives a clean 1·0 kg/cm² ✓.

◆ **WORKED NUMERICAL — N12 | *3-bottom plough — specific draft, power & rate of work*** **[OPSC-CSE 2016–17 | P2/Q.2(d)–3(a) | 15M]**

**Problem.** *The total draft of a 3-bottom 30 cm MB plough ploughing 20 cm deep at 5 km/h was 12 kN. Calculate the specific draft (N/cm²), the actual power requirement, and — at 80 % field efficiency — the rate of work (ha/h).*

**Given.** n = 3; width 30 cm; d = 20 cm; V = 5 km/h = 1·389 m/s; D = 12 kN; ηf = 0·80.

**Specific draft.** = D/(n×w×d)

= 12000/(3×30×20)

= 12000/1800

= **6·67 N/cm².**

**Power.** = D×V = 12000×1·389

= 16 670 W = **16·7 kW.**

**Rate of work.** w = 0·9 m; TFC = 0·9×5/10 = 0·45 ha/h; actual = 0·45×0·80 = **0·36 ha/h.**

**Result. Specific draft 6·67 N/cm²; power 16·7 kW; rate of work 0·36 ha/h.**

**Check.** 6·67 N/cm² lies in the loam–clay band ✓; N·m/s = W ✓.


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◆ **WORKED NUMERICAL — N13 | *Tractive force & weight transfer to rear wheel*** **[OPSC-CSE 2015–16 | P2/Q.1(d) | 20M]**

**Problem.** *Tractor 2500 kg, wheelbase 2·2 m, CG 0·8 m ahead of the rear axle, CG height 0·8 m; pull 1500 kg at 30° to horizontal; angle of internal friction (cohesion) 20°; rear contact area 2000 cm²; soil resistance 0·1 kg/cm². Find the tractive force and the weight transferred to the rear wheels.*

**Method note.** Standard rigid-body model: static rear reaction + transfer from the horizontal pull acting at CG height, then tractive force from H = c·A + W_rear·tanϕ (taking the given 0·1 kg/cm² as cohesion c). Model-based; flagged.

**Static rear reaction.** $R_{r0} = W(L-a)/L = 2500(2{\cdot}2-0{\cdot}8)/2{\cdot}2$

$= 2500\times1{\cdot}4/2{\cdot}2 = 1591$ kgf.

**Weight transfer from pull.** horizontal pull $P_h = 1500\cos30° = 1299$ kgf at height h = 0·8 m;

$\Delta R = P_h\times h/L = 1299\times0{\cdot}8/2{\cdot}2$

**= 472 kgf to the rear.**

**Loaded rear reaction.** $R_r \approx 1591 + 472 = 2063$ kgf.

**Tractive force.** $H = c{\cdot}A + R_r{\cdot}\tan\phi = 0{\cdot}1\times2000 + 2063\times\tan20°$

$= 200 + 2063\times0{\cdot}364$

$= 200 + 751 =$ **≈ 951 kgf.**

**Result. Weight transferred to rear ≈ 472 kgf ($R_r$ ≈ 2063 kgf); tractive force ≈ 951 kgf. (Values depend on the assumed model — flagged.)**

**Check.** transfer raises rear load, aiding grip ✓; H exceeds a plausible drawbar demand, so no gross slip ✓.

◆ **WORKED NUMERICAL — N14 | *Disc harrow — actual field capacity*** **[HP-PSC RFO 2021 | Q.5(a) | 10M]**

**Problem.** *A disc harrow (disc dia 560 mm) covering a width of 1·25 m operates at 4·5 km/h. The average soil resistance is 0·63 kg/cm² and the field efficiency is 75 %. Determine the actual field capacity (and note what is needed for the horse-power).*

**Note.** The paper prints the width as '125 mm', which is implausibly narrow for a harrow; the intended working width is 1·25 m — used here and flagged. Depth of cut is not given, so the draft (and hence hp) cannot be found; only the field-capacity part is fully determinate.

**Given.** w = 1·25 m; V = 4·5 km/h; ηf = 0·75.

**Formula.** TFC = w·V/10; AFC = TFC·ηf.

**Substitution.** TFC = 1·25×4·5/10

= 0·5625 ha/h;

AFC = 0·5625×0·75 = **0·422 ha/h.**

**Horse-power (method).** if depth d were known: area = w×d, draft

D = 0·63×area (kgf),

hp = D×V/75. Cannot be evaluated without d.

**Result. Actual field capacity ≈ 0·422 ha/h; hp indeterminate (depth missing).**

**Check.** AFC < TFC ✓.

◆ **WORKED NUMERICAL — N15 | 4×40 cm MB plough — power, time & grassy-land effect** [OPSC-CSE 2015–16 | P2/Q.3(b) | 20M]

**Problem.** *A tractor pulls a 4 × 40 cm mould-board plough in barren land at 15 cm depth and 6 km/h. Soil resistance 0·4 kg/cm², rectangular furrow, field efficiency 85 %. Calculate the power to pull the plough and the time to plough 8 ha. Comment on draft, power and field capacity if the plough is operated in grassy land.*

**Given.** n = 4; width 40 cm → w = 160 cm = 1·6 m; d = 15 cm;

V = 6 km/h = 1·667 m/s;

soil resistance 0·4 kg/cm²;

ηf = 0·85; area to plough = 8 ha.

**Draft.** area of cut = n×width×depth = 4×40×15 = 2400 cm²;

D = 0·4×2400 = 960 kgf.

**Power.** hp = D×V/75 = 960×1·667/75 = **21·3 hp (≈ 15·7 kW).**

**Field capacity & time.** TFC = w·V/10 = 1·6×6/10 = 0·96 ha/h;

AFC = 0·96×0·85 = 0·816 ha/h;

time = 8/0·816 = **9·80 h.**

**Grassy-land comment.** grass roots raise the soil resistance, so the **draft and power increase**, the plough may choke and lose penetration, and — needing slower speed and more turns to clear trash — the **field capacity falls and the time rises**. A jointer/skimmer and coulter help by cutting and burying the grass.

**Result. Power ≈ 21·3 hp; time for 8 ha ≈ 9·8 h; in grassy land draft/power ↑, field capacity ↓.**

**Check.** kgf·m·s$^{-1}$/75 = hp ✓; AFC < TFC ✓.

Remaining note: the OPSC-CSE 2020-21 'two-bottom MB plough test observations' problem is omitted here because the source paper lists the heading but the observation data are not reproduced in the PYQ file, so it cannot be solved without inventing values. The seed-drill and combine sub-parts of the 2016 IFoS question belong to other chapters and are excluded per the PYQ file's own note.

## 14 FORMULA SHEET | SUMMARY | LAST-NIGHT REVISION

### 14.1 Consolidated Formula Sheet

| Quantity | Formula | Notes / units |
|---|---|---|
| Theoretical field capacity | TFC = w·V/10 | w (m), V (km/h) → ha/h |
| Actual/effective FC | AFC = TFC·ηf | ηf = field efficiency |
| Field efficiency | ηf = productive time/total | or 10/(10+loss per 10 h) |
| Unit / specific draft | = D/(w·d) | N/cm² or kg/cm² |
| Draft–speed (MB plough) | $D_s$ = D_r(0·83+0·0073 S²) | S in km/h |
| Drawbar pull | P = F - R | F gross traction, R rolling resist. |
| Drawbar power | DBP = P·V (hp = D·V/75) | V (m/s); 1 hp = 75 kgf·m/s |
| Coeff. of traction | μ = F/W | gross; net = P/W |
| Soil thrust (max traction) | H = c·A + W·tanϕ | c cohesion, A area, ϕ friction |


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| | | |
|---|---|---|
| Gross traction coeff. | GTC = H/W | - |
| Wheel slip | $s = (V_t - V_a)/V_t = (L_o - L)/L_o$ | $V_t = \pi DN$ |
| Tractive efficiency | TE = (P/F)(1-s) | peak ≈ 0·7-0·8 |
| Coulomb shear | $\tau = c + \sigma \cdot \tan\phi$ | clay τ=c; sand $\tau = \sigma \tan\phi$ |
| Wheel numeric | $C_n = CI \cdot b \cdot d/W$ | Wismer-Luth |
| Horizontal CG | $x_1 = R_f \cdot L/W$ | from rear axle |
| Weight transfer (pull) | $\Delta R = P \cdot y/L$ | y = pull height, L = wheelbase |
| Disc radius of curvature | $R = t/2 + D^2/8t$ | t = concavity, D = disc dia |

## 14.2 Chapter Summary

- ***Tillage*** : mechanical soil manipulation for tilth; primary (deep, inverting: MB/disc plough, sub-soiler) vs secondary (fine seedbed: harrow, cultivator); conventional (<15 % residue) vs conservation (≥30 %), minimum, zero-till.
- ***MB plough*** : share–mould-board–landside–frog bottom; vertical suction (3–5 mm, depth) and horizontal suction (5–13 mm, width); mould-board types (general/stubble/sod/slat); complete inversion.
- ***Disc plough/harrow*** : rolling disc; disc angle 42–45°, tilt angle 15–25°, gang angle 0–50°; single vs double action, tandem vs offset; penetration by angle, weight, sharpness, soil.
- ***Attachment*** : trailed (own wheels) / semi-mounted (shared) / mounted (3-point, full weight transfer).
- ***Forces*** : soil reaction resolves into L (draft), V, S; centre of resistance = centroid of cut; line of pull must pass through it to avoid side draft.
- ***Traction*** : P = F − R; μ = F/W; H = cA + W tanϕ (sand→weight, clay→area); slip (driven) vs skid (towed); TE = (P/F)(1−s); weight transfer ΔR = Py/L; CG $x_1 = R_f L/W$.

## 14.3 One-Page Last-Night Revision

- ***Definitions to recite*** : tillage, tilth; primary/secondary; conventional vs conservation (15 %/30 %); vertical vs horizontal suction; disc vs tilt vs gang angle; centre of resistance vs centre of pull; traction, drawbar pull, coeff. of traction, tractive efficiency; slip vs skid.
- ***Numbers to remember*** : suction 3–5 / 5–13 mm; disc 42–45°, tilt 15–25°, gang 0–50°; specific draft sand 1·4–2, loam 2–5, clay 4–8 N/cm²; working slip 8–15 %; peak TE 0·7–0·8; rear-axle load 55–80 % (2WD).
- ***Master equations*** : TFC = wV/10; unit draft = D/(wd); P = F − R; DBP = P·V (hp = DV/75); H = cA + W tanϕ; s = (V_t−V_a)/V_t; TE = (P/F)(1−s); $x_1 = R_f L/W$; ΔR = Py/L.
- ***Exam reflexes*** : 'improve traction' → quote H = cA + W tanϕ (sand=weight, clay=area). 'Differentiate' → table. Numerical → Given/Find/Formula/Substitute/Result/Check, answer to 3 s.f., watch km/h→m/s.

CHAPTER

# 5

# SOWING & PLANT PROTECTION EQUIPMENT

*Seed drills · planters & transplanters · furrow openers & metering · sprayers · dusters · nozzles & atomization*

**SYLLABUS :** Sowing and planting equipment; plant protection equipment — sprayers and dusters. (UPSC IFoS, Agricultural Engineering, Paper II, Section A — Farm Power & Machinery.) Chapter 5 covers sowing equipment — seed drill, fertilizer & seed-cum-fertilizer drill, planters (row/precision/plate), transplanters, broadcasters; seed-drill components & metering — furrow openers (shoe, hoe, disc, shovel), fluted-roller, cell/inclined-plate, cup-feed, pneumatic; seed/fertilizer rate, calibration, seed spacing; sowing methods — broadcasting, drilling, hill-dropping, check-row, precision planting, transplanting; plant-protection equipment — sprayers (hydraulic / air-assisted / knapsack / rocker / power / boom) and dusters, manual vs power; sprayer components — pumps, nozzles (cone, flat-fan, flood), spray pattern, atomization, droplet size (VMD/NMD), application rate; and sprayer & sowing numericals.

## Chapter Outline


1. **Scope & Introduction**
2. **Sowing & Planting Methods**
3. **Seed Drill & Seed-cum-Fertilizer Drill**
4. **Seed & Fertilizer Metering Mechanisms**
5. **Furrow Openers**
6. **Calibration of a Seed Drill**
7. **Planters, Precision Planters & Transplanters**
8. **Sprayers — Types, Classification & Working**
9. **Sprayer Components, Pumps & Nozzles**
10. **Atomization & Droplet Characteristics; Application Rate**
11. **Dusters**
12. **Solved Numericals Bank (all PYQ numericals, fully worked)**
13. **Formula Sheet · Summary · Last-Night Revision**

**▣ MIND-MAP — *Chapter 5 concept map***

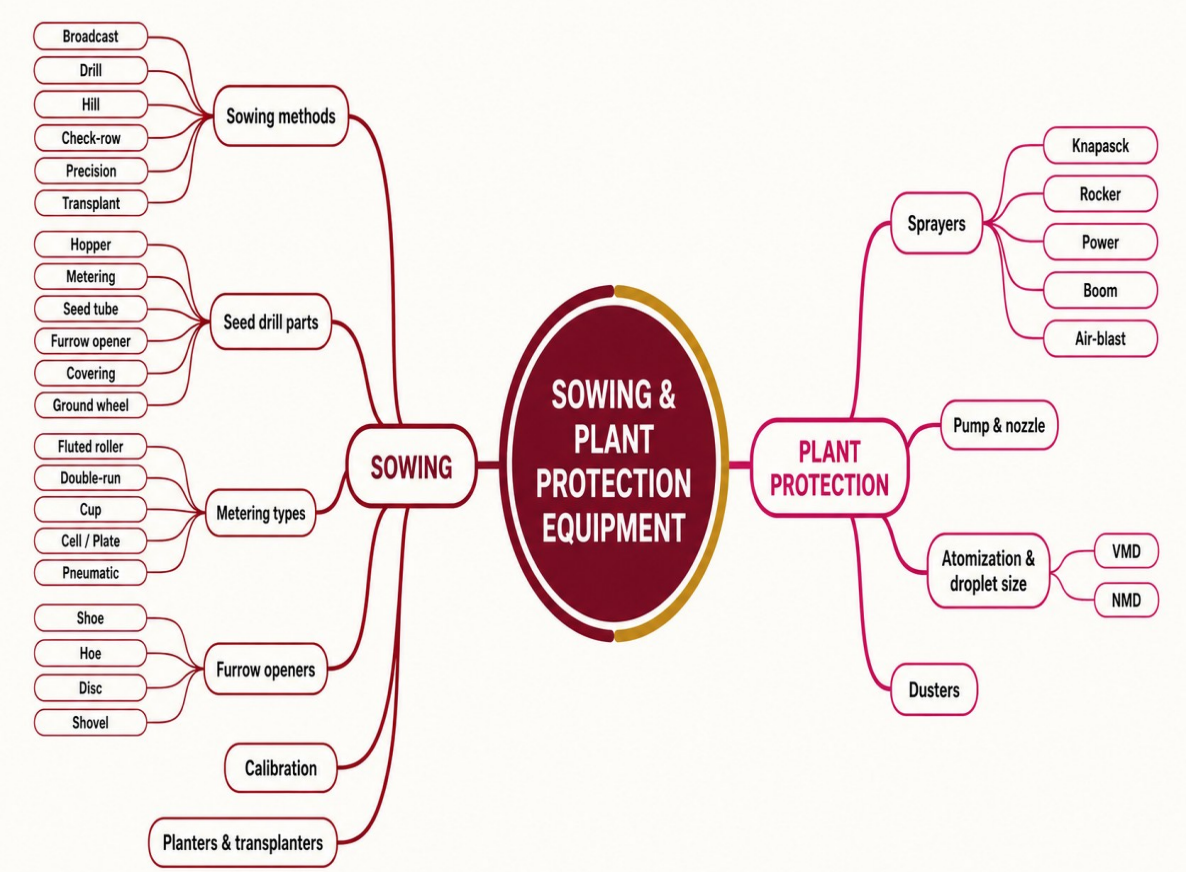



*Fig. 5.0 Chapter-5 concept map — sowing/planting and plant-protection equipment.*

## 1 SCOPE & INTRODUCTION

This chapter covers the two operations that ***establish and protect the crop***: placing seed in the soil at the right rate, depth and spacing (***sowing & planting***), and applying agro-chemicals to control pests, diseases and weeds (***plant protection***). Both are heavily examined and both are ***numerically rich*** — seed-drill calibration and seed spacing on the sowing side, and nozzle flow, pump power and application rate on the spraying side — so the worked-numerical bank in §12 is again the core.

***Sowing*** — *placing seed in or on the soil for germination — by scattering (broadcasting) or in rows (drilling), with or without covering.*

***Planting*** — *placing seed or plant material at definite spacing (seed, tuber, set or seedling) — i.e. precise placement, as by a planter or transplanter.*

## 2 SCOPE & THE SOIL–WATER–PLANT SYSTEM

The method chosen depends on crop, seed size and the spacing precision needed.

- ***Broadcasting*** : Scattering seed ***uniformly over the surface*** by hand or a broadcaster, then covering by harrow/plank. Simple and fast but uneven depth and spacing; high seed rate. Used for close-spaced crops (wheat, small millets).
- ***Drilling*** : Placing seed in ***continuous rows*** at controlled depth and rate with a seed drill; spacing within the row is not controlled. The standard method for cereals.

- ***Dibbling*** : Placing seed in individually-made holes at fixed spacing — precise but slow and labour-intensive; used for large-seeded, high-value crops.
- ***Hill dropping*** : Dropping a ***group of 2–3 seeds ('hills') at fixed intervals*** along the row; spacing between hills is constant. Saves seed and eases inter-culture.
- ***Check-row planting*** : Planting in hills so precisely that the rows line up in ***both directions (a square grid)***, allowing two-way inter-cultivation. Requires a check-row planter with a knotted wire.
- ***Precision (single-seed) planting*** : Placing ***single seeds at exact, equal spacing*** with a precision planter — optimum plant population, no thinning, minimum seed. Used for maize, cotton, sugar-beet, vegetables.
- ***Transplanting*** : Raising seedlings in a nursery and ***planting them out*** at fixed spacing (paddy, vegetables) by hand or a transplanter.

| Basis | Hill dropping | Check-row planting |
|---|---|---|
| Placement | Groups of seeds at set spacing along the row | Hills aligned in a square grid (both ways) |
| Cross-cultivation | One direction | Two directions (across & along) |
| Mechanism | Hill-drop planter | Check-row planter with knotted wire |

**PREVIOUS YEAR QUESTIONS**

- Briefly describe: Hill dropping and Check-row planting. [HP-PSC RFO 2021 | Q.5(d)(ii) | part]
- Write the difference between: Sowing and Transplanting operation. [IFOS 2024 | P2/1(c)(ii) | 2M]

| Basis | Sowing (drilling) | Transplanting |
|---|---|---|
| What is placed | Seed, directly in the field | Nursery-raised seedlings |
| Spacing | Row spacing set; in-row not fixed (drill) | Both spacings fixed |
| Crops | Cereals, pulses, oilseeds | Paddy, vegetables, tobacco |
| Establishment | Depends on field germination | Uniform, vigorous seedlings; saves main-field time |

### 2.1 PRINCIPLE: DRILLING VS PLANTING; FIELD CONFIGURATIONS

The ***principal difference between drilling and planting*** is spacing control. A ***seed drill (drilling)*** meters a continuous stream and controls only the row (inter-row) spacing; the seed-to-seed (intra-row) spacing is random. A ***planter (planting)*** meters single seeds and controls both row and plant spacing, giving the exact population a row crop needs.

- ***Flat planting*** : Seed on a level surface — most cereals.
- ***Furrow planting*** : Seed in the furrow bottom — conserves moisture in dry regions.
- ***Bed / ridge planting*** : Seed on raised beds/ridges — drainage-sensitive crops and furrow irrigation.

**PREVIOUS YEAR QUESTIONS**

- Explain the working of most commonly used metering mechanism in a seed drill for wheat crop. What is the principle difference between seed drilling and planting? [OPSC-Forest 2023–24 | P2/3 (a) | 20 M]

## 3 SEED DRILL & SEED-CUM-FERTILIZER DRILL

***Seed drill :*** *a machine that places seed in rows at a controlled rate and depth and covers it. A seed-cum-fertilizer drill has a second hopper a nd metering to place fertilizer with the seed; a fertilizer drill meters only fertilizer.*


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**TYPES OF SEED DRILLS**

- ***Plain seed drill*** : Meters and sows only seed.
- ***Seed-cum-fertilizer drill*** : Separate seed and fertilizer hoppers/metering; places both together — the standard Indian drill.
- ***Fertilizer drill*** : Meters only fertilizer for basal/top dressing.
- ***Zero-till drill*** : Sows into untilled, residue-covered soil with inverted-T/disc openers.
- ***Pneumatic (air) drill*** : Air-assisted seed delivery/metering for precise, high-speed sowing.
- ***Multi-crop / precision drill*** : Adjustable metering & spacing for several crops; precision types singulate seed.

**FUNCTIONS OF A SEED DRILL**

- ***Meter the seed*** : Deliver seed at the set rate (kg/ha).
- ***Open the furrow*** : Cut a channel of the right depth with the furrow opener.
- ***Convey & place seed*** : Carry seed from hopper to furrow through the seed tube.
- ***Cover & compact*** : Close the furrow and firm the soil over the seed for germination.

## 3.1 COMPONENTS & THEIR FUNCTIONS

- ***Hopper (seed & fertilizer box)*** : Holds the seed/fertilizer; feeds the metering device by gravity.
- ***Metering mechanism*** : The heart of the drill — delivers a ***uniform, controlled quantity*** of seed to each row (fluted roller, cup, plate, etc.; §4).
- ***Seed tube*** : A flexible/telescopic tube conveying metered seed from the metering box to the furrow opener.
- ***Furrow opener*** : Opens the furrow to the set depth (shoe, hoe, disc, shovel; §5).
- ***Covering device*** : Chains, press wheels or a light harrow that close the furrow over the seed.
- ***Ground (drive) wheel & transmission*** — Drives the metering mechanism through gears/chain-sprocket, so the seed rate is ***linked to distance travelled*** and independent of forward speed.
- ***Frame, hitch & seed-rate control*** : Carry the units and set the metering rate (fluted-roller exposed length or gear ratio).

**CONSTRUCTION & WORKING (TRACTOR-DRAWN DRILL)**

The drill is mounted or trailed. As the tractor moves, the ***ground wheel*** turns and, through the transmission, rotates the ***metering shaft***. Each metering unit drops a steady stream of seed (and fertilizer) into its ***seed tube***, which delivers it to the ***furrow opener***; the openers cut parallel furrows at the set row spacing and depth, and the ***covering device*** closes them. Seed rate is set by the metering control and checked by calibration (§6).

**PREVIOUS YEAR QUESTIONS**

- Explain the construction and working of a tractor-drawn seed drill. [IFOS 2023 | P2/2 (b) | 15 M]
- What is seed drill and what are the functions of a seed drill? [AP-PSC RFO 2012| Q.4(c) | 10 M]
- What is a seed drill? Mention the functions of various parts of seed drill. Explain the stepwise procedure for calibration of a seed drill. [UK-PSC RFO 2012| Q.6(iv) | 10 M]

▣ *Fig. 5.1 Tractor-Drawn Seed-Cum-Fertilizer Drill — Labelled*

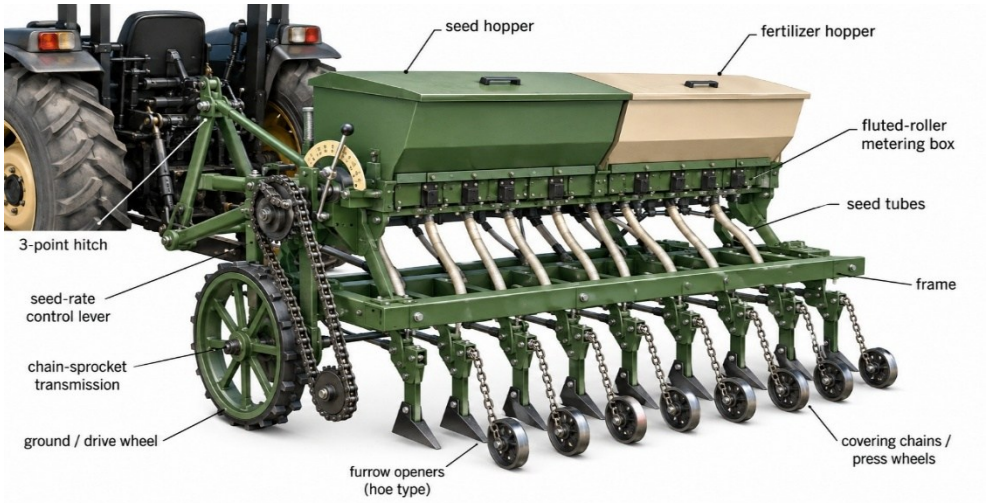



*Fig. 5.1 Principal components of a seed-cum-*

## 4 SEED & FERTILIZER METERING MECHANISMS

The metering mechanism fixes the seed rate and its uniformity. Two broad classes: ***bulk-flow*** metering (a stream of seed, for drilling) and ***precision (single-seed)*** metering (one seed at a time, for planting).

### 4.1 BULK-FLOW (SEED-DRILL) METERING

- ***Fluted roller*** : A grooved (fluted) roller rotates under the hopper; seed fills the flutes and is carried to the seed tube. Rate is varied by ***sliding the roller sideways to change the exposed (working) length*** of the flutes. The commonest metering for cereals — simple, reliable.
- ***Internal double-run*** : A disc with large teeth on one face and small teeth on the other; the appropriate face is presented to the seed for ***large or small seed***. Gives a fairly uniform bulk flow; rate set by the drive gear.
- ***Cup feed*** : cups on a rotating wheel/belt lift a small charge of seed from the hopper and drop it into the tube — common on animal-drawn drills.
- ***Auger / brush / star feed*** : An auger, rotating brush or star wheel pushes seed to the outlet; used for particular seed shapes and for fertilizer.

**HOW THE RATE OF APPLICATION VARIES**

For fluted-roller and cup feeds the rate depends on the ***volume of seed per revolution × revolutions per unit distance***. It is changed by (i) the working length of the fluted roller, (ii) the drive gear ratio (metering-shaft speed per ground-wheel turn), and (iii) the size of cups/flutes. Because the drive is off the ground wheel, the rate is fixed per unit distance and does not change with forward speed.

**WORKING OF THE FLUTED-ROLLER FEED (THE WHEAT-DRILL METERING)**

This is the ***most commonly used seed-drill metering for wheat***. A fluted roller (a shaft with longitudinal grooves) turns in the seed cup below the hopper. Seed fills the ***flutes*** at the top and is carried round and dropped into the seed tube at the bottom; a spring-loaded feed flap keeps a steady flow. The seed rate is changed by sliding the roller ***axially*** to expose more or less of the fluted length — a longer exposed length delivers more seed per revolution. A cut-off plate stops flow to unwanted rows.

**WORKING OF THE INTERNAL DOUBLE-RUN FEED**


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A vertical disc rotates inside the seed cup with ***large notches on one face and small notches on the other***; the operator turns the appropriate face toward the seed for ***bold or small seeds*** respectively. Seed lodged in the notches is carried down and discharged. Rate is set by the drive gear. It handles a range of seed sizes but meters less precisely than the fluted roller.

**FERTILIZER METERING**

Fertilizer is corrosive and free-flowing, so its metering uses ***star wheel, auger, gravity-feed or edge-cell*** devices in a separate hopper, with plastic/stainless parts. In a ***seed-cum-fertilizer drill*** seed and fertilizer are metered by separate mechanisms and delivered to the same furrow, the fertilizer usually placed a little below/beside the seed.

## 4.2 PRECISION (SINGLE-SEED) METERING

- ***Horizontal plate*** : A rotating plate with edge cells, one seed per cell, dropped through a hole — classic maize/groundnut planter metering.
- ***Inclined / vertical plate & vertical rotor*** : Cells on an inclined or vertical disc pick single seeds; gentler on seed, good for precision spacing.
- ***Pneumatic (vacuum / pressure)*** : A vacuum holds one seed on each hole of a rotating disc; released over the furrow. Very accurate, handles many seed sizes — the basis of the ***pneumatic precision planter***.
- ***Finger-pickup & cell-belt*** : Mechanical fingers or a celled belt select single seeds for high-speed precision planting.

**PREVIOUS YEAR QUESTIONS**

- List the different types of seed and fertilizer metering mechanisms used in modern seed-cum-fertilizer drills commonly used in India. How does the rate of application vary using these mechanisms? [IFOS 2016 | P2/3(a) | 10 M]
- What are the different types of seed metering mechanism? Explain the working of fluted roller type and internal double run type metering mechanism. [OPSC-Forest 2019–20 | P2/3(a) | 20 M]
- Classify different types of seed metering mechanisms used in sowing machines. [OPSC-Forest 2015–16 | P2/2(b) | M]
- Explain the working of most commonly used metering mechanism in a seed drill for wheat crop. What is the principle difference between seed drilling and planting? [OPSC-Forest 2023–24 | P2/3(a) | 20 M]

***Fig.5.2 Seed Metering Mechanisms***

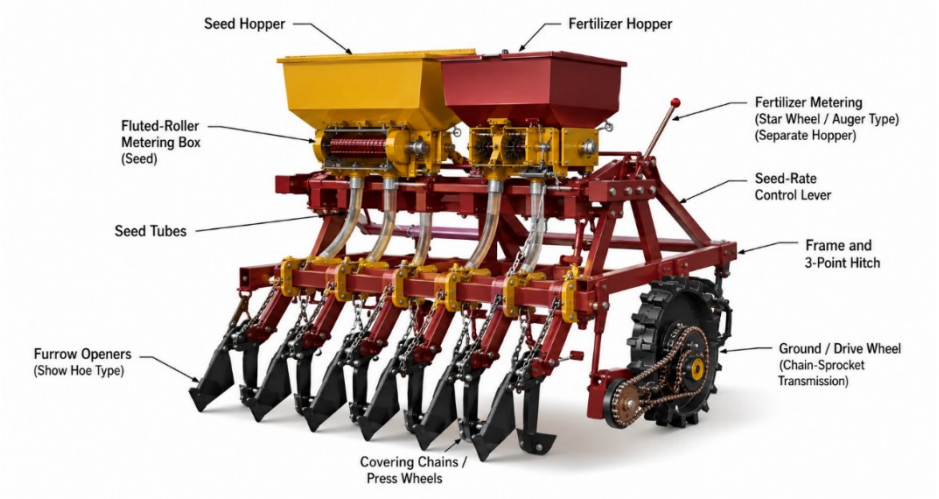



*Fig. 5.2 Common bulk-flow and precision seed-*

## 5 FURROW OPENERS

***Furrow opener :*** *the part that opens a channel in the soil to receive the metered seed at the required depth and guides the seed to the furrow bottom. Its type is chosen for the soil and trash conditions.*

- ***Shovel (reversible/single point)***: A small shovel-shaped opener for ***loose, well-prepared, trash-free soils***; cheap and simple, common on cereal drills; chokes in trashy soil.
- ***Shoe type*** : A pointed shoe that opens a clean furrow in ***well-prepared, stone-free soils***; gives good depth control; not for hard or trashy land.
- ***Hoe type*** : A stronger, hoe-shaped opener for ***hard, dry and rough seedbeds***; penetrates well and is used on rougher fields.
- ***Single-disc*** : A concave disc that cuts through ***trashy, stony or hard soil*** by rolling; less choking, but places seed to one side of the cut.
- ***Double-disc*** : Two discs set in a V open a clean furrow in ***trashy or stubble-mulch conditions*** and drop seed centrally; the standard opener for conservation/zero-till drilling. More expensive.

| Furrow opener | Construction | Suitable soil / condition |
|---|---|---|
| Shovel | Small shovel on a shank | Loose, clean, well-tilled soil |
| Shoe | Pointed hollow shoe | Well-prepared, stone-free soil |
| Hoe | Robust hoe/tyne shape | Hard, dry, rough seedbeds |
| Single-disc | One concave rolling disc | Trashy, stony, hard soil |
| Double-disc | Two discs in a V | Trashy / stubble-mulch / zero-till |

**PREVIOUS YEAR QUESTIONS**

What is the function of furrow opener in a seed drill? Write down the different types of furrow openers, their construction and the soil conditions in which they are suitable. [IFOS 2018 | P2/2(a) | 10 M]

▣ ***Fig. 5.3 Types Of Furrow Openers***

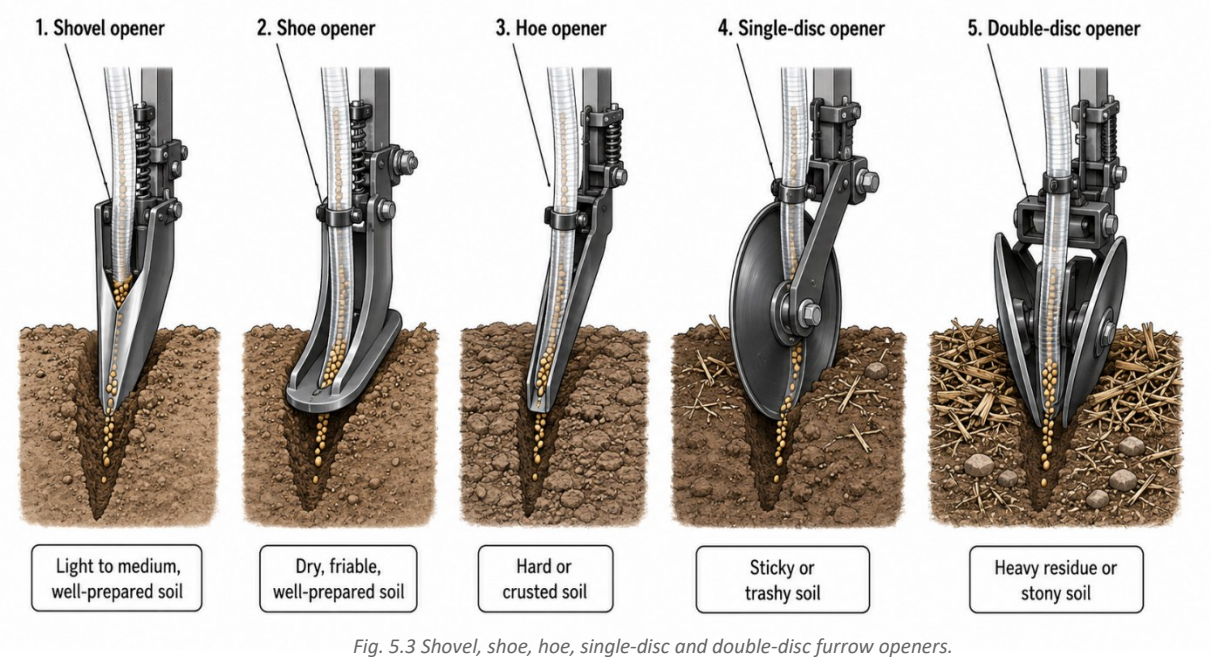



*Fig. 5.3 Shovel, shoe, hoe, single-disc and double-disc furrow openers.*


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## 6 CALIBRATION OF A SEED DRILL

**Seed-drill calibration :** *the procedure of running the drill to check and set it for the correct seed rate (kg/ha) before field sowing, by collecting and weighing the seed delivered while the ground wheel is turned a known number of revolutions.*

**NECESSITY OF CALIBRATION**

- ***Correct seed rate*** : To deliver the recommended kg/ha — too little wastes land, too much wastes seed and crowds the crop.
- ***Uniformity across rows*** : To check every furrow delivers the same quantity.
- ***Adjust for seed & setting*** : Seed size, shape and the metering setting all change the rate, so it must be verified for each seed lot.

**STEPWISE PROCEDURE**

1. ***Find the test length/area*** : Determine the strip length for a convenient fraction of a hectare (say 1/25 ha) from the working width W = M × S (M = number of furrows, S = row spacing).
2. ***Compute wheel revolutions*** : Number of drive-wheel turns N for that length = length ÷ (π × wheel diameter).
3. ***Jack up & mark*** : raise the drill so the ground wheel turns free; mark a reference point on the wheel.
4. ***Fill hoppers & place trays*** : Fill seed (and fertilizer); place a tray/sack under each furrow opener.
5. ***Set the rate control*** : Set the metering (fluted-roller length / gear) to the estimated position and note it.
6. ***Rotate the wheel N times*** : Turn the wheel N revolutions at working speed.
7. ***Weigh the collected seed*** : Weigh the seed from each opener; sum for the total.
8. ***Compute seed rate*** : Scale up to kg/ha (formula below).
9. ***Adjust & repeat*** : If the rate differs from the target, reset the control and repeat until it matches.

Seed rate (kg/ha) = (seed collected in N rev × 10 000) / (area covered in N rev, $m^2$)

*Area covered = W × (π·D·N); W = working width (m) = M×S; D = ground-wheel diameter (m); N = revolutions. Distance per revolution = π·D.*

**PREVIOUS YEAR QUESTIONS**

- What is the necessity of seed drill calibration? Explain the sequential steps followed in seed drill calibration. [IFOS 2020 | P2/3(c) | 15 M]
- What is necessity of seed drill calibration? Explain the sequential steps followed in seed drill calibration. [MH-PSC Forest 2024 | Q.6(a) | 15 M]

### 6.1 CALIBRATION OF PLANTERS & PNEUMATIC DRILLS

- ***Planter (spacing) calibration*** : Jack up and turn the drive wheel a known number of turns; count the seeds dropped by each metering unit; compute the ***seeds per metre of row*** and compare with the target plant spacing; change the plate/cell count or drive gear until correct. Also record the ***percent cell fill*** (= seeds discharged ÷ cells passing the outlet) and misses/doubles.
- ***Pneumatic seed drill calibration*** : As for a normal drill, but first set the ***vacuum/pressure*** so that each disc hole holds exactly one seed (check singulation), then run the wheel N revolutions, collect and weigh, and adjust vacuum and drive to hit the target rate; verify singulation quality (singles/doubles/misses) alongside the weight.

**PREVIOUS YEAR QUESTIONS**

- Explain, in brief, various sowing and planting machines. Also, discuss the calibration of Pneumatic seed drill. [OPSC-CSE 2016–17 | P2/4(a) | 15 M]

## 7 PLANTERS, PRECISION PLANTERS & TRANSPLANTERS

### 7.1 PLANTER VS SEED DRILL

| Basis | Seed drill | Planter |
|---|---|---|
| Placement | Continuous stream in rows | Single seeds at set in-row spacing |
| Spacing control | Row spacing only | Both row and plant spacing |
| Metering | Bulk-flow (fluted roller) | Precision (plate / pneumatic) |
| Seed rate | Higher | Lower (optimum population) |
| Typical crops | Wheat, other cereals | Maize, cotton, groundnut, vegetables |

**PREVIOUS YEAR QUESTIONS**

- Differentiate between a seed drill and a planter. Describe the operation of a planter.
  [UK – PSC RFO 2021 | Q.5(iii) | 10 M]

**OPERATION OF A PLANTER**

A row-crop planter has, per row, a ***seed hopper, a precision metering plate/vacuum disc, a furrow opener, a seed tube and covering/press wheels***. The ground wheel drives the metering discs; each disc drops single seeds at fixed spacing into the opened furrow, which the press wheel then covers and firms. A fertilizer attachment and markers complete it.

### 7.2 PRECISION, PNEUMATIC & ZERO-TILL DRILLS — SALIENT FEATURES

- ***Precision planter***: Single-seed metering → exact spacing, optimum plant population, ***no thinning, minimum seed***, uniform emergence and higher yield.
- ***Pneumatic (vacuum) seed drill*** : Vacuum metering handles ***many seed sizes at high speed*** with gentle, damage-free, highly-uniform singulation; accurate depth; suits precision planting of vegetables and maize.
- ***Zero-till (seed-cum-fertilizer) drill***: Sows directly into ***untilled soil with residue***, using inverted-T or disc openers; saves tillage energy, time, fuel and moisture, cuts cost and enables timely sowing (e.g. wheat after rice). Basis of conservation agriculture.

### 7.3 TRANSPLANTERS

A ***transplanter*** sets nursery-raised seedlings in the field at fixed spacing. Paddy transplanters (manual walk-behind or self-propelled riding type) pick seedlings from a mat/tray with ***planting fingers/forks*** and push them into puddled soil; vegetable transplanters use a rotating finger/cup or a chain-and-cup mechanism. Feed rate of seedlings is set by rows × forward speed ÷ in-row spacing (see N-transplanter numerical, §12).

**PREVIOUS YEAR QUESTIONS**

- What are the advantages and salient features of zero till seed drill and pneumatic seed drill over the conventional seed drill? What are the advantages of precision seed drill / precision planter?
  [OPSC-CSE 2016–17 | P2/1(b) | 20 M]
- What are the advantages and salient features of Pneumatic Seed Drill and Zero Till Seed Cum Fertilizer Drill over the conventional seed drill? [OPSC-CSE 2015–16 | P2/4(a) | 20 M]
- Explain, in brief, various sowing and planting machines. Also, discuss the calibration of Pneumatic seed drill. [OPSC-CSE 2016–17 | P2/4(a) | 15 M]


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### 7.4 POTATO & SUGARCANE PLANTERS

- ***Potato planter*** : Carries seed tubers in a hopper and drops them at fixed spacing into a ridger-opened furrow using a cup/pick or automatic-cup mechanism; covers and re-ridges in one pass. Semi-automatic types need a worker to fill empty cups.
- ***Sugarcane planter***: Opens a deep furrow, drops ***setts (cane pieces)*** end-to-end (sometimes cutting whole cane into setts), applies fertilizer and insecticide, and covers — mechanizing a heavy manual job.

## 8 SPRAYERS — TYPES, CLASSIFICATION & WORKING

***Sprayer*** – *A plant-protection machine that breaks a liquid agro-chemical into droplets and distributes it uniformly over the crop. Its functions: break the liquid into droplets, regulate the dose, and deposit it on the target with minimum drift and waste.*

| Class | Examples | Atomizing energy |
|---|---|---|
| Manually operated | Hand-atomizer, knapsack, rocker, compression, foot/pedal | Hydraulic (hand-pumped pressure) |
| Power operated | Boom/field sprayer, air-blast/mist blower, aircraft | Hydraulic or air-energy |
| Hydraulic-energy | Knapsack, boom, high-pressure sprayers | Liquid pressure through nozzle |
| Air-energy | Mist blower, air-blast, ULV | High-speed air shears the liquid |
| Gaseous-energy | Aerosol/compression | Compressed gas |

### 8.1 CLASSIFICATION

- ***By power source*** : Manually-operated (hand/knapsack/rocker/foot) and power-operated (engine/PTO/tractor-mounted).
- ***By energy used to atomize*** : Hydraulic-energy (liquid forced through a nozzle), ***air-energy*** (air-blast / mist blower shears the liquid), and gaseous-energy (compressed gas).

**MANUALLY-OPERATED SPRAYERS**

- ***Knapsack sprayer*** : A 10–15 L tank carried on the back; a hand lever works a ***pump*** that pressurises the liquid (via an air chamber) and forces it through a lance and nozzle; an agitator stirs the liquid. Simple, cheap, for small holdings.
- ***Rocker sprayer*** : A rocker arm worked by one person builds high pressure in a chamber, letting another spray tall crops/trees at a distance.
- ***Compression (pneumatic) sprayer*** : The whole tank is pre-pressurised by a built-in air pump; liquid then sprays continuously until pressure falls.
- ***Foot / pedal sprayer*** : A foot-operated pump for medium-pressure spraying.

**POWER-OPERATED SPRAYERS**

- ***Hydraulic (field/boom) sprayer*** : A pump forces liquid to a boom carrying many nozzles — high output for field crops.
- ***Air-blast / mist blower***: A high-speed air stream shears low-volume liquid into fine droplets and carries them into orchard canopies — low volume, good penetration.

**PREVIOUS YEAR QUESTIONS**

What are the different types of sprayers used on agricultural farms? Explain the functioning of manually operated knapsack sprayer with suitable diagram. [IFOS 2021 | P2/3(b) | 15 M]

What are the different types of sprayers? Describe the working of Knapsack type sprayer with the help of a neat sketch. [OPSC-FOREST 2025 | P2/2(b) | 20 M]

**BOOM (FIELD) SPRAYER CONSTRUCTION**

A tractor-operated boom sprayer has a ***tank, pump (roller/plunger), pressure regulator with gauge, agitator, and a horizontal boom*** divided into sections carrying equally-spaced nozzles. Liquid is drawn through a suction strainer, pressurised, passed through the regulator (excess returns to the tank for agitation) and distributed along the boom to the nozzles; boom width and nozzle spacing set the swath. Folding booms and section valves ease transport and headland control.

**ROCKER & COMPRESSION SPRAYERS**

- ***Rocker sprayer*** : A rocking lever drives a high-pressure pump feeding an air chamber; one worker pumps while another sprays tall crops/trees — high pressure, long reach.
- ***Compression sprayer*** : The sealed tank is pre-charged with air by a built-in pump; the stored pressure sprays continuously until it falls, then is re-pumped.

**AIR-BLAST / MIST BLOWER**

A high-speed fan produces an air stream that ***shears a lo+w-volume liquid feed into fine droplets*** and carries them deep into orchard/plantation canopies — low volume, excellent penetration and coverage, less water to cart.

**PREVIOUS YEAR QUESTIONS**

Describe the construction of a tractor operated boom sprayer. [OPSC-CSE 2022-23 | P2/15(a) | 10 M]

***Fig. 5.4 Knapsack Sprayer — Labelled***




*Fig. 5.4 Construction of a manually-operated knapsack sprayer.*

## 9 SPRAYER COMPONENTS, PUMPS & NOZZLES

### 9.1 MAIN COMPONENTS

- ***Pump*** : Develops the pressure — plunger/piston, roller, diaphragm or centrifugal (§9.2).
- ***Tank*** : Holds the spray liquid; fitted with a strainer and filler.
- ***Agitator*** : Keeps the mixture uniform — ***mechanical*** (paddle/propeller) or ***hydraulic*** (a bypass jet stirs the tank).


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- ***Pressure regulator & gauge*** : Set and show the working pressure; return excess liquid to the tank.
- ***Nozzle*** : Atomizes the liquid and forms the spray pattern (§9.3).
- ***Boom, hoses & cut-off*** : Distribute liquid to the nozzles and start/stop the spray.

**PREVIOUS YEAR QUESTIONS**

Draw a neat sketch showing the basic components of a tractor mounted hydraulic sprayer having mechanical agitation. Explain the different factors that affect the amount of spray liquid applied per hectare by a field sprayer. [IFoS 2019 | P2/3(a) | 10 M]

▣ *Fig. 5.5 Tractor-Mounted Hydraulic Sprayer (Mechanical Agitation)*

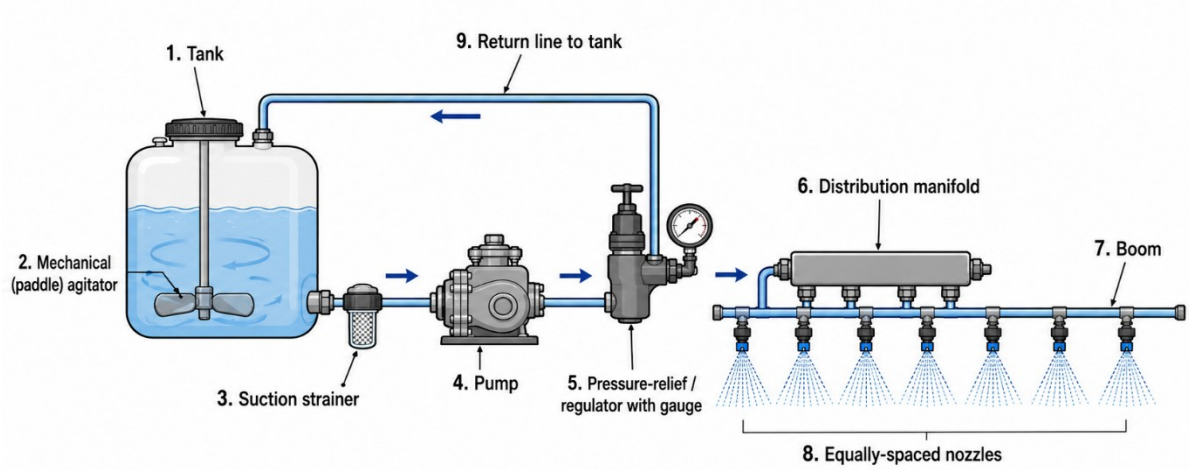



*Fig. 5.5 Basic components of a hydraulic field sprayer with mechanical agitation.*

## 9.2 PUMPS

- ***Plunger / piston pump*** : Positive-displacement; gives ***high pressure*** for hydraulic-energy sprayers; discharge per stroke = plunger area × stroke × number of plungers (see numerical N9, §12).
- ***Roller & gear pumps*** : Moderate pressure, compact; common on tractor boom sprayers.
- ***Diaphragm pump*** : Resists abrasive/corrosive chemicals; medium pressure.
- ***Centrifugal pump*** : High volume, low pressure; follows the ***affinity laws*** ($Q \propto N$, $H \propto N^2$, power $\propto N^3$).

### FUNCTION OF A HYDRAULIC NOZZLE

A nozzle performs three jobs: it ***meters*** the flow (with pressure), ***atomizes*** the liquid into droplets, and ***distributes*** them in a defined pattern for uniform coverage. Discharge rises with pressure as $q \propto \sqrt{P}$ and with orifice area as $q \propto d^2$.

### HYDRAULIC-ENERGY VS AIR-SHEAR NOZZLES

- ***Hydraulic-energy nozzle*** : Liquid pressure alone breaks the sheet — cone, fan and flood types.
- ***Air-shear (air-atomizing) nozzle*** : A fast air stream tears a low-pressure liquid film into very fine droplets — used in mist blowers and controlled-droplet applicators.

## 9.3 NOZZLES & SPRAY PATTERN

***Hydraulic nozzle :*** *the device that converts the pressure energy of the liquid into kinetic energy, breaking it into droplets and forming a defined spray pattern. It fixes discharge, droplet size and pattern.*

| Nozzle | Spray pattern | Typical use |
|---|---|---|
| Hollow cone | Ring/annular cone of fine droplets | Insecticides/fungicides needing good foliage cover |

| | | |
|---|---|---|
| Solid (full) cone | Filled circular cone | Heavier deposits; soil/pre-emergence |
| Flat fan | Flat elliptical (tapered-edge) fan | Boom spraying of herbicides; even swath overlap |
| Flood (impact) | Wide flat fan, large drops | Fertilizer/herbicide, low pressure, low drift |

**PREVIOUS YEA R QUESTIONS**

- What is the function of hydraulic nozzle in plant protection equipment? Enlist different types of hydraulic nozzles and their application. [IFOS 2017 | P2/3(d) | 10 M]
- List the different types of nozzles used for the application of agro-chemicals in manually operated sprayers used in India. How does their spray pattern differ? Write about their specific use in plant protection. [IFOS 2016 | P2/3(b) | 10 M]

▣ ***Fig. 5.6 Nozzle Types & Spray Patterns***

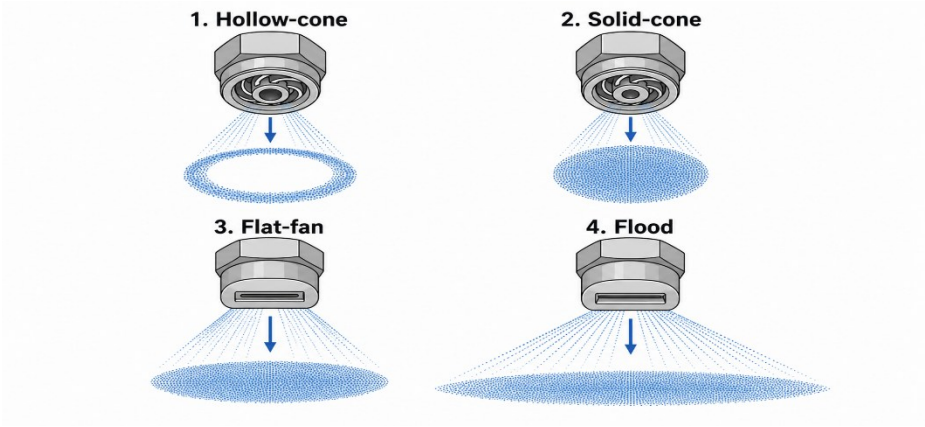



*Fig. 5.6 Hollow-cone, solid-cone, flat-fan and flood nozzles with their*

## 10 ATOMIZATION & DROPLET CHARACTERISTICS; APPLICATION RATE

**Atomization** — *the breaking-up of the spray liquid into a large number of small droplets. In a hydraulic nozzle the pressurised liquid emerges as a thin sheet that becomes unstable and disintegrates into ligaments and then droplets.*

### FLUID PROPERTIES & FACTORS AFFECTING DROPLET SIZE

- ***Surface tension*** : Higher surface tension resists break-up → ***larger droplets***; surfactants lower it and give finer sprays.
- ***Viscosity*** : Higher viscosity resists sheet break-up → larger droplets.
- ***Density*** : Affects sheet velocity and momentum, hence break-up.
- ***Operating pressure*** : Higher pressure → thinner, faster sheet → ***finer droplets*** (VMD ∝ 1/√P roughly), but more drift.
- ***Nozzle size & type*** : Larger orifice → coarser droplets; cone nozzles give finer sprays than flood nozzles.

### MECHANISM OF ATOMIZATION & SPRAY DRIFT

Liquid leaving a nozzle forms a thin ***sheet*** that stretches, becomes wavy and unstable, tears into ligaments, and finally collapses into droplets. Higher pressure and lower surface tension/viscosity make the sheet thinner and give finer droplets. Very fine droplets (small VMD) cover well but ***drift*** on wind and evaporate; coarse droplets resist drift but cover poorly and may run off — so droplet size is chosen for the target (fine for foliage insects/fungi, coarse for soil herbicides).

### DROPLET-SIZE MEASURES


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**DROPLET-SIZE CATEGORIES & WHY SIZE MATTERS**

| Spray quality | Approx. VMD | Use / behaviour |
|---|---|---|
| Very fine / fine | < 150 µm | Best foliage coverage; high drift & evaporation |
| Medium | 150–250 µm | General field spraying — balance of cover & drift |
| Coarse / very coarse | > 250 µm | Soil herbicides; low drift, poorer leaf cover |

Droplet size is a compromise: fine drops cover leaves and reach pests but drift and evaporate; coarse drops resist drift but cover poorly and may run off. VMD and NMD (below) quantify the spectrum.

**VMD (Volume Median Diameter) :** *The droplet diameter that divides the spray volume into two equal halves — half the liquid volume is in droplets smaller, half in larger. Governs coverage and drift.*

**NMD (Number Median Diameter) :** *The diameter that divides the number of droplets into two equal halves. The VMD/NMD ratio indicates spray uniformity — a ratio near 1 means a very uniform spray.*

**PREVIOUS YEAR QUESTIONS**

- What is Atomization? Discuss the main fluid properties that affect droplet size in agricultural spraying. [IFOS 2025 | P2/4(b)(ii) | 7 M]
- Briefly describe: VMD and NMD. [HP-PSC RFO 2021 | Q.5(d)(iii) | 0 M]

**FACTORS AFFECTING SPRAY LIQUID APPLIED PER HECTARE**

The application rate (L/ha) of a field sprayer depends on: ***nozzle discharge*** (nozzle size and working pressure, q = KVP), ***forward speed*** (faster → lower L/ha), ***nozzle spacing / swath width***, and the number of nozzles. These combine as the application-rate formula in §12.

$$\text{Application rate (L/ha)} = (600 \times q) / (v \times s)$$

*q = discharge per nozzle (L/min); v = forward speed (km/h); s = nozzle spacing (m). Equivalently total flow Q = n·q; raising pressure raises q as q ∝ √P; raising speed lowers L/ha.*

## 11 DUSTERS

**Duster :** *a plant-protection machine that applies the chemical in dry powder (dust) form, using an air stream to carry and deposit the dust on the crop. No water is needed.*

- ***Plunger / knapsack duster***: A hand-worked plunger or bellows blows air through a dust hopper; small, for kitchen gardens and small plots.
- ***Rotary (hand) duster***: A hand-cranked fan blows air past a metering device; higher, steadier output than the plunger type.
- ***Power duster***: An engine-driven blower gives a strong air blast for field-scale and orchard dusting.

| Basis | Sprayer | Duster |
|---|---|---|
| Chemical form | Liquid (solution/suspension) | Dry powder (dust) |
| Carrier | Water + pressure/air | Air stream only |
| Deposit & drift | Better adhesion, less drift | More drift, poorer retention |
| Water need / weight | Needs water; heavier | No water; lighter, faster |

| Basis | Knapsack (plunger) duster | Rotary duster |
|---|---|---|
| Air source | Hand plunger/bellows | Hand-cranked fan/blower |

| | | |
|---|---|---|
| Output | Low, pulsating | Higher, steadier |
| Use | Small plots | Larger fields |

**PREVIOUS YEAR QUESTIONS**

- What is the difference between a sprayer and a duster? How a knapsack type duster differs from rotary duster? [OPSC-Forest 2019–20 | P2/3(b) |20 M]

## 12 SOLVED NUMERICALS BANK

◆ **WORKED NUMERICAL — N1 · *Planter rotor diameter & cell pitch*** [IFoS 2022 · P2/2(b) · 15M]

**Problem.** *Calculate the diameter and the peripheral distance between two consecutive cells to get 20 cm seed spacing by a seed planter having a speed ratio between ground wheel and rotor of 4 : 3. Wheel diameter 70 cm, rotor speed for 93 % fill 27 m/min, travel speed 3·2 km/h.*

**Given.** seed spacing = 0·20 m; ground-wheel: rotor speed ratio = 4 : 3; wheel dia $D_w$ = 0·70 m; rotor peripheral speed $v_r$ = 27 m/min; travel speed V = 3·2 km/h = 53·33 m/min.

**Ground-wheel & rotor rpm.**

$N_{gw} = V/(\pi \cdot D_w) = 53{\cdot}33/(\pi \times 0{\cdot}70) = 24{\cdot}25$ rpm;

rotor $N_r = N_{gw} \times 3/4 = 18{\cdot}19$ rpm.

(a) **Rotor diameter.** $v_r = \pi \cdot D_r \cdot N_r$

$D_r = v_r/(\pi \cdot N_r) = 27/(\pi \times 18{\cdot}19) =$ **0·473 m ≈ 47·3 cm.**

(b) **Cell pitch.** seeds per min = V/spacing = 53·33/0·20 = 266·7; cell pitch = $v_r$/(seeds per min) = 27/266·7 = **0·101 m ≈ 10·1 cm.**

**Result. Rotor diameter ≈ 47·3 cm; peripheral distance between cells ≈ 10·1 cm (≈ 15 cells round the rotor).**

**Check.** $\pi \cdot D_r$ = 1·485 m ÷ 0·101 ≈ 14·7 cells — a whole-number-ish result ✓.

◆ **WORKED NUMERICAL — N2 · *Sprayer nozzle flow, pressure & pump power*** [IFoS 2018 · P2/3(c) · 20M]

**Problem.** *A tractor-operated hydraulic sprayer has 13 nozzles at 40 cm spacing. Application rate 800 L/ha, speed 5 km/h. Determine the nozzle flow rate (L/min); also the working pressure and pump power if nozzle diameter = 1·5 mm, coefficient of discharge = 0·35, pump mechanical efficiency = 0·6.*

**Given.** n = 13; spacing s = 0·40 m; application A = 800 L/ha; V = 5 km/h; nozzle d = 1·5 mm; Cd = 0·35; $\eta m$ = 0·6.

(a) **Flow rate.** swath w = 13×0·40 = 5·2 m;

area rate = w×V = 5·2×(5000/60) = 433·3 $m^2$/min = 0·0433 ha/min;

total Q = 800×0·0433 = 34·7 L/min;

per nozzle q = 34·7/13 = **2·67 L/min.**

(b) **Working pressure.** $q = Cd \cdot A_o \cdot \sqrt{(2P/\rho)}$, $A_o = (\pi/4)(1{\cdot}5\times10^{-3})^2 = 1{\cdot}77\times10^{-6}$ $m^2$;

solving gives P ≈ **$2{\cdot}58 \times 10^6$ Pa (≈ 26 bar).**

(c) **Pump power.** $P_{pump} = P \times Q/\eta m = 2{\cdot}58\times10^6 \times 5{\cdot}78\times10^{-4} / 0{\cdot}6 \approx 2{\cdot}49$ kW, with Q = 34·7 L/min = $5{\cdot}78\times10^{-4}$ $m^3$/s.

**Result. Nozzle flow ≈ 2·67 L/min; working pressure ≈ 2·58 MPa (~26 bar); pump power ≈ 2·49 kW.**

**Check.** flow: L/ha × ha/min = L/min ✓; the 1·5 mm nozzle gives a realistic high-pressure-sprayer pressure (~26 bar) and a modest pump power ✓.


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◆ **WORKED NUMERICAL — N3 · *Maize seed spacing from plant population*** [OPSC-CSE 2018–19 · P2/Q.3(c) · 20M]

**Problem.** *Maximum maize yield needs 40 000 plants per hectare. Rows are 100 cm apart and average emergence is 90 %. What should be the seed spacing?*

**Given.** population = 40 000 plants/ha; row spacing R = 1·0 m; emergence = 90 %.

**Plant spacing.** area per plant = 10 000/40 000 = 0·25 m²; along-row plant spacing = 0·25/R = 0·25/1·0 = 0·25 m = 25 cm.

**Seed spacing (emergence-corrected).** more seeds are dropped to offset 10 % failure: seed spacing = plant spacing × emergence = 0·25 × 0·90 = **0·225 m = 22·5 cm.**

**Result. Seed spacing ≈ 22·5 cm.**

**Check.** seed spacing < plant spacing (extra seeds for losses) ✓.

◆ **WORKED NUMERICAL — N4 · *Horizontal throw of seed from a rotor*** [OPSC-CSE 2022–23 · P2/Q.4(a) · 10M]

**Problem.** *A planter's vertical rotor (no ejector, no seed tube) releases seed at its lowest point; the seed falls freely 90 mm to the furrow. Rotor peripheral speed 20 m/min, ground-wheel speed 5 km/h, rotor turning opposite to the wheels. How far does the seed move horizontally between discharge and impact?*

**Given.** fall height h = 0·090 m; rotor peripheral speed v_r = 20 m/min = 0·333 m/s;

planter speed V = 5 km/h = 1·389 m/s; rotor opposite to wheels (so it subtracts from forward speed).

**Fall time.** t = √(2h/g) = √(2×0·090/9·81) = **0·1355 s.**

**Net horizontal velocity.** because the rotor turns opposite to the wheels, at the bottom it throws the seed backward relative to the machine, reducing its ground velocity: v = V − v_r = 1·389 − 0·333 = 1·056 m/s (forward).

**Horizontal distance.** x = v × t = 1·056 × 0·1355 = **0·143 m ≈ 143 mm forward.**

**Result. The seed lands ≈ 143 mm ahead of the discharge point (absolute). Relative to the moving planter it lands ≈ 45 mm behind the rotor.**

**Check.** if v_r equalled V the seed would drop straight down (x = 0) — the classic zero-throw condition ✓.

◆ **WORKED NUMERICAL — N5 · *Transplanter seedling feed rate*** [OPSC-CSE 2016–17 · P2/Q.4(b) · 15M]

**Problem.** *An 8-row automatic transplanter operates at 0·25 m/s. Seedling spacing along the row is 0·25 m and row-to-row 0·75 m. Calculate the feed rate of seedlings into the planter.*

**Given.** rows = 8; V = 0·25 m/s; in-row spacing = 0·25 m (row spacing 0·75 m not needed for feed rate).

**Per-row rate.** seedlings/s per row = V/spacing = 0·25/0·25 = 1·0 /s.

**Total feed rate.** = rows × per-row = 8 × 1·0 = 8 seedlings/s = **480 seedlings/min.**

**Result. Feed rate = 8 seedlings/s (480 per minute).**

**Check.** units (m/s)/(m) = /s ✓.

◆ **WORKED NUMERICAL — N6 · *Bullock seed drill — capacity & seed use*** [OPSC-CSE 2017–18 · P2/Q.4(a) · 20M]

**Problem.** *A 3 × 22 cm bullock-drawn seed drill sows wheat at 3 km/h with a seed-rate setting of 90 kg/ha. (The source question is truncated after the data; the determinate quantities are worked.)*

**Given.** furrows = 3; row spacing = 22 cm → width w = 0·66 m; V = 3 km/h; seed rate = 90 kg/ha.

**Theoretical field capacity.** TFC = w·V/10 = 0·66×3/10 = **0·198 ha/h.**

**Seed consumption.** = seed rate × TFC = 90 × 0·198 = **17·8 kg/h.**

**Flag.** the printed question ends at the data with no explicit 'find' clause; field capacity and seed use are the standard determinate answers — refer to the source paper for the intended sub-parts.

**Check.** ha/h × kg/ha = kg/h ✓.

◆ **WORKED NUMERICAL — N7 · *Seed-drill calibration — seed rate*** [UK-PSC RFO 2015 · Q.5(ii) · 10M]

**Problem.** *Calibration of a seed drill: size 10 × 20 cm, 10 furrows, spacing 20 cm, ground-wheel diameter 1·2 m, 100 revolutions, seed collected 3·5 kg. Calculate the seed rate per hectare.*

**Given.** furrows M = 10; row spacing S = 0·20 m → width w = M×S = 2·0 m; wheel dia D = 1·2 m; N = 100 rev; seed = 3·5 kg.

**Distance & area.** distance = π·D·N = π×1·2×100 = 376·99 m;

area = w×distance = 2·0×376·99 = 754·0 m².

**Seed rate.** = (seed × 10 000)/area = (3·5×10 000)/754·0 = **46·4 kg/ha.**

**Result. Seed rate ≈ 46·4 kg/ha.**

**Check.** kg per m² × 10 000 = kg/ha ✓.

◆ **WORKED NUMERICAL — N8 · *Plunger-pump sprayer — efficiency & torque*** [OPSC-CSE 2020–21 · P2/Q.1(d·ii) · 12M]

**Problem.** *A plunger-barrel PTO sprayer pump must deliver 91·6 L/min at 1500 rpm against 15 MPa. Shaft power to drive it is 27·5 kW. Calculate the pump efficiency and the torque requirement.*

**Given.** Q = 91·6 L/min = 1·527×10⁻³ m³/s; N = 1500 rpm; P = 15 MPa; shaft power = 27·5 kW.

**Hydraulic power.** $P_h = P \times Q = 15 \times 10^6 \times 1{\cdot}527 \times 10^{-3}$

= 22 900 W = 22·9 kW.

**Efficiency.** $\eta = P_h/\text{shaft} = 22{\cdot}9/27{\cdot}5$

= **0·833 = 83·3 %.**

**Torque.** ω = 2πN/60 = 157·1 rad/s; T = shaft/ω = 27 500/157·1 = **175·1 N·m.**

**Result. Pump efficiency ≈ 83·3 %; torque ≈ 175 N·m.**

**Check.** Pa·m³/s = W ✓; η < 1 ✓.

◆ **WORKED NUMERICAL — N9 · *Power sprayer — suction capacity & shaft power*** [OPSC-CSE 2015–16 · P2/Q.2(b) · 20M]

**Problem.** *Find the suction capacity of a power sprayer with plunger diameter 30 mm, speed 1000 rpm, stroke 25 mm, 3 plungers. If the pump efficiency is 90 %, calculate the shaft power at a pressure of 40 kg/cm².*

**Given.** d = 0·030 m; N = 1000 rpm; stroke L = 0·025 m; plungers = 3; η = 0·90; P = 40 kg/cm² = 3·923×10⁶ Pa.

**Suction (theoretical) capacity.** per plunger per rev = (π/4)d²·L = 0·7854×(0·03)²×0·025 = 1·767×10⁻⁵ m³; Q = ×3×1000 = 0·0530 m³/min = **53·0 L/min.**

**Hydraulic power.** $P_h = P \times Q = 3{\cdot}923 \times 10^6 \times (0{\cdot}0530/60) = 3{\cdot}47$ kW.

**Shaft power.** = $P_h/\eta = 3{\cdot}47/0{\cdot}90 =$ **3·85 kW.**

**Result. Suction capacity ≈ 53 L/min; shaft power ≈ 3·85 kW.**


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**Check.** m³/min × 1000 = L/min ✓; shaft > hydraulic ✓.

◆ **WORKED NUMERICAL — N10 · *Air-blast sprayer — number of nozzles*** [OPSC-CSE 2016–17 · P2/Q.3(d) · 15M]

**Problem.** *An air-blast sprayer runs at 3 km/h; desired rate 18 L per tree; tree spacing 9 m × 9 m; each nozzle delivers 5 L/min at 4·0×10 $^{5}$ N/m². If one half-row is sprayed from each side, how many nozzles are needed?*

**Given.** V = 3 km/h = 50 m/min; rate = 18 L/tree; spacing 9×9 m; nozzle q = 5 L/min; half-row each side → effective swath = one row spacing = 9 m.

**Volume per unit area.** area per tree = 9×9 = 81 m²; v

olume rate = 18/81 = 0·2222 L/m².

**Total flow needed.** area rate = swath×V = 9×50 = 450 m²/min;

Q = 0·2222×450 = 100 L/min.

**Number of nozzles.** = Q/q = 100/5 = **20 nozzles.**

**Result. 20 nozzles (10 per side).**

**Check.** L/m² × m²/min = L/min ✓.

◆ **WORKED NUMERICAL — N11 · *Forward speed from a pressure change*** [OPSC-CSE 2022–23 · P2/Q.15(b) · 10M]

**Problem.** *A power sprayer applies insecticide at 1·1 kg/ha; the mix is 0·9 kg insecticide in 90 L water. Each nozzle was rated 0·5 L/min at 2·7 kg/cm²; nozzles are 60 cm apart. Find the forward speed for a pressure setting of 2·1 kg/cm².*

**Given.** dose = 1·1 kg/ha; mix 0·9 kg in 90 L; $q_1$ = 0·5 L/min at $P_1$ = 2·7 kg/cm²; s = 0·60 m; $P_2$ = 2·1 kg/cm².

**Application rate.** to apply 1·1 kg/ha at 0·9 kg per 90 L: A = 90×(1·1/0·9) = 110 L/ha.

**Nozzle flow at 2·1 kg/cm².** $q_2 = q_1\sqrt{(P_2/P_1)}$ = 0·5×√(2·1/2·7) = 0·5×0·882 = 0·441 L/min.

**Forward speed.** A = 600·$q_2$/(V·s) → V = 600·$q_2$/(A·s) = (600×0·441)/(110×0·60) = **4·01 km/h.**

**Result. Forward speed ≈ 4·0 km/h.**

**Check.** lower pressure → lower q → to keep 110 L/ha the sprayer must slow down; 4 km/h is a sensible spraying speed ✓.

## 13 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

### 13.1 CONSOLIDATED FORMULA SHEET

| Quantity | Formula | Notes / units |
|---|---|---|
| Working width | w = M × S | M furrows, S row spacing (m) |
| Distance per wheel rev | = π·D | D = ground-wheel dia (m) |
| Area covered in N rev | = w × π·D·N | m² |
| Seed rate | = seed collected ×10 000 / area(m²) | kg/ha (calibration) |
| Theoretical field capacity | TFC = w·V/10 | w (m), V (km/h) → ha/h |
| Plant spacing (in row) | = (10 000/pop) / R | pop plants/ha, R row spacing (m) |
| Seed spacing | = plant spacing × emergence | corrects for % emergence |
| Planter rotor rpm | N_r = N_gw × ratio | N_gw = V/(π·D_w) |
| Cell pitch | = v_r / (V/spacing) | v_r rotor periph. speed |
| Seed projectile | x = (V − v_r)·√(2h/g) | h = fall height |
| Transplanter feed rate | = rows × V/spacing | seedlings per s |

| | | |
|---|---|---|
| Nozzle discharge | $q = Cd \cdot A \cdot \sqrt{(2P/\rho)} = K\sqrt{P}$ | $q_2/q_1 = \sqrt{(P_2/P_1)}$ |
| Application rate | $A = 600 \cdot q/(V \cdot s)$ | q L/min, V km/h, s m → L/ha |
| Total sprayer flow | $Q = n \cdot q$ | n nozzles |
| Plunger pump capacity | $Q = (\pi/4)d^2 \cdot L \cdot n_pl \cdot N$ | displacement × rpm |
| Hydraulic power | $P_h = P \cdot Q$ | shaft power = $P_h/\eta$ |
| Pump torque | T = shaft power / ω | $\omega = 2\pi N/60$ |

## 13.2 CHAPTER SUMMARY

- ***Sowing methods*** : Broadcasting, drilling, dibbling, hill-dropping, check-row, precision planting, transplanting — increasing spacing precision.
- ***Seed drill*** : Hopper–metering–seed tube–furrow opener–covering–ground-wheel drive; rate linked to distance, not speed.
- ***Metering*** : Bulk-flow (fluted roller, double-run, cup) for drilling; precision (plate, pneumatic) for planting; rate set by working length/gear/cell size.
- ***Furrow openers*** : Shovel/shoe (clean soil), hoe (hard/rough), single/double disc (trashy/zero-till).
- ***Calibration*** : Run the wheel N rev, collect & weigh seed, seed rate = seed×10 000/area; adjust and repeat.
- ***Sprayers*** : Manual (knapsack, rocker, compression) & power (boom, air-blast); pump–tank–agitator–regulator–nozzle; $q = K\sqrt{P}$; $A = 600q/(Vs)$.
- ***Atomization*** : Liquid sheet breaks into droplets; finer with higher pressure, lower surface tension/viscosity; VMD & NMD describe droplet size; VMD/NMD → uniformity.
- ***Dusters*** : Apply dry dust by air; more drift than sprayers; plunger vs rotary vs power.

## 13.2 ONE-PAGE LAST-NIGHT REVISION

- ***Definitions*** : Sowing vs planting; drilling vs hill-dropping vs check-row; seed drill vs planter; furrow-opener types & soils; calibration; atomization; VMD vs NMD; sprayer vs duster.
- ***Numbers*** : Knapsack tank 10–15 L; row spacing wheat ~20–22 cm; fluted-roller rate set by working length; nozzle $q \propto \sqrt{P}$; VMD > NMD; VMD/NMD → 1 means uniform.
- ***Master equations*** : Seed rate = seed×10 000/area; TFC = wV/10; plant spacing = (10 000/pop)/R; $q = K\sqrt{P}$, $q_2/q_1 = \sqrt{(P_2/P_1)}$; $A = 600q/(Vs)$; $Q = nq$; $P_h = PQ$, shaft = $P_h/\eta$; $T = P/\omega$.
- ***Exam reflexes*** : 'Construction & working' → labelled diagram + part-function list + working sequence. 'Differentiate' → table. Numerical → convert km/h→m/min, use $q \propto \sqrt{P}$ for pressure changes, answer to 3 s.f.


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CHAPTER

# 6

# HARVESTING, THRESHING & COMBINE EQUIPMENT

*Reaper · mower · cutter bar · thresher · threshing cylinders · combine harvester · grain losses*

**SYLLABUS :** Harvesting and threshing equipment — reapers, harvesters, threshers, combine harvesters. (UPSC IFoS, Agricultural Engineering, Paper II, Section A — Farm Power & Machinery.) Chapter 6 covers reapers (manual, self-propelled, tractor-mounted/drawn); mowers — reciprocating & rotary, cutter-bar mechanism, alignment & registration; threshers — paddy/multi-crop/mechanical; threshing cylinder/drum types (spike-tooth, rasp-bar, wire-loop, hammer-mill), concave clearance, cleaning unit; axial-flow vs through-flow vs tangential threshers; combine harvester — header, reel, auger, threshing & separation, straw walker, cleaning shoe, grain tank, functions, types and sources of grain loss; balers, windrowers; harvest index; and capacity/throughput numericals.

## Chapter Outline


1. **Scope & Harvesting Terminology**
2. **Cutting Mechanisms & the Reciprocating Cutter Bar**
3. **Mowers — Types, Components; Alignment & Registration**
4. **Reapers & Reaper-Binders**
5. **Threshers — Principle, Cylinder Types, Concave & Cleaning**
6. **Combine Harvester — Functions, Components, Working, Grain Losses**
7. **Balers, Windrowers & Harvest Index**
8. **Comparison of Harvesting Methods & Machines**
9. **Solved Numericals Bank (illustrative, fully worked)**
10. **Formula Sheet · Summary · Last-Night Revision**

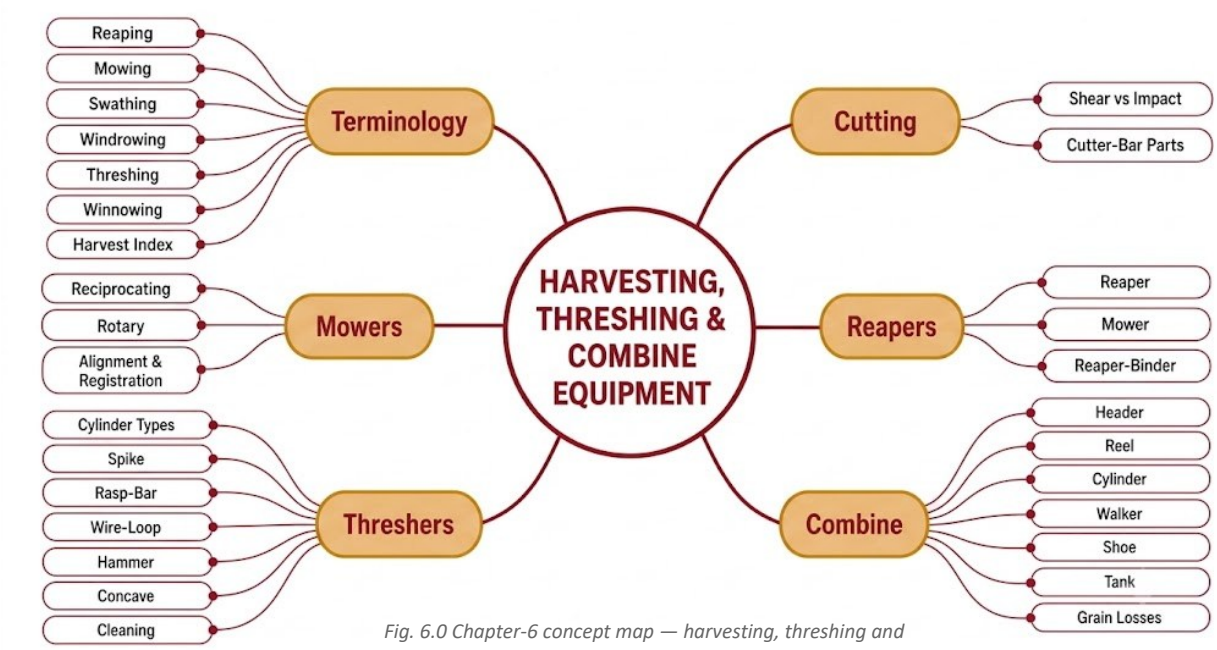



*Fig. 6.0 Chapter-6 concept map — harvesting, threshing and*

▣ ***MIND-MAP — Chapter 6 concept map***

## 1 SCOPE & HARVESTING TERMINOLOGY

Harvesting gathers the mature crop; threshing detaches the grain; cleaning removes the chaff. This chapter covers the machines for each — ***mowers and reapers*** (cutting), ***threshers*** (grain detachment) and the ***combine harvester*** (which does all three in one pass). It is a ***theory-and-description*** chapter — the marks come from parts, working, differences and grain-loss analysis rather than heavy numericals.

### 1.1 KEY TERMINOLOGY

***Reaping*** : *Cutting of grain (cereal) crops at or near ground level.*

***Mowing*** : *Cutting of herbage / fodder / grass and laying it in a swath.*

***Swath & windrow*** : *Swath = the band of cut crop left by one pass of the machine; windrow = several swaths raked together into a continuous row for drying/pickup.*

***Threshing*** : *Detaching the grain from the ear/panicle by impact, rubbing or stripping, usually at 15–17 % grain moisture.*

***Winnowing*** : *Separating the clean grain from chaff and light material using an air blast.*

***Gleaning*** : *Collecting the grain/produce left after the main harvest.*

***Harvest index (HI)*** : *The ratio of economic (grain) yield to total biological yield — a measure of how much dry matter went into grain (see §7 and numerical N1).*

## 2 CUTTING MECHANISMS & THE RECIPROCATING CUTTER BAR

### 2.1 SHEAR-TYPE VS IMPACT-TYPE CUTTING

- ***Shear (scissor) cutting*** : The crop is cut by ***shearing between a moving knife and a fixed ledger plate*** — as in a reciprocating cutter bar. Needs a counter-shear; gives a clean low cut; used for grain and fodder.


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- ***Impact cutting*** : The stalk is cut by the ***momentum of a single fast blade*** with no counter-edge — as in rotary and flail mowers (blade tip 1300–2700 m/min). Simpler, handles tangled/heavy growth; higher power; a rougher cut.

## 2.2 PARTS OF THE RECIPROCATING CUTTER BAR

- ***Knife / sickle*** : The reciprocating blade carrying triangular ***knife sections*** riveted to a knife back; driven by the pitman.
- ***Ledger plate*** : The stationary cutting edge inside each guard against which the knife section shears the crop.
- ***Guard (finger)*** : protects the knife, ***divides the crop*** and holds the ledger plate; guards are spaced at 76·2 mm (3 in).
- ***Wearing plate*** : A hardened backing on the bar on which the knife back slides.
- ***Knife clips (grass guards)*** : Hold the knife down against the ledger plates for a clean shear.
- ***Pitman & crank*** : the connecting rod and crank that convert rotary drive into the knife's reciprocating motion.

The knife ***stroke*** (distance travelled per half-revolution of the crank) is normally made equal to the guard spacing, so each section moves from the centre of one guard to the centre of the next — the basis of ***registration*** (§3.3).

### REGISTER GEOMETRY & KNIFE BALANCING

The crank throw is chosen so the ***knife travel = guard spacing (76·2 mm)***. With the crank at a radius R, the stroke = 2R, so R = 38·1 mm makes each section sweep exactly from one guard centre to the next. This is what puts the mower 'in register'; if the stroke does not match the guard pitch, sections stop off-centre and shear poorly.

$$\text{Knife inertia force } F \propto (W_knife) \cdot R \cdot \omega^2$$

*R = crank radius (m); ω = crank angular speed (rad/s). The reciprocating knife mass must be accelerated and reversed each stroke, so the inertia force rises with the SQUARE of speed — hence a counter-balance weight (R_b·m_b = R·m_reciprocating) is fitted to smooth the drive and limit vibration.*

▣ ***Fig. 6.1 Reciprocating Cutter Bar — Labelled***

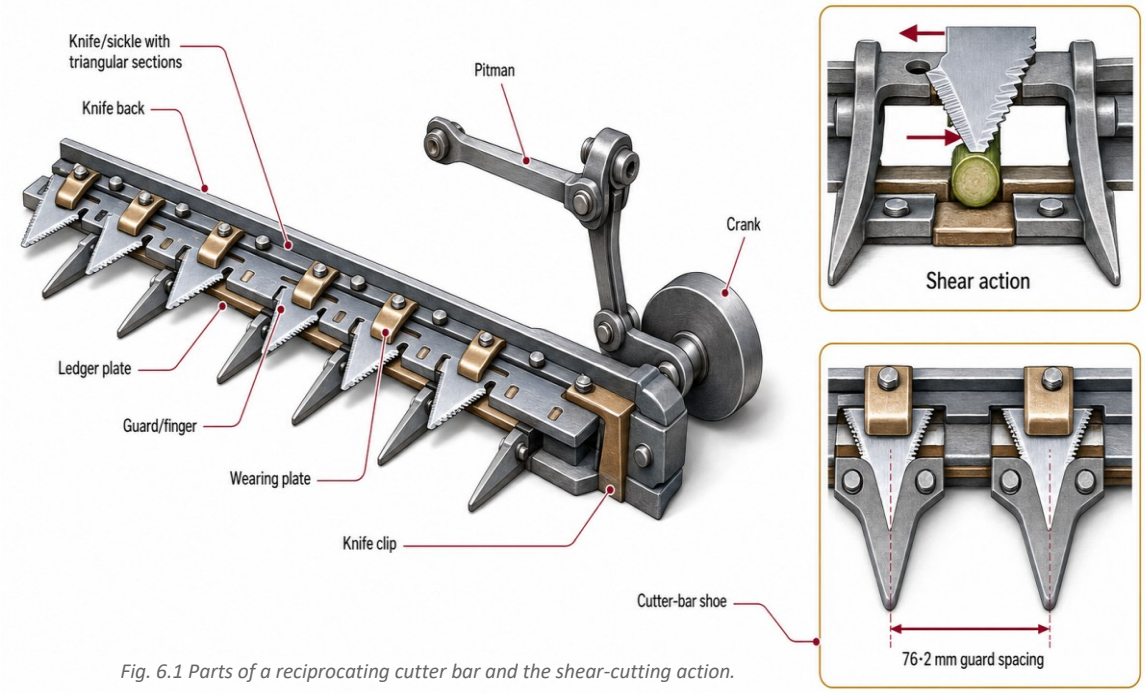



*Fig. 6.1 Parts of a reciprocating cutter bar and the shear-cutting action.*

## 3 MOWERS — TYPES, COMPONENTS; ALIGNMENT & REGISTRATION

**Mower** — *a machine to cut herbage / fodder crops and grasses and lay them in a swath for drying. Its function is clean, low, uniform cutting of standing fodder.*

### 3.1 TYPES OF MOWERS

- ***Reciprocating (cutter-bar) mower*** : A sickle bar shears the crop against ledger plates — the classic fodder mower; low power, clean cut; needs alignment/registration upkeep.
- ***Rotary mower*** : Horizontal-axis or vertical-axis blades cut by ***impact***; handle tall, tangled, heavy growth; higher power, rougher cut.
- ***Disc & drum mower*** : High-speed discs/drums for fast fodder mowing.
- ***Flail mower*** : free-swinging blades on a horizontal rotor; also chop/mulch the herbage.

| Basis | Reciprocating (cutter-bar) mower | Rotary mower |
|---|---|---|
| Cutting action | Shear (knife vs ledger plate) | Impact (single fast blade) |
| Crop | Fodder / grass, lighter growth | Tall, tangled, heavy, woody growth |
| Power need | Low | High |
| Cut quality | Clean, low | Rougher |
| Maintenance | Needs alignment & registration | Simple; blade sharpening/replacement |

### 3.2 COMPONENTS OF A RECIPROCATING MOWER

A conventional reciprocating mower has: ***cutter bar*** (knife, ledger plates, guards, wearing plates, knife clips), ***pitman & crank drive***, ***inner & outer shoes*** (set height of cut and divide crop), grass/divider board, ***drag bar / pull bar***, ***lifting mechanism***, gears/PTO drive and the frame & wheels. The cutter bar hinges so it can lift over obstacles and fold for transport.

**PREVIOUS YEAR QUESTIONS**

- Enlist the different components of conventional reciprocating mower. Explain the effect of improper registration and alignment of cutter bar on its performance. [IFOS 2022 | P2/4(a) | 10 M]
- What is the function of a mower? Write down the different parts of a conventional reciprocating mower. What do you understand by Alignment and Registration of mower? [IFOS 2022 | P2/2(b) | 10 M]

### 3.3 ALIGNMENT & REGISTRATION OF THE CUTTER BAR

**Registration :** *the condition in which the knife section comes to rest exactly at the centre of its guard at each end of the stroke — i.e. the centre of the knife section coincides with the centre of the ledger plate/guard. A mower 'in register' shears cleanly; it is set by moving the whole cutter bar in or out relative to the pitman.*

**Alignment :** *the correct angular setting of the cutter bar relative to the direction of travel. The bar is given a slight inward lead (about 2 cm per metre of bar, i.e. ~88° to the line of travel) so that crop back-thrust brings it square during work and the knife and pitman stay in a straight line.*

**EFFECT OF IMPROPER REGISTRATION**

- ***Poor / clogged cutting*** : If the section stops off-centre, the crop is not sheared fully — it bends, tears and clogs between knife and guard.
- ***Uneven load & vibration*** : The knife strikes the guards unevenly, giving jerky, unbalanced loading and rapid wear.

**EFFECT OF IMPROPER ALIGNMENT**

- ***Choking & missed cut*** : A mis-aligned bar drags the crop instead of cutting; standing crop bunches ahead of the bar.
- ***Pitman/knife strain*** : The knife and pitman no longer run in a straight line, so side loads bend the pitman and over-heat the bearings.

**HOW THEY ARE ADJUSTED**

- ***Registration*** : Shift the cutter bar laterally (in/out) via the drag-bar/lead adjustment until each section centres on its guard at the stroke ends.
- ***Alignment*** : Set the lead by adjusting the drag-bar length/angle so the bar leads inward ~2 cm per metre; check the knife and pitman are in line.

**PREVIOUS YEAR QUESTIONS**

- Explain the terms 'Registration' and 'Alignment' as applied to the cutter bar of a Mower and state how these adjustments are done. [OPSC-CSE 2020–21 | P2/2(b)(i) | 8 M]
- What do you understand by registration of alignment of mower? [AP-PSC RFO 2012 | Q.3(f) | 8 M]

★ **MODEL Q** Define both crisply (registration = knife section centres on the guard each stroke; alignment = ~2 cm/m inward lead), then give the effect of each when wrong (registration → incomplete shear/clogging; alignment → dragging/pitman strain) and the one-line adjustment for each. A small sketch earns the last marks.

***Fig. 6.2 Alignment & Registration Of A Cutter Bar***

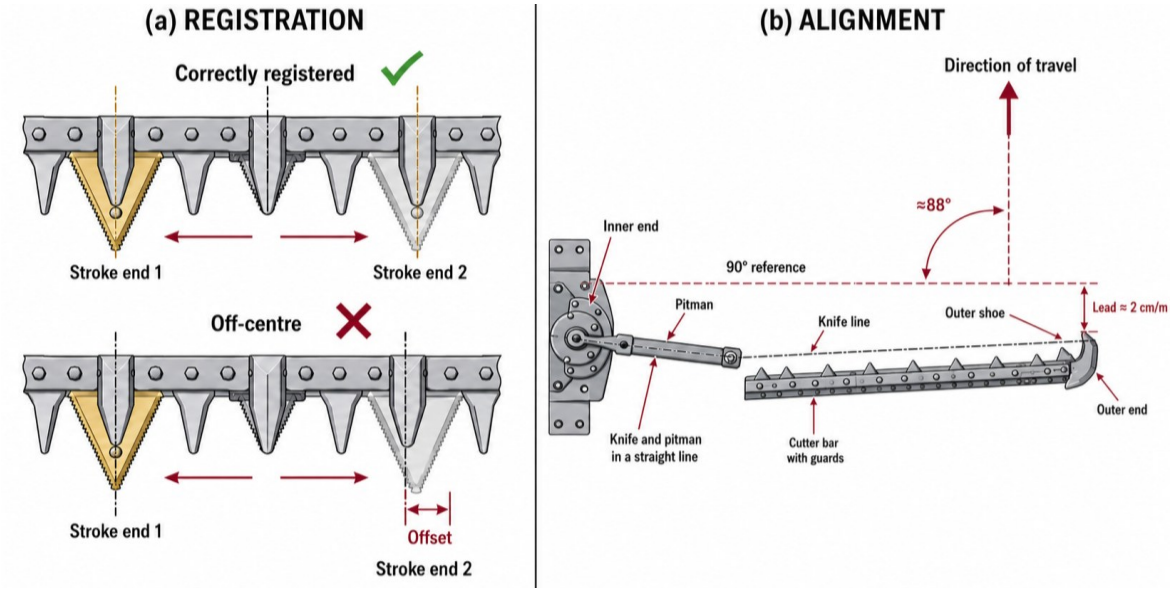



*Fig. 6.2 Correct registration (knife centered on guard) and alignment (2 cm/m lead) of a mower cutter*

## 4 REAPERS & REAPER-BINDERS

***Reaper :*** *a machine that cuts grain (cereal) crops and lays them in a swath or windrow for later collection; it does not bind.*

- ***Types of reaper*** : by power: ***manual/animal-drawn***, ***self-propelled (walk-behind) reaper***, ***tractor-front-mounted / tractor-drawn reaper***, and ***power-tiller-operated vertical-conveyor reaper***. Main parts: cutter bar, star wheels/crop dividers, conveyor belts/lugs that windrow the cut crop to one side.

***Reaper-binder :*** *a reaper that additionally ties the cut crop into uniform bundles (sheaves) with twine in one pass, using a packer and knotter mechanism.*

**WORKING OF A VERTICAL-CONVEYOR REAPER**

Crop dividers split the standing crop into the cutting width; ***star wheels*** hold it against the reciprocating cutter bar; after cutting, ***vertical conveyor belts with lugs*** carry the cut crop sideways and lay it in a neat windrow at one end for manual bundling or pickup. Power-tiller- and tractor-mounted versions differ only in the prime mover and drive.

### 4.1 REAPER VS MOWER VS REAPER-BINDER

| Basis | Mower | Reaper | Reaper-binder |
|---|---|---|---|
| Crop cut | Fodder / grass | Grain (cereal) crop | Grain (cereal) crop |
| Output form | Swath of herbage | Cut crop windrowed | Tied sheaves/bundles |
| Binding | No | No | Yes (twine + knotter) |
| Extra parts | — | Crop dividers, conveyor | + Packer, knotter, needle |
| Use | Fodder harvesting | Grain cutting only | Cut + bundle in one pass |

**PREVIOUS YEAR QUESTIONS**

- Differentiate among 'Reaper', 'Mower' and 'Reaper Binder'. [OPSC-CSE 2020–21 | P2/2(c)(i) | 8 M]

## 5 THRESHERS — PRINCIPLE, CYLINDER TYPES, CONCAVE & CLEANING

### 5.1 PRINCIPLE OF THRESHING

Threshing detaches grain from the ear by a combination of ***impact, rubbing (friction) and stripping*** as the crop passes through the narrowing gap between a rotating ***cylinder (drum)*** and a stationary ***concave***. The cylinder does the detaching; the concave both rubs the crop and lets grain fall through. Different crops need different cylinder actions, hence different cylinder types.

### 5.2 TYPES OF THRESHING CYLINDERS / DRUMS

- ***Spike-tooth (peg-tooth) cylinder***: Pegs on the drum strike and rub the crop against a pegged concave — a strong impact-and-rub action for ***wheat and most cereals***; the commonest Indian multi-crop cylinder.
- ***Rasp-bar cylinder***: Corrugated bars on the drum rub the crop over a grated concave — a gentler rub-and-impact for ***wheat, and cereals where low grain damage matters***; standard on combines.
- ***Wire-loop (loop-type) cylinder***: Loops of wire gently strip the grain — for ***paddy***, which threshes easily and must not crack.
- ***Angle-bar (raspbar variant)***: Angle-iron bars for general threshing of tough-strawed crops.
- ***Hammer-mill (syndicator) cylinder***: Swinging hammers beat the crop — a strong action for ***maize, sorghum and tough crops***; also chops the straw.

| Cylinder type | Action | Best-suited crop |
|---|---|---|
| Spike / peg tooth | Impact + rub | Wheat, multi-crop (general) |
| Rasp bar | Rub + mild impact | Wheat; low grain damage |
| Wire loop | Gentle stripping | Paddy (rice) |
| Angle bar | Rub + impact | Tough-strawed cereals |
| Hammer mill | Strong beating | Maize, sorghum, tough crops |

**PREVIOUS YEAR QUESTIONS**

- What are the different types of threshing cylinders/drums employed on mechanical threshers for different crops? Explain them briefly with the help of sketches. [IFOS 2019 | P2/1(c) | 8 M]
- Write about the principle of threshing for different types of threshing cylinders. [IFOS 2024 | P2/4(c)(ii) | 8 M]

***Fig. 6.3 Threshing cylinder types***

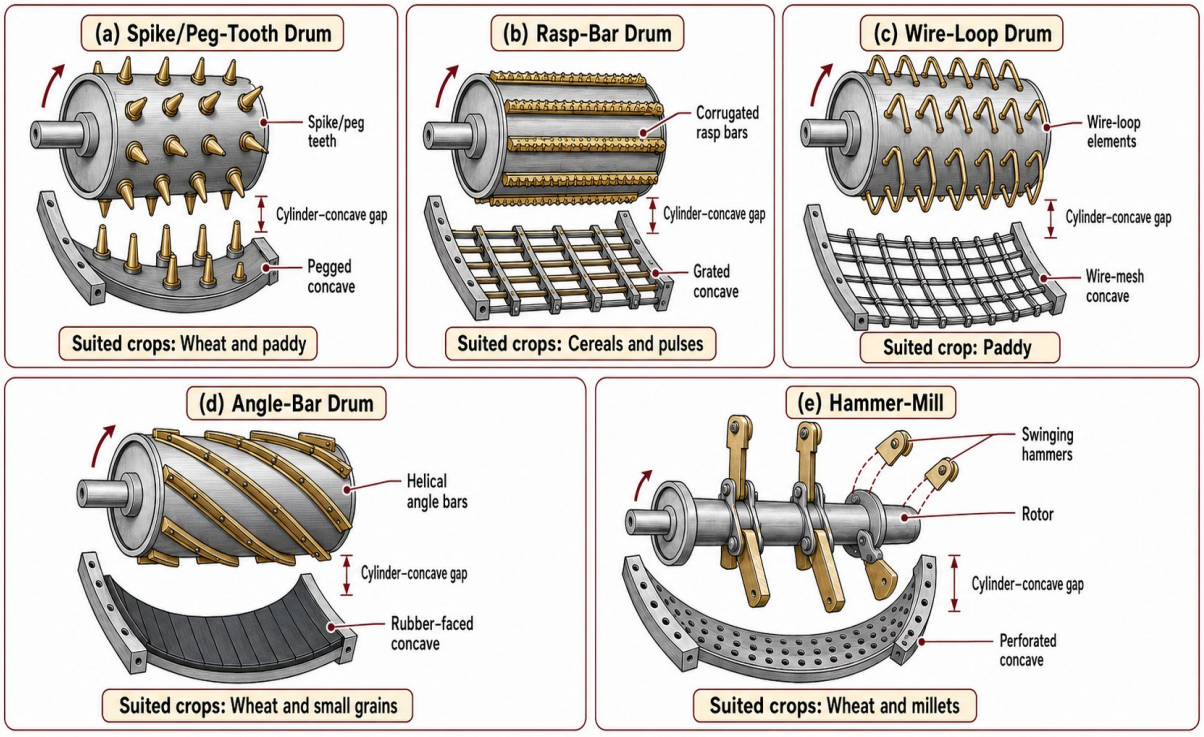



*Fig. 6.3 Spike-tooth, rasp-bar, wire-loop, angle-bar and hammer-mill threshing cylinders.*

## 5.3 CONCAVE, CLEANING UNIT & CLASSIFICATION

- ***Concave & clearance*** : The curved grate under the cylinder; the ***cylinder–concave clearance*** narrows front-to-rear and is set for the crop — too small cracks grain, too large leaves grain unthreshed.
- ***Cleaning / winnowing unit*** : Oscillating ***sieves/screens*** plus an ***aspirator/blower*** separate clean grain from chaff, straw bits and dust; grain falls through, light material is blown out.

### CLASSIFICATION OF THRESHERS

- ***By crop-flow*** : Tangential (through-flow) — crop passes tangentially across the cylinder; ***axial-flow*** — crop spirals along the cylinder axis, giving more rubbing and better separation; ***hammer-mill (throw-in)*** type.
- ***By feeding & mobility*** : Hold-on vs throw-in feeding; stationary/PTO/self-propelled.

### PERFORMANCE TERMS

Key terms: ***threshing efficiency*** (fraction of grain detached), ***cleaning efficiency*** (purity of grain at the outlet), ***grain damage*** (broken grain %), and ***throughput/output capacity*** (kg grain per hour). These are computed in §9 (N2–N4).

### FEEDING & POWER-THRESHER COMPONENTS

- ***Feeding methods*** : Hold-on (crop held and only the ear presented to the cylinder — low grain damage) vs throw-in (whole crop fed through — higher capacity).

- ***Main components*** : Feeding chute/hopper, ***cylinder (drum) & concave***, aspirator/blower, oscillating sieves/screens, straw outlet, grain outlet, and the frame with a power source (electric motor / engine / PTO).

**FACTORS AFFECTING THRESHING PERFORMANCE**

- ***Cylinder speed***: Higher speed threshes more but cracks grain; set to the crop.
- ***Concave clearance***: Narrow clearance threshes hard (risk of damage), wide leaves grain unthreshed.
- ***Feed rate & moisture***: Over-feeding or damp crop lowers threshing and cleaning efficiency.

| Basis | Tangential (through-flow) | Axial-flow |
|---|---|---|
| Crop path | Across the cylinder, once | Spirals along the cylinder axis |
| Rubbing action | Short | Prolonged → better separation |
| Grain damage | Can be higher | Generally gentler for a given output |
| Straw | Longer | More broken |

**PREVIOUS YEAR QUESTIONS**

Discuss the working of power thresher, its classification and important terminology.
[OPSC-CSE 2015–16 | P2/4(a) | 0 M]

## 6 COMBINE HARVESTER — FUNCTIONS, COMPONENTS, WORKING & GRAIN LOSSES

***Combine harvester*** *— a machine that combines reaping, threshing, separating and cleaning in one continuous pass, delivering clean grain to a tank and straw to the field.*

### 6.1 FUNCTIONS

- ***Cut & gather*** : Cut the standing crop and feed it in (header, reel, cutter bar, auger).
- ***Thresh*** : Detach grain from straw (cylinder & concave).
- ***Separate*** : Separate loose grain from straw (straw walker/rack).
- ***Clean*** : Remove chaff from grain (cleaning shoe: sieves + fan).
- ***Collect & discharge*** : Store clean grain (tank/auger) and spread/windrow the straw.

### 6.2 COMPONENTS & WORKING SEQUENCE

Crop flow: the ***reel*** holds the crop against the ***cutter bar***, which cuts it; the header auger and ***feeder conveyor*** carry it to the ***cylinder & concave*** where it is threshed; a ***beater*** throws the straw onto the ***straw walkers*** which shake out the last grain and discharge straw at the rear; grain and chaff fall to the ***cleaning shoe*** (chaffer + sieve + fan) where the fan blows away chaff; clean grain is augered to the ***grain tank*** and unloaded by the ***unloading auger***.

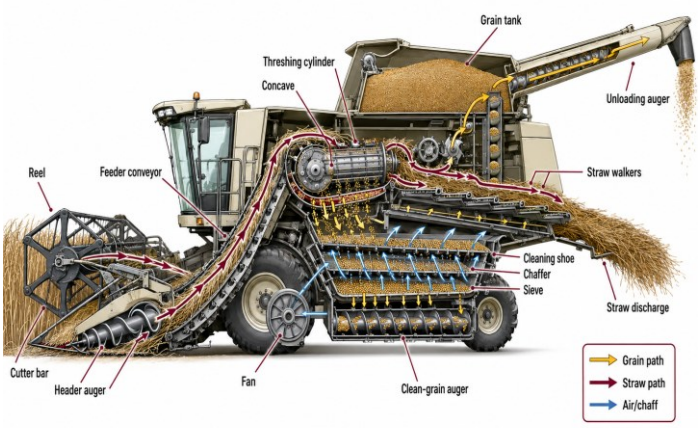



*Fig. 6.4 Functional components and crop-flow path of a combine*

**TYPES OF COMBINE**

- ***Self-propelled combine*** : Has its own engine and drive; high capacity, manoeuvrable.
- ***Tractor-drawn / PTO combine*** : Mounted or trailed, driven by tractor PTO; lower cost, lower capacity.


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**PREVIOUS YEAR QUESTIONS**

- What are the functions of Combine harvester? Discuss the different types and sources of grain losses. [IFOS 2019 | P2/4(c) | 15 M]
- How does a combine harvester simplify the process of harvesting grain crops and what are the key steps involved in its operation, from cutting the crop to storing the harvested grain? [OPSC-CSE 2023–24 | P2/6(b) | 15 M]

## 6.3 COMBINE ADJUSTMENTS & SEPARATION

- ***Cylinder speed & concave clearance*** : Set for the crop — enough to thresh fully without cracking grain.
- ***Fan blast & sieve opening*** : Balanced so chaff blows out but grain is not carried over (shoe loss).
- ***Reel speed & height*** : Reel index (reel speed ÷ forward speed) kept ~1·25–1·5 so the reel gathers without shattering.

Separation over the straw walkers follows an ***exponential decay*** — the fraction of free grain still un-separated falls off along the walker length:

$$R_L = e^{(-b \cdot L)}$$

*R_L = fraction of grain NOT yet separated after walker length L; b = separation coefficient (per m). Longer walkers or lower feed rate → smaller R_L → less walker loss. This is why overloading or high forward speed raises separation loss.*

## 6.4 SOURCES OF GRAIN LOSS

- ***Pre-harvest / shatter loss*** : Grain shed on the ground before or by the reel before cutting — worse in over-ripe crop.
- ***Gathering / header loss*** : Grain lost at the header (shattering by the reel, stalks cut and dropped, ear loss).
- ***Cylinder loss*** : Grain left ***un-threshed on the ear***, or ***cracked/damaged***, at the cylinder — from wrong cylinder speed or concave clearance.
- ***Separation (straw-walker) loss*** : Free grain carried out with the straw over the walkers — from overloading or high speed.
- ***Cleaning (shoe) loss*** : Grain blown over the sieves with the chaff — from too much fan blast or sieve overload.

**REASONS FOR UN-THRESHED GRAIN FROM A COMBINE**

- ***Low cylinder speed*** : Too slow to detach the grain.
- ***Wide concave clearance*** : Gap too large to rub the ears.
- ***Over-feeding / high forward speed*** : Crop passes too fast to thresh fully.
- ***Damp / tough crop*** : High-moisture crop resists threshing.

**PREVIOUS YEAR QUESTIONS**

- What are the main functions of a combine? What are the possible reasons for getting un-threshed materials from the combine? [OPSC-CSE 2020–21 | P2/4(a)(ii) | 15 M]

Total ***processing loss*** (cylinder + walker + shoe) is usually held to about **3 %** of yield; gathering and pre-harvest losses are additional (numerical N6, §9).

# 7 BALERS, WINDROWERS & HARVEST INDEX

## 7.1 BALERS & WINDROWERS

**Windrower (swather) :** *a machine that cuts the crop and lays it in a windrow to dry before pickup by a baler or combine; combines mowing and swathing.*

**Baler :** *a machine that picks up windrowed hay/straw and compresses it into bales (rectangular or round) tied with twine/wire, for easy handling and storage.*

- ***Baler working*** : A ***pickup cylinder*** lifts the windrow, an auger/packer feeds it into a bale chamber where a reciprocating ***plunger*** (rectangular baler) or rollers/belts (round baler) compress it; the ***knotter/tying*** mechanism ties the bale and it is ejected. Bale density depends on chamber restriction and feed rate.

**FORAGE HARVESTER (BRIEF)**

A ***forage harvester*** cuts green fodder and ***chops it into short pieces*** for silage/feeding in one pass, using a flywheel or cylinder cutter head; a blower loads the chopped forage into a trailed wagon. Cut length is set by the number of knives and feed-roll speed.

## 7.1 HARVEST INDEX

**Harvest index (HI) :** *the fraction of the total above-ground dry biomass that is economic yield (grain): HI = economic (grain) yield ÷ total biological yield.*

$$HI = (\text{Economic / grain yield}) / (\text{Total biological yield}) \times 100\ \%$$

*HI (%) relates grain to total dry matter; a related index is the grain-straw ratio = grain mass ÷ straw mass. Higher HI means more assimilate partitioned to grain.*

## 8 COMPARISON OF HARVESTING METHODS & MACHINES

| Method/ machine | Brief description | Advantages | Limitations |
|---|---|---|---|
| Manual (sickle) harvesting | Hand cutting + manual threshing | Low cost, no fuel, selective, low grain loss | Very slow, labour-intensive, weather risk |
| Reaper / reaper-binder | Machine cuts (and binds) grain | Fast cutting, less labour; binder eases handling | Separate threshing needed; upkeep |
| Power thresher | Stationary threshing of cut crop | High threshing capacity, good cleaning | Needs crop carted to it; feeding labour |
| Self-propelled reaper + thresher | Reaper cuts, thresher threshes separately | Flexible, lower cost than combine | Two operations, more handling |
| Combine harvester | Cuts, threshes, cleans in one pass | Very fast, minimum labour & handling, timely | High cost, high grain loss if mis-set, large field needed |

**PREVIOUS YEAR QUESTIONS**

- Compare different harvesting methods/machines indicating brief description, advantages and disadvantages [OPSC-Forest 2015–16 | P2/2(a) | 20 M]
- Combine harvester vs Self-propelled reaper and thresher vs Tractor-drawn front-mounted reaper and thresher — comment with supporting reasons. Discuss the working of power thresher, its classification and important terminology. [OPSC-CSE 2015–16 | P2/4(a) | 20 M]

★ **MODEL Q** For the 'combine vs reaper-thresher' comment: pick by scale — combine for large, timely, labour-scarce operations; reaper + separate thresher for smaller/fragmented holdings and where straw must be saved. Support with cost, grain-loss and handling reasoning.


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## 9 SOLVED NUMERICALS BANK (ILLUSTRATIVE)

The Chapter-6 contains ***no numericals asked in the PYQ*** — the questions are descriptive. The worked examples below are the ***standard capacity/efficiency calculations*** the syllabus lists ('capacity/throughput numericals for threshers and combines'), included for completeness and revision.

◆ **WORKED NUMERICAL — N1 · *Harvest index*** [Illustrative]

**Problem.** *A wheat crop yields 4 t/ha of grain and 6 t/ha of straw. Find the harvest index and the grain-straw ratio.*

**Given.** grain = 4 t/ha; straw = 6 t/ha; total biological yield = 4 + 6 = 10 t/ha.

**Harvest index.** HI = grain/total × 100 = 4/10 × 100 = **40 %.**

**Grain-straw ratio.** = 4/6 = **0·67 (1 : 1·5).**

**Check.** HI < 100 % and grain < total ✓.

◆ **WORKED NUMERICAL — N2 · *Threshing efficiency*** [Illustrative]

**Problem.** *A thresher is fed grain-bearing crop; of the total grain, 1·5 % is found still attached (un-threshed) in the outputs. Find the threshing efficiency.*

**Given.** total grain = 100 %; un-threshed = 1·5 %.

**Formula.** $\text{threshing efficiency} = (\text{total grain} - \text{un-threshed})/\text{total grain} \times 100.$

**Substitution.** = (100 − 1·5)/100 × 100 = **98·5 %.**

**Check.** typical good threshers give 98–99·5 % ✓.

◆ **WORKED NUMERICAL — N3 · *Cleaning efficiency*** [Illustrative]

**Problem.** *At the grain outlet of a thresher, a sample contains 95 g clean grain and 5 g of chaff/foreign matter. Find the cleaning efficiency.*

**Given.** clean grain = 95 g; other material = 5 g.

**Formula.** $\text{cleaning efficiency} = \text{clean grain}/(\text{clean grain} + \text{other}) \times 100.$

**Substitution.** = 95/(95 + 5) × 100 = **95 %.**

**Check.** in the usual 90–99 % band ✓.

◆ **WORKED NUMERICAL — N4 · *Threshing-cylinder speed (pulley drive)*** [Illustrative]

**Problem.** *A thresher cylinder is belt-driven from a 1440 rpm engine through a 200 mm driver pulley to a 100 mm cylinder pulley. Find the cylinder speed and its peripheral speed if the cylinder diameter is 0·6 m.*

**Given.** engine $N_p$ = 1440 rpm; driver $D_p$ = 200 mm; cylinder pulley d = 100 mm; cylinder dia D = 0·6 m.

**Cylinder rpm.** $N_d = N_p \cdot D_p/d$ = 1440×200/100 = **2880 rpm.**

**Peripheral speed.** $v = \pi DN/60$ = π×0·6×2880/60 = **90·5 m/s.**

**Check.** pulley ratio 2:1 doubles speed ✓; peg-tooth cereal cylinders run ~30–90 m/s depending on crop.

◆ **WORKED NUMERICAL — N5 · *Combine field capacity*** [Illustrative]

**Problem.** *A combine with a 3 m header works at 4 km/h with a field efficiency of 70 %. Find the theoretical and effective field capacities and the time to harvest 20 ha.*

**Given.** w = 3 m; V = 4 km/h; ηf = 0·70; area = 20 ha.

**Theoretical FC.** TFC = w·V/10 = 3×4/10 = **1·20 ha/h.**

**Effective FC.** EFC = TFC×ηf = 1·20×0·70 = **0·84 ha/h.**

**Time for 20 ha.** = 20/0·84 = **23·8 h.**

**Check.** EFC < TFC ✓.

◆ **WORKED NUMERICAL — N6 · *Combine total grain loss*** [Illustrative]

**Problem.** *A combine shows losses of 1·2 % (gathering), 0·8 % (cylinder), 1·0 % (straw walker) and 0·5 % (shoe) of the grain yield. Find the total grain loss and the field (harvesting) efficiency.*

**Given.** gathering 1·2 %; cylinder 0·8 %; walker 1·0 %; shoe 0·5 %.

**Total loss.** = 1·2 + 0·8 + 1·0 + 0·5 = **3·5 %.**

**Grain-saving efficiency.** = 100 − 3·5 = **96·5 %.**

**Note.** processing loss (cylinder + walker + shoe = 2·3 %) is within the ~3 % design target; gathering loss is separate.

**Check.** all losses expressed as % of yield ✓.

◆ **WORKED NUMERICAL — N7 · *Thresher output capacity*** [Illustrative]

**Problem.** *A power thresher delivers 350 kg of clean grain in 30 minutes of steady operation. Find its output (grain) capacity in kg/h.*

**Given.** grain output = 350 kg; time = 30 min = 0·5 h.

**Capacity.** = output/time = 350/0·5 = **700 kg/h.**

**Check.** kg ÷ h = kg/h ✓ — typical of a medium multi-crop thresher.

## 10 FORMULA SHEET · SUMMARY · LAST-NIGHT REVISION

### 10.1 CONSOLIDATED FORMULA SHEET

| Quantity | Formula | Notes / units |
|---|---|---|
| Harvest index | HI = grain yield / total biological yield | × 100 % |
| Grain-straw ratio | = grain mass / straw mass | — |
| Threshing efficiency | = (total grain − un-threshed)/total × 100 | % (98–99·5 typical) |
| Cleaning efficiency | = clean grain/(clean grain + other) × 100 | % (90–99) |
| Cylinder speed (pulley) | N_d = N_p · D_p / d | driver→driven pulley |
| Cylinder peripheral speed | v = π·D·N/60 | D drum dia (m), N rpm → m/s |
| Theoretical field capacity | TFC = w·V/10 | w (m), V (km/h) → ha/h |
| Effective field capacity | EFC = TFC · ηf | ηf field efficiency |
| Combine total loss | = gathering + cylinder + walker + shoe | % of yield |
| Straw-walker separation | R_L = e^(−bL) | fraction unseparated over length L |
| Cutter-bar alignment lead | ≈ 2 cm per m of bar | (~88° to travel) |
| Guard spacing / stroke | = 76·2 mm (3 in) | register basis |
| Thresher output capacity | = grain output / time | kg/h |

### 10.2 CHAPTER SUMMARY

- ***Cutting*** : Shear (cutter bar: knife, ledger plate, guard, pitman) vs impact (rotary/flail).


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- ***Mower alignment & registration*** : Registration = knife section centred on guard each stroke; alignment = ~2 cm/m inward lead; wrong settings → clogging, incomplete cut, pitman strain.
- ***Reaper vs mower vs binder*** : Mower = fodder swath; reaper = grain, windrowed; reaper-binder = grain + tied sheaves.
- ***Threshers*** : Cylinder–concave impact + rub; spike-tooth (wheat/multi-crop), rasp-bar (low damage), wire-loop (paddy), hammer-mill (maize); axial-flow vs tangential; cleaning by sieve + fan.
- ***Combine*** : Cut→thresh→separate→clean→collect; header/reel/cylinder/walker/shoe/tank; grain losses = gathering + cylinder + walker + shoe (+ pre-harvest), held near ~3 % processing.
- ***Harvest index*** : Grain ÷ total biomass; grain-straw ratio a related measure.

## 10.3 ONE-PAGE LAST-NIGHT REVISION

- ***Definitions*** : Reaping/mowing/swathing/windrowing/threshing/winnowing; registration & alignment; reaper vs mower vs reaper-binder; threshing cylinder types; combine grain losses; harvest index.
- ***Numbers*** : Guard spacing 76·2 mm; alignment lead 2 cm/m (~88°); threshing eff 98–99·5 %; cleaning eff 90–99 %; combine processing loss ~3 %; grain-straw ratio ~1:1·5.
- ***Master relations*** : HI = grain/total; threshing eff = (total−unthreshed)/total; cleaning eff = clean/(clean+other); $N_d = N_p \cdot D_p/d$; $v = \pi DN/60$; TFC = wV/10.
- ***Exam reflexes*** : Mower Qs → parts list + registration/alignment (define, effect, adjust) + sketch. Thresher Qs → cylinder-type table + crop. Combine Qs → function list + component flow + 5 grain-loss sources. 'Differentiate' → table.

CHAPTER

# 7

# EARTH-MOVING EQUIPMENT & ERGONOMICS

*Bulldozer · Dragline · Grader · Excavator · Post-hole Digger · Ergonomics · Anthropometry · Noise & Vibration*

**SYLLABUS :** Equipment for earth-moving and land development: bulldozer, dragline, motor grader, scraper, excavator, backhoe, loader, post-hole digger, pavement breaker, compactor/roller, laser land leveler. Ergonomic considerations in the design of farm machines for safety and comfort: human factors, anthropometry, the man–machine system, operator comfort, safety design (ROPS, FOPS), tractor seat and cabin design, reach and grip parameters. Operator physiology and work assessment: physiological cost, heart rate, energy expenditure, human efficiency, work–rest cycles. Noise, vibration and thermal environment: sound pressure, decibel scale, tractor noise, whole-body vibration, tractor cabin design. [UPSC IFoS – Agricultural Engineering, Paper II, Section A, Topic 1.]

## Chapter Outline


1. **Scope — the Man–Machine–Environment System**
2. **Earth-Moving & Land-Development Machines**
3. **Ergonomics: Concepts, Anthropometry & the Man–Machine System**
4. **Ergonomic Design of Tractors & Farm Machines**
5. **Operator Physiology & Work Assessment**
6. **Noise, Vibration & Thermal Environment**
7. **Formula Sheet**
8. **Summary**
9. **Last-Night Revision**

### ▣ *Mind-Map — Chapter 7 Concept Map*

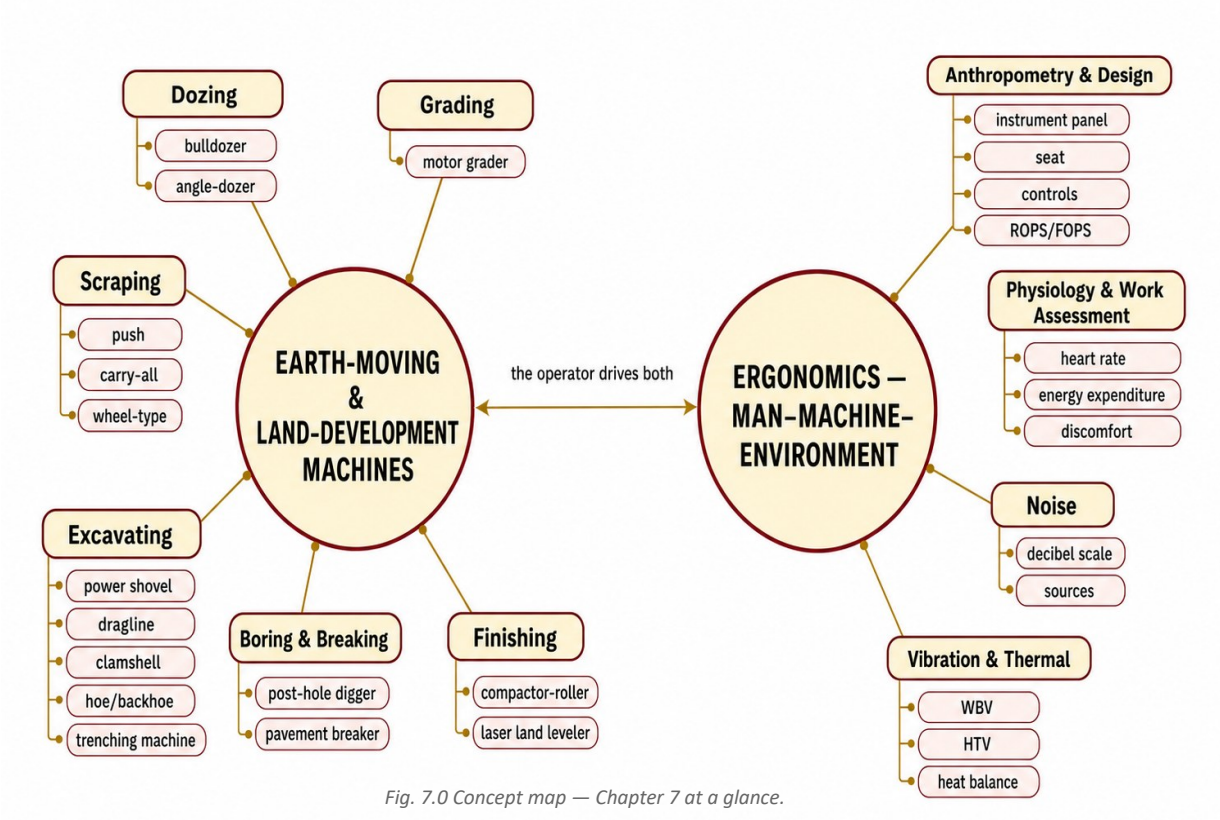



*Fig. 7.0 Concept map — Chapter 7 at a glance.*

## 1 SCOPE — THE MAN–MACHINE–ENVIRONMENT SYSTEM

Earth-moving machines (bulldozers, graders, scrapers, excavating equipment, loaders, levellers) are among the highest-power, highest-vibration and highest-noise machines an agricultural/forestry engineer specifies — and every one of them is driven by a human operator for many hours at a stretch. The syllabus therefore pairs earth-moving equipment with ***ergonomics***: how the machine, the operator and the working environment must be jointly designed so that the work gets done safely, efficiently and without long-term harm to the operator. This chapter covers both halves — the machines (§2) and the human-factors science that shapes their controls, seats, cabins and safety systems (§3–§6).

> **Ergonomics :** (Greek *ergon* = work, *nomos* = laws) is the science of designing equipment, workplaces and systems to fit the physical and cognitive characteristics of the human operator, so as to optimise performance, safety and comfort. It is also called ***Human Factors Engineering*** or Human Engineering. Ergonomics is built around the ***Man–Machine–Environment (M-M-E) System*** — the operator (his physiology, anthropometry, skill), the machine (its controls, displays, seat, cabin) and the working environment (noise, vibration, heat, dust) interacting as one system that determines output, safety and operator well-being.

- ***Goal of ergonomics*** : Not merely to raise output, but to design the workplace to conform to the physiological, psychological and behavioural capabilities of the worker — improving comfort and safety along with performance.
- ***Why it matters for earth-movers*** : Bulldozers, scrapers, graders and excavators impose high whole-body vibration, high noise and awkward working postures for 8–12 h shifts; poor ergonomic design directly reduces effective working time through fatigue.

**MODEL Q** Ergonomics/anthropometry definitions (§1 above) + man–machine system (§3.2) + human-factors application to tractor design (§3.1, §4.1–4.6) together answer every 'define/describe ergonomics'-type question in the PYQ set below — scale the answer to the marks allotted.***

## 2 EARTH-MOVING & LAND-DEVELOPMENT MACHINES

### 2.1 CLASSIFICATION & METHODS OF EARTH-MOVING

Earth-moving is needed for terrace building, filling of gullies/depressions, land smoothening for irrigation or surface drainage, construction of drainage ditches, farm ponds, embankments and irrigation channels. Every earth-moving job involves three basic operations: (i) controlled cutting or loading, (ii) moving, and (iii) spreading or dumping of soil.

- ***By lifting & rolling action*** : Mould-board plough, disc plough (terrace marking).
- ***By throwing action*** : Auger plough / whirlwind terracer.
- ***By pushing action*** : Bulldozers, angle-dozers, V-drags, motor graders, land smoothers (some rolling also occurs).
- ***By carrying action*** : Scoops, carry-all/roll-over scrapers, wheel-type self-loading scrapers.

Machines commonly used for earth-moving are grouped into ***dozing*** (bulldozer), ***grading*** (motor grader), ***scraping*** (towed/self-propelled scrapers), ***excavating*** (power shovel, dragline, clamshell, hoe/backhoe, trenching machine), ***loading*** (earth loader), ***boring & breaking*** (post-hole digger, pavement breaker) and ***finishing*** (compactor/roller, laser land leveler) machines — taken up in turn below.

**PREVIOUS YEAR QUESTIONS**

- Name different machines used for earth moving and land development operations. [IFOS 2024 | P2/3(b)(i) | 5 M]
- Earth moving and development machinery. [OPSC·CSE 2020–21 | Q.4(c)(i) | 5 M]

★ **MODEL Q** List the nine families above with one example each: bulldozer/angle-dozer, motor grader, scraper (push/carry-all/wheel-type), power shovel, dragline, clamshell, hoe (backhoe), trenching machine (wheel/ladder-type), loader, post-hole digger, pavement breaker, compactor/roller, laser land leveler.***

### 2.2 Bulldozer

***Bulldozer :*** a crawler- or wheel-mounted tractor fitted with a heavy, hydraulically controlled blade at the front, used to push earth by direct pushing action (some rolling also occurs). When the blade can be angled to one side it is called an ***angle-dozer***.

- ***Farm uses*** : Land clearing; back-filling of ditches; moving earth over relatively short distances — economical only up to about 50–60 m haul.
- ***Limitation*** : Output falls off sharply as haul distance increases, because the blade-load must be pushed the entire distance with no wheeled carriage.

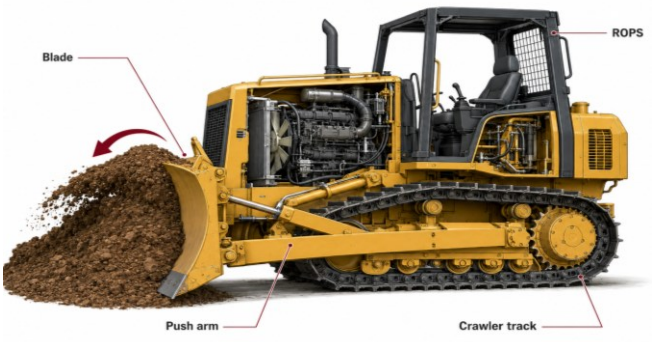



*Fig. 7.1Crawler bulldozer — parts and pushing*

▣ BULLDOZER — PARTS AND PUSHING ACTION


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## 2.3 MOTOR GRADER

**Motor grader** – a self-propelled, rubber-tyred machine (commonly tandem-drive) carrying a long blade slung beneath the frame between the front and rear axles; the blade can be set at any depth and rotated to push earth straight ahead or to either side.

- **Blade adjustment**: Provision for adjustment in all three planes — angle from the line of travel (*'crowding'* when acute), tilt, and cutting depth; adjustable scarifying teeth ahead of the blade loosen hard ground before blading.
- **Speeds** : 3 to 6 forward gears — lower speeds (2 mph range) for grading work, higher speeds (up to ~20 mph) for travel between jobs.
- **Farm/construction use** : Final spreading and levelling of fill (better finish than a bulldozer for this task), road-surface maintenance, land smoothening for irrigation.

### ▣ *Motor Grader – Blade Geometry*

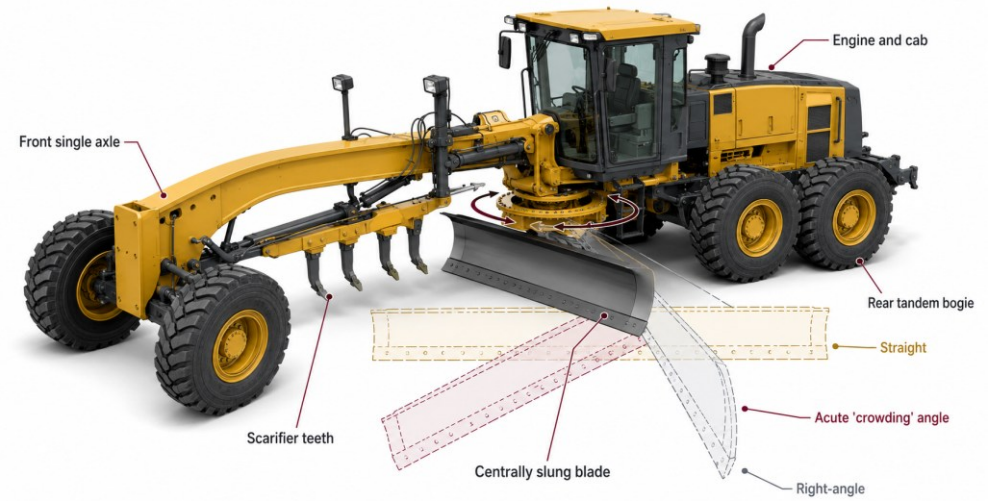



*Fig. 7.2 Motor grader — blade adjustment in plan view.*

## 2.4 SCRAPERS

Scrapers move earth by **carrying** it in a bowl rather than pushing it, so their output falls off far more slowly with haul distance than a bulldozer's.

| Type | Principle | Typical capacity | Remarks |
|---|---|---|---|
| Push-type (bulldozer scraper) | Blade pushes earth; most common earth-mover | — | Front-mounted blade; angle-dozer variant available |
| Trailed blade / land-leveler | Bottomless bowl with skirts; wheel-carried depth control | 1–4 $m^3$, width 2–5 m | Power req. 50–60 hp |
| Drag-type 'carry-all' (roll-over) | Load supported on bowl floor behind cutting edge; bowl tipped back to empty | 0.5–2 $m^3$ | Cheap, efficient for small fields |
| Wheel-type (self-loading) | Digs own load, hauls on wheels, spreads in controlled layers | 1–30 $m^3$ | Loading by blade; used on large projects |
| Long-span land plane | Long frame on wheels/skids with an adjustable levelling blade mid-span; finishing pass | Span 10–27 m, width 2–5 m | For irrigation-field land smoothing |

| Machine | Moves earth by | Economical haul | Typical job |
|---|---|---|---|
| Bulldozer | Pushing | Short — up to 50–60 m | Clearing, back-filling, short shoves |
| Motor grader | Pushing/spreading a thin layer | Medium — spreading & finishing, not bulk haul | Fill-spreading, road/field finishing |
| Scraper | Carrying in a bowl | Long — several hundred metres to a few km | Bulk cut-and-fill, borrow-pit haulage |

The three machines are frequently used ***in sequence*** on the same job: a bulldozer clears/rips, scrapers cut and haul the bulk earth, and a motor grader gives the final finish before compaction (§2.10).

## 2.5 EARTH LOADER

An ***earth (elevating) loader*** is pulled along the cut like a scraper, but its blade throws the loosened earth onto a conveyor belt/chute that discharges directly into trucks or tractor-pulled bottom-dump wagons running alongside — eliminating the bowl-fill/haul/dump cycle of a scraper. It performs best on long, relatively level borrow cuts and can turn in about a 37 m radius (180°). Output is reduced on harder material; borrow cuts should be several hundred feet long to cut down on turning losses.

◆ **WORKED NUMERICAL — *Output & Hourly Cost of an Earth Loader***

**Problem.** *A loader cuts a 4-ft-square section while advancing at 1.5 mph, with an operating factor of 50%. Hauling trucks have a net load of 12 cu yd. Delivered machine cost = $38,000, belt cost = $2,500 (7-yr life, 2,000 hr/yr); investment rate 10%. Find the loader's hourly output and the time to load one 12-cu-yd truck.*

## 2.6 EXCAVATING EQUIPMENT — POWER SHOVEL, DRAGLINE, CLAMSHELL & HOE (BACKHOE)

All four machines below belong to the ***power-crane-and-shovel family***: the same basic crane carrier (mounting, cab, boom) is fitted with a different front-end attachment — dipper, dragline bucket, clamshell bucket, or hoe dipper-stick — to suit the job.

**(a) Power Shovel** : Excavates ***above*** its own track/wheel level and loads directly into trucks, wagons or a conveyor. It can dig any class of earth except solid rock without prior loosening. Mountings: crawler (low speed, low ground pressure, works on soft ground), wheel/rubber-tyred (faster travel, firm ground), or truck-mounted.

- ***Basic parts*** : Mounting, cab, boom, dipper stick, dipper, hoist line — the dipper is lowered to the pit floor, crowded and hoisted up the face to fill; the depth of the face ('depth of cut') must match the dipper size for full loads without over-straining the machine.
- ***Size*** : Expressed by dipper capacity in cu yd, *struck* (even with the dipper lip) rather than *heaped* volume; bank-measure volume is less than loose/struck volume by the soil's swell factor (e.g. a 2-cu-yd dipper struck-full in a 25% swell soil delivers only 2 ÷ 1.25 = 1.6 cu yd bank measure). Commercial sizes run ⅜ to 2¼ cu yd.

**(b) Dragline** : A power-shovel carrier with its boom replaced by a lighter crane boom and the dipper replaced by a ***dragline bucket*** pulled toward the machine by a drag cable, then hoisted and swung to dump. It excavates below grade without the machine entering the pit — a major advantage for ditches, canals or pits containing water, and for depositing spoil directly into levees/dams within one operation (no haul units needed). Excellent for trenches whose sides are allowed to stand at their natural angle of repose.


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- ***Types*** : (i) crawler-mounted — soft ground, slow travel (<1 mph); (ii) wheel-mounted, self-propelled; (iii) truck-mounted — both (ii)/(iii) travel >30 mph; (iv) walking dragline — very large units that 'walk' on shoes for stability on soft ground.
- ***Output*** : About 75–80% of a power shovel of the same bucket size, because the flexible (cable-suspended) bucket digs less precisely than a rigid dipper.

**(c) Clamshell** : A crane carrier fitted with a hinged, self-closing ***clamshell bucket*** — used mainly for vertically lifting loose materials (sand, gravel, crushed stone, coal) and for excavating confined spaces such as cofferdams, pier foundations, manholes and sheet-piled trenches. Buckets come toothed (heavy-duty digging), medium (general purpose) or light (rehandling).

- ***Capacity definitions*** : Water-level capacity (bucket hung level, filled with water); plate-line capacity (to a line along the clam tops); heaped capacity (filled to the natural angle of repose, usually taken as 45°).

**(d) Hoe (Backhoe / Back Shovel / Pull Shovel)** : A power shovel converted by fitting a dipper stick and dipper at the boom end (often with a goose-neck boom for extra digging depth); it digs by pulling the dipper toward the machine, then hoists and swings to dump — the reverse action of a shovel.

- ***Use*** : Excavates ***below*** the ground the machine stands on — trenches, basement pits, precise-depth grading. Because it is rigid (cable-free digging force), it out-performs a dragline for close-range, precise-depth work and dumping straight into trucks, and it out-performs wheel-/ladder-type trenching machines on unshored trenches because it can remove earth as the sides cave in to their natural slope, avoiding the cost of trench shoring.

| Machine | Digs relative to grade | Rigidity | Best suited to |
|---|---|---|---|
| Power shovel | Above grade | Rigid (dipper stick) | High-output loading into trucks |
| Dragline | Below grade, from natural ground | Flexible (cable bucket) | Wet pits, canals/ditches, long-reach spoil disposal |
| Clamshell | Vertical lift, confined spaces | Flexible (cable bucket) | Cofferdams, manholes, rehandling loose material |
| Hoe (backhoe) | Below grade, close range | Rigid (dipper stick) | Precise-depth trenches/pits, unshored trench banks |

### ▣ *Excavating-Equipment Family*

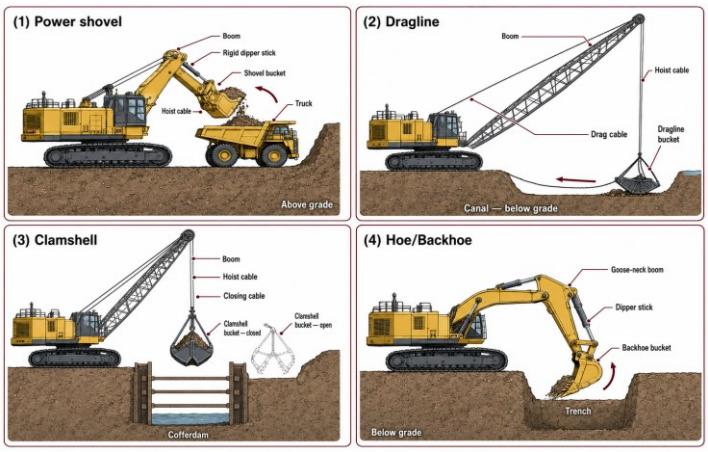



*Fig. 7.3 The power-crane-and-shovel family: shovel, dragline,*

**MODEL Q** OPSC·CSE 2016–17 Q.4(c) (15M) asks for the role of earth-moving machines in land development, with emphasis on the laser land leveler in rice fields — the excavating family above covers the general land-development role; the full PYQ box and laser-leveler answer are at §2.11.***

**FACTORS AFFECTING THE OUTPUT OF EXCAVATING EQUIPMENT**

- ***Depth of cut*** : Output is maximum at an ***optimum depth of cut*** for the soil/dipper combination — too shallow a face cannot fill the dipper without excessive crowding and hoist tension; too deep a face cannot be fully excavated in one pass.
- ***Angle of swing*** : Output falls as the swing angle (dig-to-dump slew) increases, because more of the cycle time is spent swinging rather than digging/dumping — the machine should be positioned to keep the swing angle as small as possible.
- ***Job-management (efficiency) factor*** : Actual output = ideal output × job-efficiency factor, which accounts for operator skill, job layout and management; typical factors are well below 1.0 even under good management, which is why probable/practical output (used in the worked numericals of this chapter) is always quoted, not the theoretical ideal output.

## 2.7 TRENCHING MACHINES

Purpose-built machines for digging utility trenches (water, gas, oil pipelines, telephone cable, drainage) with positive control of depth and width, giving fast digging and minimal hand finishing. They cannot dig rock, and — unlike a hoe — cannot easily remove earth that caves in from unshored banks.

| Type | Mechanism | Depth range | Width range |
|---|---|---|---|
| Wheel-type | Power-driven wheel carrying removable cutter-tooth buckets; spoil thrown onto a conveyor for side-discharge | up to ~8 ft (2.4 m) | 12–60 in (0.3–1.5 m) |
| Ladder-type | Endless chain of buckets on an inclined ladder/boom; extensions add buckets/links for extra depth | up to 30 ft (9 m) with extensions | varies with bucket width |

Both types are usually crawler-mounted for stability and low ground pressure, and are available with a wide range of digging speeds to suit soil conditions.

## 2.8 POST-HOLE DIGGER

Perennial-crop plantation (horticulture/forestry) requires pits at planting; conventional spade/pick-axe pitting is slow, and roots often fail to penetrate the hard-walled conventional pit. A ***tractor-operated post-hole digger*** drills a hole of controlled size and depth mechanically, saving time and giving a safer, more economical planting hole for nurseries, orchards, plantations and fencing/marking-stone erection.

- ***Tractor-PTO type*** : Consists of an auger driven through bevel gears from the tractor PTO, mounted on the 3-point hitch; auger points and leading (cutting) blades are replaceable to suit soil hardness.
- ***Hand-portable (auger) digger*** : A small 2-stroke petrol engine (~1.3 kW) drives an auger of 680 mm length, 60 mm diameter; unit weight only ~8 kg; capacity ≈ 30 pits/h — favoured for hill-region horticulture where tractor access is limited.
- ***Soil counter-sinking attachment*** : Fits on the co-operating auger of the PTO digger: a sleeve carrying three equally-spaced, upward-facing cutting blades on struts, coupled to the digger's propelling shaft. The straight auger first cuts a cylindrical hole; the counter-sinking blades then enlarge it into an ***inverted truncated cone*** — the shape needed for coconut-palm and rubber planting pits. Auger perpendicularity is held by a four-bar linkage formed with the hitch tie-rod; the auger tip is diamond-shaped or pointed with wings for different soils, and hole diameter/depth are changed by swapping the auger assembly.


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▣ *Tractor-operated post-hole digger*

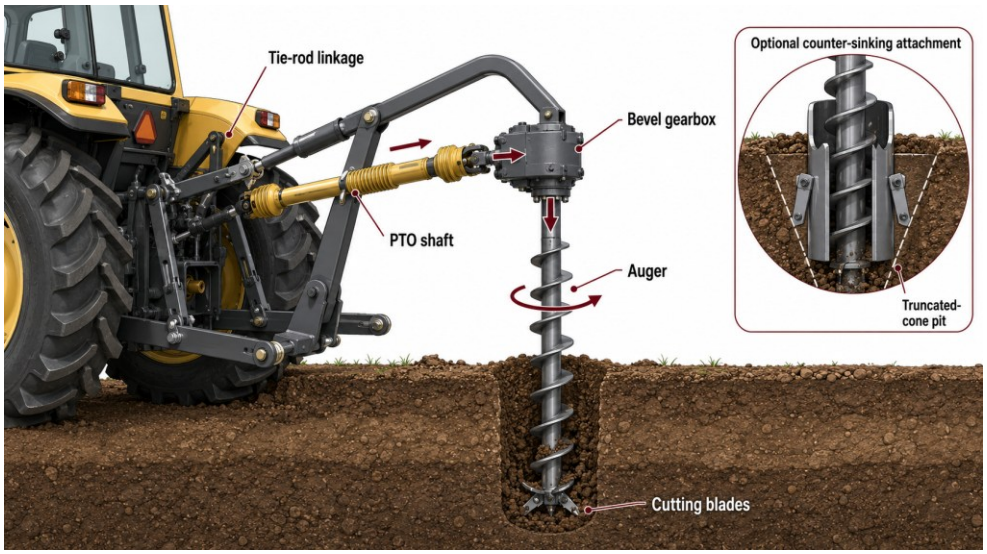



*Fig. 7.4 Tractor-PTO post-hole digger with counter-sinking (conical-pit) attachment.*

**PREVIOUS YEAR QUESTIONS**

Explain the working of a tractor operated post-hole digger for horticultural and forestry plantation.

[IFOS 2024 | P2/3(b)(ii) | 10 M]

★ **MODEL Q** Describe construction (auger, bevel-gear PTO drive, 3-point hitch, replaceable points) then working (auger cuts cylindrical hole; counter-sinking attachment, where fitted, enlarges it to an inverted truncated cone for coconut/rubber-type plantation pits) — both given in full above.

## 2.9 PAVEMENT BREAKER

A ***pavement/rock breaker*** fractures hard pavement, laterite crust, murram or rock in land-development and reclamation work where a bulldozer or ripper tooth cannot penetrate. It works on the same ***percussion (hammer) principle*** as a construction jack-hammer: a piston, driven by compressed air, hydraulic oil, or the tractor's own hydraulic/PTO power, delivers rapid repeated blows to a chisel- or point-shaped tool that concentrates the impact energy and shatters the hard layer. In agricultural use the breaker is usually carried on a tractor's 3-point hitch or a loader/excavator arm and powered from the tractor hydraulics, avoiding a separate air compressor.

- ***Use in land development***: Breaking a hard pan/crust ahead of ploughing or levelling, removing buried rock/boulders, trench-rock breaking where a trenching machine cannot cut.

## 2.10 COMPACTORS & ROLLERS

After a fill is spread (§2.3, §2.4), it must be tamped/compacted to raise its density and strength; if too dry, water is added first to bring the soil to its optimum moisture content for compaction.

| Roller/compactor type | Working principle | Best suited to |
|---|---|---|
| Sheep's-foot roller | Drum studded with projecting 'feet' that knead and compact from the bottom of the lift upward | Cohesive (clayey) soils |
| Grid roller | Open steel-grid/mesh drum; high contact pressure through small grid bars | Rocky or weathered/broken material |

| | | |
|---|---|---|
| Smooth-wheel roller | Plain steel drum; kneads by pressure only, no penetration | Granular soils, finishing pavement/base courses |
| Pneumatic-tyred roller | Multiple closely spaced rubber tyres; kneading + some vibration | Wide range of soils; good for sealing surface |
| Hand-held compactor (pneumatic/petrol) | Small vibrating/tamping plate or rammer | Compaction around obstructions/confined spots that rollers cannot reach |

***Passes required.*** The number of roller passes needed to reach the specified compaction varies with the class of material, layer thickness, moisture content, and roller weight; with a sheep's-foot roller it is typically ***6 to 15 passes per layer***.

▣ ***Compaction rollers***

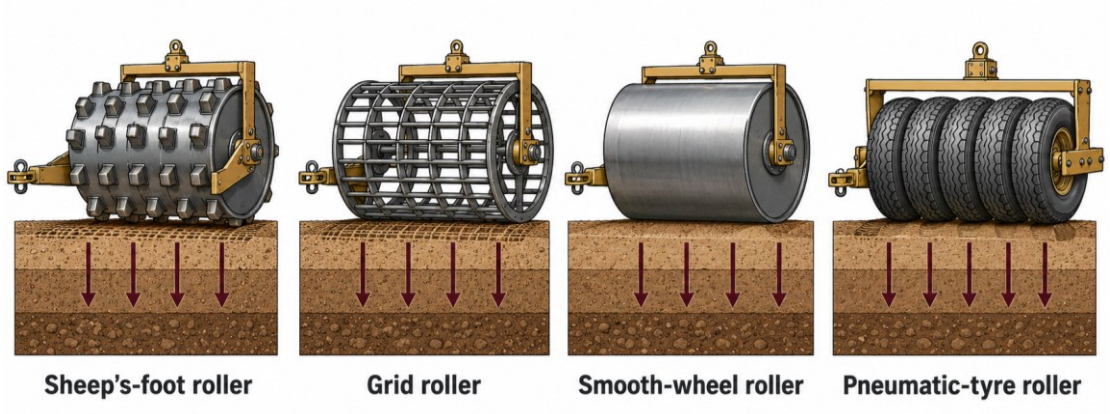



*Fig. 7.5 Sheep's-foot, grid, smooth-wheel and pneumatic-tyred compaction*

**WORKED NUMERICAL — *Grading & Compacting an Earth Fill — Production Balance*** **[Illustrative · after Peurifoy]**

**Problem.** *A dam requires placing 1,000,000 cu yd of sandy clay (2,400 lb/cu-yd bank, swell 25%), average haul 4,200 ft at a 2% favourable grade, sheep's-foot roller needs 12 passes/layer at a compacted layer thickness of 6 in. Excavation is by a Euclid loader (probable output 600 cu yd/hr bank measure) into 15-cu-yd bottom-dump wagons (12 cu yd net load). Estimate the number of hauling units required and the spreading rate of a 100-hp, 12-ft-blade motor grader at 2.0 mph.*

**Given.** Loader output 600 cu yd/hr; wagon net load 12 cu yd; haul 4,200 ft; grader blade 12 ft, speed 2.0 mph, effective width 9 ft, 4 passes/layer.

**Hauling cycle.** loaded @ 22 mph → 4,200/(22×88) = 2.17 min;

empty @ 26 mph → 4,200/(26×88) = 1.84 min; + 2.50 min fixed (load/spread/turn) → total ≈ 6.51 min/round trip

**Trips & units.** 50-min hr → 50/6.51 = 7.68 trips/hr/unit × 12 cu yd = 92 cu yd/hr per unit;

units required = 600 ÷ 92 ≈ 6.5 → use 7 units (plus 1 stand-by).

**Grader spreading rate.** area/hr = speed × 5,280 × width × (passes$^{-1}$) = 2.0 × 5,280 × 9 × (5/6) ≈ 79,300 sq ft/hr, i.e. the grader can keep pace with the ≈600 cu yd/hr delivered by the loader/wagon train.

**Interpretation.** this is the classic earth-moving *balance-the-fleet* calculation — hauling-unit count is fixed by matching wagon cycle time to loader output, and grader/roller capacity is then checked against the same delivered volume so no stage of the operation becomes the bottleneck.


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## 2.11 LASER LAND LEVELER

Traditional levelling (wooden planks drawn by draft animals, or tractor-drawn scrapers) leaves a staggered 4–5% cross-slope and an accuracy of only 10–15 cm — poor for uniform flood/border irrigation. A ***laser-guided land leveler*** achieves 1–2% slope and about ±2 cm accuracy, allowing water to spread evenly over the whole field.

| Component | Function |
|---|---|
| Laser transmitter | Tripod-mounted; rotates to sweep a level (or graded) laser reference plane over the whole field — one transmitter can serve several tractor-mounted units at once |
| Laser receiver ('eye') | Omnidirectional sensor on a mast above the drag bucket; detects whether the bucket is above, on, or below the reference plane |
| Control box (in cab) | Auto/Manual switch + Manual raise/lower switch; in Auto mode it drives the hydraulic valve so the bucket self-corrects to grade |
| Hydraulic system | Draws oil from the tractor's own hydraulics to raise/lower the bucket; a relief valve returns excess oil to the reservoir |
| Drag/scraper bucket | 3-point-linkage mounted; cutting edge set 1–2 cm above ground; scoops soil from high spots and deposits it in low spots as the tractor drives over the field |

- ***Procedure*** : (i) topographic survey on a grid of 15–20 points to fix the average field elevation (macro-levelling target); (ii) set the transmitter to this grade and operate the tractor in continuous circular passes over the field — ***never*** corner-to-corner — cutting highs and filling lows; (iii) a final fine (micro-levelling) pass trims any remaining local deviation. Typical output ≈ 2–3 hr/acre; unit cost ₹2–4 lakh; custom-hire rate ₹600–800/hr.

| Benefit | Typical improvement |
|---|---|
| Irrigation water saving | 25–43% |
| Crop yield (rice / wheat) | +7% / +7–9% (up to 12–15% reported) |
| Water productivity | +16–60% |
| Energy (pumping) saving | ≈ 24% |
| Farmer income | +16–56% |

***History.*** Introduced to South Asia around 2001 (technology transfer from Pakistan via CIMMYT/IRRI, with ICAR-CSSRI Karnal among the collaborating institutes); now widely promoted across the Indo-Gangetic Plain rice–wheat system as a climate-smart, water-saving technology.

- ***Limitations*** : High initial cost (₹2–4 lakh) puts outright ownership beyond small holdings, though custom-hire spreads this; requires a reasonably regular (not steeply undulating) starting field, since very large cut/fill volumes raise cost and may expose infertile sub-soil; laser beam range and line-of-sight are affected by very large fields, tall standing crop residue, or dust/haze; needs a trained operator for the grid survey and control-box setting.

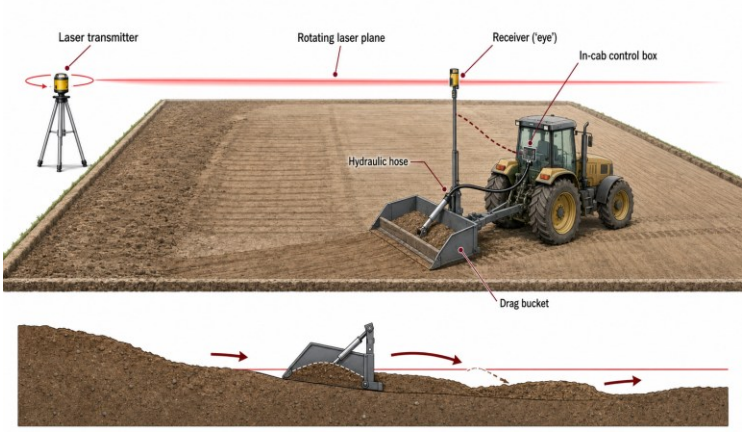



*Fig. 7.6Laser-guided land-levelling system — transmitter, receiver, control box, bucket.*

▣ ***Laser land leveler – system layout***

**PREVIOUS YEAR QUESTIONS**

- Explain the role of earth moving machines in land development works, particularly the use of laser land leveler in rice fields. [OPSC· CSE 2016-17|Q.4(c)| 15 M]

**MODEL Q** For the laser-leveler part: components → procedure (grid survey, circular macro pass, micro pass) → why it matters for rice specifically (precise levelling is essential for uniform flood-irrigation depth and simultaneous crop maturity) → quantified water/yield/income benefits from the table above.***

## 3 ERGONOMICS: CONCEPTS, ANTHROPOMETRY & THE MAN–MACHINE SYSTEM

### 3.1 ERGONOMICS & HUMAN FACTORS IN TRACTOR/MACHINERY DESIGN

Ergonomic aspects matter greatly in agricultural-machinery design because the operator works the machine in the field, often for long hours; physiological *and* psychological fatigue both degrade performance. If ergonomics is neglected, system performance drops and effective working time is reduced. Human factors, properly incorporated, let the operator work with better ***efficiency, comfort and safety***.

- ***Sources of stress on the operator***: Workload, prolonged immobilisation, ambient temperature and humidity, vibration, noise, dust, smoke/gases, fear of accident, information overload, space confinement.
- ***Strain – physiological*** : Heart activity, respiration, muscular fatigue, general discomfort.
- ***Strain – psychological*** : Eye strain, hearing loss, increased errors, reduced speed of work.

***Five design areas*** are where human factors are applied in tractor design: (1) operator–machine interface, (2) instrument-panel/dashboard design, (3) operator exposure to environmental factors, (4) location/arrangement of controls, (5) operator seat — each is developed in §4.

**PREVIOUS YEAR QUESTIONS**

- Define Ergonomics and Anthropometry. Describe in brief about the human factors considered in design of modern tractors. [IFOS 2018|P2/1(c)| 8 M]
- Explain human factors in tractor design. [OPSC·CSE 2020–21|Q.3(b)(ii)|10 M]
- Describe the importance and role of human factors in tractor design. [OPSC·CSE 2017–18|Q.2(b)| 20 M]

**MODEL Q** For the 20-mark question, combine: definitions (§1, §3.1) + operator–machine interface & 5 design areas (§3.1, §4.1) + instrument-panel guidelines (§4.2) + control design (§4.3) + seat/cabin design (§4.4) + ROPS/FOPS (§4.6) — a genuinely comprehensive answer needs all of §3–§4.***

### 3.2 THE MAN–MACHINE–ENVIRONMENT SYSTEM & OPERATOR–MACHINE INTERFACE

In any tractor operation the operator senses information (sight, hearing, touch, smell, heat/cold), the brain interprets it, and the operator then acts through the controls to change the machine's state — a continuous ***sense → decide → act*** loop linking operator and machine. This loop operates through repeated interfaces: riding in/out, maintenance (cleaning/servicing/refuelling), and operating the controls.

- ***Workplace-design factors (operator side)*** : Safety, comfort and convenience; good location/construction of the workplace; visibility without awkward posture; ability to change position; logically located levers/pedals/instruments; fits both tall and short operators; free of sharp edges/obstructions.

**PREVIOUS YEAR QUESTIONS**


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- Discuss the significance of ergonomics in the man-machine system related to tractor operation [OPSC·CSE 2023–24 |Q.11(A)| 15 M]
- Describe, in brief, the ergonomics of man-machine system.[ OPSC·CSE 2020|Q.4(a)(i) | 8 M]
- Write about the importance of ergonomics in farm machinery design. Enlist anthropometric parameters used in design of farm implements. [IFOS 2020 |P2/4(b)(I) | 8 M]

**MODEL Q** Define the M-M-E system (§1) → describe the sense-decide-act loop and the seven workplace-design factors above → close with why it matters (reduced fatigue, fewer errors, higher safety, longer effective working hours). ***

## 3.3 ANTHROPOMETRY & ANTHROPOMETRIC PARAMETERS

***Anthropometry*** – the technology of measuring human physical traits — body dimensions and strength — of workers; ***Engineering Anthropometry*** applies this data to equipment/workplace design to raise the efficiency, safety and comfort of the operator. Data must be considered at the *conception* stage of design, not as an afterthought; a national database of 79 body dimensions and 16 strength parameters of agricultural workers is maintained for this purpose. Because the range of human sizes is continuous, designs are fitted to the ***5th–95th percentile*** of the target population, not to a single 'average' individual.

| Dimension | How measured | Design use |
|---|---|---|
| Stature | Standing surface to top of head, erect posture | General body description, workplace design |
| Vertical (arm) reach | Standing surface to fingertip, arm extended vertically | Workplace layout, control design |
| Eye height (standing) | Standing surface to inner corner of eye | Design of controls/displays |
| Knee height (standing) | Standing surface to mid-knee-cap | Workplace/body-linkage design |
| Arm reach from wall | Wall to fingertip, shoulder against wall, arm forward | Control/display-panel layout |
| Sitting height | Sitting surface to top of head, erect | Control-panel & workplace layout |
| Sitting eye height | Sitting surface to external canthus of eye, erect | Seat & display design, visual field |
| Knee height (sitting) | Footrest surface to musculature above knee, erect | Seat & workplace layout |
| Hand length | Base of hand to middle-fingertip, along hand axis | Handle/control/hand-tool design |
| Span | Tip-to-tip of middle fingers, arms extended laterally | Workplace and control design |

### ▣ *Key Anthropometric Dimensions For Tractor-Operator Design*

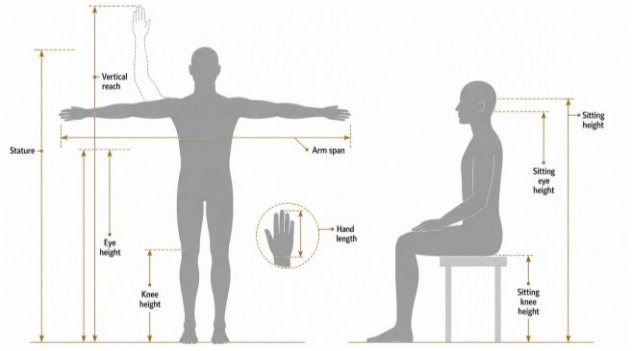



*Fig. 7.7 Anthropometric dimensions used in tractor-workplace*

**MODEL Q** For the 2020 IFoS 'enlist anthropometric parameters' sub-part, list stature, vertical reach, eye height, knee height, arm reach, sitting height, sitting eye height, sitting knee height, hand length, span — from the table above — with one design-use each. ***

## 4 ERGONOMIC DESIGNS OF TRACTORS & FARM MACHINES

### 4.1 OPERATOR–MACHINE INTERFACE — DESIGN GUIDELINES

Human factors are incorporated into tractor design under five heads (§3.1): the operator–machine interface, the instrument panel, exposure to environmental factors, control location, and the operator seat. §4.2–§4.6 develop each in turn; together they form the standard, comprehensive answer to any 'human factors in tractor design' question.

### 4.2 DESIGN OF THE INSTRUMENT PANEL (DASHBOARD)

Good ***visibility*** of displays matters more than the sheer quantity of information shown. The panel must sit close to the operator's normal line of vision, needing minimum eye movement away from the driving task.

1. ***Symmetry***: The panel layout should be as symmetrical as possible.
2. ***Priority cone***: The high-priority instrument zone should fall within a 30° cone of the operator's eye — about 380 mm wide at 700 mm eye distance.
3. ***Functional grouping***: Instruments/controls with similar function are grouped together; grouped instruments should be of similar size.
4. ***Horizontal priority layout*** : Gauges are arranged horizontally in the priority zone by function — e.g. engine gauges to the left, steering column/tachometer/indicator lights at centre, other functional gauges to the right.
5. ***Secondary instruments***: Placed either side of the priority group, keeping their relative position consistent across models.
6. ***Control placement standard***: Priority controls go on the right, positioned so they do not interfere with the steering wheel.
7. ***Horn button***: Always placed to the left of the ignition key switch, so it can be found instantly in an emergency.

**PREVIOUS YEAR QUESTIONS**

- How does considering human factors influence the design process of tractor dashboard instrument panels to enhance usability? Explain. [OPSC·CSE 2023–24 |Q.5(b)| 15 M]

**MODEL Q** Give the seven guidelines above in full, framing each around 'usability' — minimum eye movement, quick recognition by grouping/symmetry, and emergency accessibility (horn button). ***

### 4.3 CONTROL DESIGN & LOCATION

A ***control*** is the hardware link that converts the operator's action into a change of machine state. Two families are used on a tractor: ***hand controls*** and ***foot controls***.

- ***Hand controls*** : Precise and fast; usable even without looking (e.g. gear lever); preferred over foot controls where positioning accuracy matters and where a continuous or prolonged force of ≥ 89 N is required. Seated operation is more accurate than standing.


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- ***Optimum hand-control zone*** : About 600 mm wide, 300 mm either side of the operator's midline, referenced to the seat reference point (which itself should be adjustable ≥ 75 mm horizontally, ≥ 125 mm vertically); upper arm at ~50° to the body line, forearm at ~165° to the upper arm, elbow not required to move more than ~20° sideways from the body.
- ***Grouping rule*** : Accurate-manipulation controls (throttle, gear shift, hydraulics) go on the operator's right; controls needing only visibility, not accuracy (PTO clutch, differential lock, parking brake), go on the left; knob shapes should differ to prevent mix-ups, with 25–50 mm clearance between visible-use knobs and 125–175 mm between blind-use knobs.
- ***Foot controls*** : Used in the seated position with a backrest; right leg preferred for critical tasks; a maximum of about 4 foot controls can be handled without special skill; best suited to continuous tasks needing powerful, sustained force rather than fine positioning.

## 4.4 OPERATOR SEAT & CABIN DESIGN

The seat is the single component most closely tied to operator comfort: it must give a comfortable, controlled seated posture, adequate task vision, ease of reaching all hand/foot controls, and must absorb/reduce the shocks and vibration transmitted from the chassis — while fitting the 5th–95th percentile of operators.

| Design item | Governing rule / dimension |
|---|---|
| Seat height adjustment | ≥ 100 mm vertical travel to span small→large operators |
| Fore–aft adjustment | ≥ 150 mm travel |
| Seat width & depth | Sized for the 95th-percentile operator |
| Cushion pressure (ischial tuberosities) | ≤ 90 g/cm² — bony ischial tuberosities should carry most of the body weight, transmitted through a flat, firm central cushion |
| Cushion pressure (thighs) | ≤ 30 g/cm² — avoids nerve-pinching under the thighs |
| Seat-cushion angle | 5°–7° up from horizontal at the front |
| Back-cushion (lumbar) angle | 110°–115° between backrest and seat |
| Back-cushion width/height | ≤ 330 mm — allows free swing of shoulders/arms |
| Armrests | Provided for shoulder support; adjustable vertically |
| Leg-to-thigh angle (pedal use) | 110°–120°, minimum foot-to-leg angle 90° |

Discomfort beyond about 2–4 hours of sitting results if the cushion does not match this physiology, because the ischial tuberosities are meant to carry load directly and uniformly from the spine.

**▣ *Optimum Tractor-Seat Geometry***

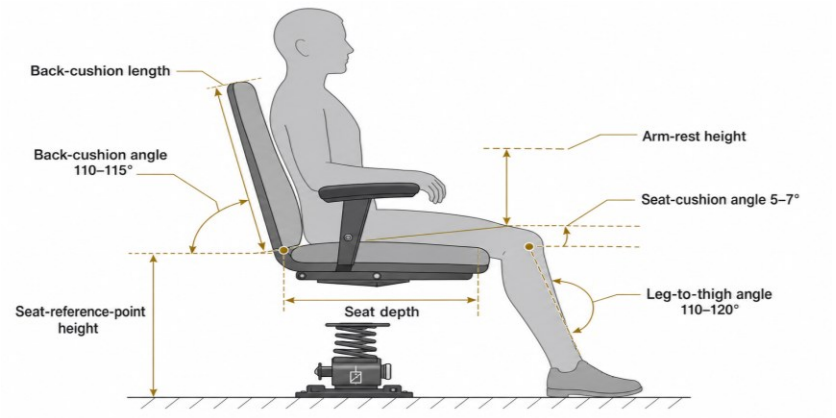



*Fig. 7.8 Optimum tractor-seat design geometry (after*

### 4.5 WHEEL BASE, WHEEL TRACK & THE SOIL-TRACTION EQUATION

**Wheel base (X) :** the longitudinal distance between the centre-lines of the front and rear axles, taken from the manufacturer's specification or measured directly; it governs static weight distribution — for a common rear-wheel-drive tractor the front axle typically carries about 30% of static weight.

**Wheel track :** the lateral distance between the centre-lines of the two wheels on the same axle.

$$F = A \cdot c + W \tan \varphi$$

*A = tyre–soil contact area; c = soil cohesion/adhesion; W = normal load (weight) on the wheel; φ = angle of internal friction of the soil. The first term (A·c) is the cohesive component of tractive resistance/thrust; the second (W tan φ) is the frictional component proportional to normal load — the same Coulomb shear form used for soil-metal friction in traction mechanics.*

**PREVIOUS YEAR QUESTIONS**

- Define wheel base and wheel track. Explain the terms used in the empirical equation F = Ac + W tan ϕ, related to tire performance. [IFOS 2020 |P2/4(b)(ii) | 7 M]

**MODEL Q** Define both terms as above, then explain each symbol of F = A·c + W tanϕ — this is the Coulomb-type shear equation giving the maximum tractive force a tyre/track can develop, split into a cohesive term (A·c) and a frictional term (W tanϕ). ***

### 4.6 SAFETY DESIGN — ROPS & FOPS

**FOPS (Falling-Object Protective Structure) :** a reinforced canopy/frame fitted over the operator station to protect against injury from falling material or debris — used together with ROPS on machines such as loaders, forestry and earth-moving tractors where overhead hazards are significant.

- ***Other mandated safety items*** : The Slow-Moving-Vehicle Emblem (SMVE) — a fluorescent orange the tractor/trailer.
- ***Testing standards*** : ROPS/FOPS structures are qualified by static or dynamic load/energy-absorption tests to codes such as IS 4931, OECD Code 4/6/7 and SAE J1194/J231 before a tractor model is certified — the structure must absorb the specified energy without intruding into the operator's protective zone.

## 5 OPERATOR PHYSIOLOGY & WORK ASSESSMENT

### 5.1 PHYSIOLOGICAL COST OF WORK — THE HEART-RATE METHOD

Ergonomic field studies need trial ***subjects*** (real user population, selected by gender/age/weight, medically fit) so that individual variation can be separated from the workload being measured. Physical activity stimulates physiological responses that are measured mainly through heart and respiration activity.

**Heart rate (HR) :** the most reliable *dependent* parameter in ergonomic studies, because HR rises linearly with workload/stress. A 2–3 minute settling period is allowed for HR to stabilise; the operator must never be pushed beyond HRmax.

$$HRmax = 220 - age\ (years)$$

*empirical upper limit of heart rate permissible during an activity.*

### 5.2 ENERGY EXPENDITURE — THE RESPIRATION/OXYGEN-CONSUMPTION METHOD

Respiration rate is the other basic work-physiology variable, linearly related to workload; it is measured as the rate of air inhaled/exhaled or as oxygen intake ($VO_2$) — the harder the muscular activity, the more oxygen is consumed. ***Human energy expenditure = oxygen consumption × calorific value of oxygen.*** Workload is graded from light to extremely heavy on this basis:


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| Work category | $O_2$ consumption (l/min) | Heart rate (beats/min) |
|---|---|---|
| Light work | < 0.5 | up to 90 |
| Moderate work | 0.5 – 1.0 | 90 – 110 |
| Heavy work | 1.0 – 1.5 | 110 – 130 |
| Very heavy work | 1.5 – 2.0 | 130 – 150 |
| Extremely heavy work | > 2.0 | 150 – 170 |

***Human efficiency:*** the ratio of useful mechanical work output by the operator to the total physiological energy he expends to produce it — a measure of how much of the expended energy is converted to productive output rather than lost as fatigue/heat.

- ***Work-postures and body angles*** : In seated tractor operation the key joint angles are: leg-to-thigh 110°–120° for pedal use, forearm-to-upper-arm ≈165°, upper-arm-to-body ≈50°; field/manual workers additionally adopt bending, stooping, squatting and overhead-reach postures whose discomfort is separately scored (§5.3) — the combination of joint angle, task duration and load determines overall musculoskeletal stress.

### 5.3 DISCOMFORT RATING & BODY POSTURE

Awkward working posture is the principal risk factor for musculoskeletal injury in occupational activity, reducing work efficiency, capacity and safety. Discomfort is scored on the ***Overall Discomfort Rate (ODR)*** scale

| ODR score | Subjective feeling | ODR score | Subjective feeling |
|---|---|---|---|
| 0 | Comfortable | 4 | Moderately painful |
| 1 | Uncomfortable | 5–6 | Highly painful |
| 2 | Pain starts | 7–9 | Very highly painful |
| 3 | Slightly painful | 10 | Extremely painful |

***Psychological strain*** is assessed separately where the task demands vigilance/information overload — measured via blink rate, flicker-fusion threshold, hearing threshold shift, and speed/error rate of work.

**PREVIOUS YEAR QUESTIONS**

What is the significance of ergonomics in farm machine design? Define human efficiency. Describe the methods to assess human energy consumption of a farm worker. What are various angles the agriculture worker has to work? [IFOS 2017 | P2/4(c) | 10 M]

**MODEL Q** Significance → §3.1/§3.2; human efficiency → definition above; methods to assess energy consumption → heart-rate method (§5.1) and oxygen-consumption method with the work-category table (§5.2); working angles → leg-thigh 110–120°, forearm-upper-arm 165°, upper-arm-body 50°, plus the ODR-scored postures of §5.3. ***

## 6 NOISE, VIBRATION & THERMAL ENVIRONMENT

### 6.1 NOISE — THE DECIBEL SCALE & SOUND PRESSURE LEVEL

***Noise*** is unwanted/wasted acoustic energy — mechanical vibration transmitted through a gaseous, fluid or solid medium, characterised by frequency, amplitude and phase. The human ear responds to sound pressures spanning about six to seven orders of magnitude (from the ~$2\times10^{-5}$ N/m² threshold of hearing up to >20 N/m²

at the threshold of pain) — a linear scale over this range would be unwieldy, and the ear's own loudness perception is itself roughly logarithmic. The ***decibel (dB) scale*** is therefore used: it compresses this huge pressure range into a practical 0–140 scale and tracks how loudness is actually perceived.

$$L_p = 20 \log_{10}(P/P_0)\ \text{dB}$$

*P = measured RMS sound pressure, N/m²; $P_0$ = reference sound pressure = $2\times10^{-5}$ N/m² (≡ 0 dB, the threshold of human hearing). Measured on the A-weighting scale — dB(A) — which matches the frequency sensitivity of the human ear; B and C weightings are used for louder, lower-frequency industrial sources.*

◆ **WORKED NUMERICAL — *Sound Pressure at 80 dB(A), and the Effect of an 8-fold Pressure Increase*** [IFoS 2017 · P2/4(d) · 10M]

**Problem.** *(i) Why is the decibel scale used for sound measurement? (ii) What is the sound pressure for an 80 dB(A) tractor sound? (iii) If the sound pressure is increased 8 times, find the resulting sound level in dB(A).*

**(i) Why log scale.** the ear spans ~$10^6$–$10^7$ in pressure ratio and perceives loudness roughly logarithmically (Weber–Fechner-type response) — the log-based dB scale compresses this into a manageable 0–140 range that also matches perceived loudness steps.

**(ii) Given.** $L_p$ = 80 dB(A); $P_0 = 2\times10^{-5}$ N/m².

**Formula.** $L_p = 20 \log_{10}(P/P_0) \Rightarrow P = P_0 \cdot 10^{(L_p/20)}$

**Substitution.** $P = 2\times10^{-5} \times 10^{(80/20)} = 2\times10^{-5} \times 10^4 = 2\times10^{-1}\ \text{N/m}^2$

**Result. P = 0.200 N/m² (= 200 mPa).**

**(iii) Pressure ×8.** $P_2 = 8P = 1.60\ \text{N/m}^2$

**New level.** $L_{p2} = 20 \log_{10}(P_2/P_0) = L_p + 20 \log_{10}(8) = 80 + 20(0.9031)$

**Result. $L_{p2}$ = 98.1 dB(A) (3 s.f.).**

**Check.** doubling pressure always adds 20 $\log_{10}2 \approx 6$ dB; 8× = $2^3$ adds 3×6 = 18 dB, 80+18 = 98 dB — consistent with the exact 98.06 dB computed above (verified in Python).

| Duration/day, h | Permissible level, dB(A) | Duration/day, h | Permissible level, dB(A) |
|---|---|---|---|
| 8 | 90 | 1.5 | 102 |
| 6 | 92 | 1.0 | 105 |
| 4 | 95 | 0.5 | 110 |
| 3 | 97 | 0.25 | 115 |
| 2 | 100 | — | > 115 |

| Source | Typical level |
|---|---|
| Modern tractor with cab (operator's ear) | ≈ 80 dB(A) |
| Tractor without cab | 89 – 98 dB(A) |
| Thresher / combine harvester | 90 – 98 dB(A) |
| Power tiller (operator zone) | 105 – 110 dB(A) |
| Cotton-ginning machine | ≈ 96 dB(A) |
| Pneumatic chipper (2 m) | ≈ 113 dB(A) |

- ***Noise sources in a tractor***: Engine exhaust, intake, combustion, piston slap (the two biggest sources — from pressure pulsation and turbulent flow at valve opening/closing), fuel-injection pump, valve train, gears, bearings, crankshaft, hydraulic system, differential, brakes.


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- ***Effects***: Annoyance, reduced concentration, fatigue, interference with communication, raised pulse rate/blood pressure, temporary or permanent Deterioration In Threshold of Hearing (DITH) — Noise-Induced Hearing Loss (NIHL) — with prolonged exposure above ~90 dB(A).

## 6.2 WHOLE-BODY & HAND-TRANSMITTED VIBRATION

Vibration reaching the operator through the seat is ***Whole-Body Vibration (WBV)***; vibration through the hands (walk-behind machines, hand tools) is ***Hand-Transmitted Vibration (HTV)*** — prolonged HTV exposure can cause ***White-Finger Syndrome (Raynaud's phenomenon)*** of occupational origin; prolonged WBV exposure is linked to back injury.

- ***Resonant frequency*** : Pneumatic-tyred tractors: ≈ 1–4 Hz; track-type tractors: > 4 Hz. Human tolerance to vibration is at its ***minimum in the 4–8 Hz band*** — tractor and seat design must avoid amplifying vibration in this range.
- ***Forced vibration*** : The sustained (steady-state) motion driven by, and at the same frequency as, an external periodic excitation (engine/wheel/soil-induced) once any transient at the system's own natural frequency has died out due to friction/damping.
- ***Free vibration*** : The transient oscillation of a displaced mass–spring–damper system left to move under its own spring, weight and friction forces alone (no external force); it dies out with time due to damping — this is the condition used to find a system's natural frequency.

**$\omega_n$ (seat) < $\omega$ (chassis-input frequency)**

*the seat's own undamped natural frequency $\omega_n = \sqrt{(k/M)}$ ($k$ = spring rate, $M$ = seat + operator mass) must be kept below the input vibration frequency from the chassis, else the suspension amplifies rather than isolates the vibration; a soft spring keeps $\omega_n$ low. Practical seat suspensions use a damping ratio of about 30–50% of critical damping.*

- ***Effects of WBV*** : Increased stress/tension, localised pain and fatigue, general discomfort, abdominal/chest/testicular pain, degraded performance on visual, motor and psychomotor tasks.
- ***Governing standards*** : ISO 2631-1:1997, ISO 5349-1&2:2001, BS 6841:1987, IS 13548:1992.

★ **MODEL Q** The 'tractor seat vibration parameters' part of IFoS 2017 P2/4(d) (10M, boxed in §6.1) is answered from this sub-section: WBV/HTV definitions, resonant-frequency ranges, the 4–8 Hz danger band, seat natural-frequency criterion, and governing ISO/BS standards.

## 6.3 THERMAL ENVIRONMENT & CABIN COMFORT

Tractor operators work under varying agro-climatic loads — temperature, humidity, wind, dust and, during spraying, chemical exposure. The heat exchange between the operator's body and the environment (Gagge *et al.*, 1941) is:

**$S = M - E \pm R \pm C - W$**

S = net heat *stored by the body ($S = 0$ at thermal equilibrium); $M$ = metabolic heat generated (70–140 W/m², i.e. ≈140–348 W over an average 2 m² body-surface area); $E$ = evaporative heat loss; $R$ = radiative gain/loss; $C$ = convective gain/loss; $W$ = external work done.*

**$R = 5.7\,(t_s - t_r)$ kcal/m²/hr**

*radiant heat gain/loss; $t_s$ = skin temperature, °C; $t_r$ = radiant temperature of surroundings, °C.*

| Environmental zone | Temperature, °C | Humidity, % | Ventilation, m³/min |
|---|---|---|---|
| Comfort — lower limit | 18 | 30 | 0.37 |
| Comfort — upper limit | 24 | 70 | 0.57 |

| | | | |
|---|---|---|---|
| Bearable — lower limit | −1 | 10 | 0.14 |
| Bearable — upper limit | 38 | 90 | 1.4 |

***Fanger's comfort equation*** (1972) predicts a comfortable combination of air temperature, mean radiant temperature, humidity and air velocity for a clothed operator, given his metabolic rate (≈150 kcal/h·m² for a tractor operator) and clothing insulation ($I_{cl}$ ≈ 0.5–1.5 for light–heavy clothing); cab air velocity should be kept in the 1–3 m/s range. The related ***Effective Temperature (ET)*** scale places operator comfort between 24 °C and 27 °C ET.

- ***Dust exposure (typical)*** : Tillage operations: peak ≈577 mg/m³, mean ≈144 mg/m³; pressurised cab (50 Pa) with fine filters: ≈24.7 mg/m³ at the breathing zone; Netherlands guideline limit for combine operators: 15 mg/m³.

## 7 FORMULA SHEET

$$F = A \cdot c + W \tan \varphi$$

*Tractive-force (traction) equation — A = contact area, c = soil cohesion/adhesion, W = normal load, φ = angle of internal friction.*

$$HRmax = 220 - age$$

*Maximum permissible heart rate during physical work (years).*

$$L_p = 20 \log_{10}(P/P_0)$$

*Sound Pressure Level, dB; $P_o = 2\times10^{-5}$ N/m² (0 dB reference); doubling P adds ≈ 6 dB.*

$$S = M - E \pm R \pm C - W$$

*Body heat-balance equation; S = 0 at thermal equilibrium; M = metabolism (70–140 W/m²).*

$$R = 5.7 (t_s - t_r)$$

*Radiant heat exchange, kcal/m²/hr.*

$$\omega_n \text{ (seat)} < \omega \text{ (chassis input)}$$

*Vibration-isolation design criterion for a tractor seat suspension; human tolerance is minimum at 4–8 Hz.*

## 8 SUMMARY

- ***Earth-moving machines*** : Classified by action — dozing (bulldozer), grading (motor grader), scraping (push/carry-all/wheel-type scrapers), excavating (power shovel — above grade; dragline/clamshell — cable-operated; hoe/backhoe — below grade, rigid), trenching (wheel-/ladder-type), loading (earth loader), boring (post-hole digger), breaking (pavement breaker), and finishing (compactor/roller, laser land leveler).
- ***Ergonomics*** : Is the science of fitting the machine, the operator and the working environment together (the M-M-E system) for safety, comfort and efficiency; it is applied to tractor design through the instrument panel, control layout, seat/cabin design, and ROPS/FOPS safety structures, all sized to the 5th–95th percentile of the operator population.
- ***Physiology*** : Workload is objectively graded by heart rate (HRmax = 220 − age) or oxygen consumption, from light (<0.5 l/min) to extremely heavy (>2.0 l/min) work.
- ***Noise & vibration*** : Tractor noise (80–100 dB(A)) is governed by the logarithmic decibel scale ($L_p = 20 \log_{10} P/P_o$); whole-body vibration is most harmful in the 4–8 Hz band, which seat and tractor design must avoid amplifying.


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## 9 LAST-NIGHT REVISION

| Topic | Must-remember number/fact |
|---|---|
| Bulldozer economical haul | ≤ 50–60 m |
| Dragline output vs shovel | ≈ 75–80% |
| Wheel-type trenching depth/width | up to 8 ft / 12–60 in |
| Ladder-type trenching depth | up to 30 ft (with extensions) |
| Sheep's-foot roller passes/layer | 6–15 |
| Laser leveler accuracy | ≈ ±2 cm (vs 10–15 cm traditional) |
| Laser leveler water saving | 25–43% |
| Anthropometric design range | 5th–95th percentile |
| Instrument-panel priority cone | 30°, 380 mm wide @ 700 mm eye distance |
| Seat cushion pressure limits | ≤ 90 g/cm² (ischial), ≤ 30 g/cm² (thigh) |
| HRmax formula | 220 − age |
| Workload bands ($O_2$, l/min) | light <0.5 · moderate 0.5–1.0 · heavy 1.0–1.5 · very heavy 1.5–2.0 · extremely heavy >2.0 |
| SPL reference pressure | $P_o = 2\times10^{-5}$ N/m² = 0 dB |
| OSHA permissible (8 h/day) | 90 dB(A) |
| Tractor noise (with / without cab) | ≈ 80 dB(A) / 89–98 dB(A) |
| Vibration danger band | 4–8 Hz (human tolerance minimum) |
| Comfort zone (temp/RH) | 18–24 °C / 30–70% RH |
| Effective-temperature comfort | 24–27 °C ET |
| ROPS | prevents crush, NOT overturn — seatbelt mandatory |

CHAPTER

# 8

# SOLAR, WIND & ELECTRIC MOTORS

*Solar Constant · Collectors · Cooker/Dryer/Still/Pond · PV · Windmills · Induction & BLDC Motors*

**SYLLABUS :** Solar energy fundamentals: solar constant, solar radiation (global, diffuse, beam), instruments for solar measurement (pyranometer, pyrheliometer). Solar thermal: flat-plate collector, concentrating collector, solar cooker (box/dish/community), solar dryer, solar still, solar pond. Solar photovoltaic: PV cell working principle, silicon cell efficiency, PV module/array, PV system components (controller, battery, inverter), household & agricultural applications, solar pump. Wind energy: windmill classification (HAWT, VAWT), rotor blade types, wind-electric generating system components, cut-in/cut-out speeds, wind power calculation. Electric motors as farm power: induction motor (single-phase, three-phase), BLDC motor, AC vs DC motors, motor selection criteria, motor maintenance. [UPSC IFoS – Agricultural Engineering, Paper II, Section A, Topic 1.]

## Chapter Outline


1. **Scope — Solar, Wind & Electric Power on the Farm**
2. **Solar Energy Fundamentals**
3. **Solar Thermal Systems**
4. **Solar Photovoltaic Systems**
5. **Wind Energy**
6. **Electric Motors as Farm Power**
7. **Formula Sheet**
8. **Summary**
9. **Last-Night Revision**

▣ *Mind-Map — Chapter 8 Concept Map*

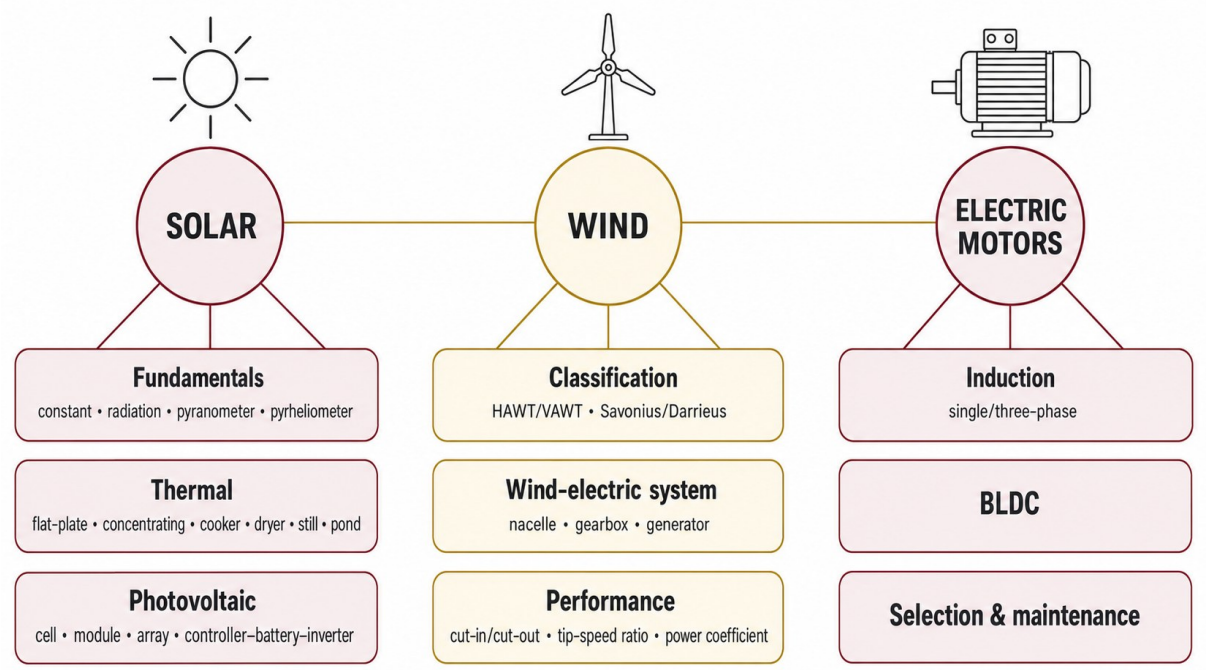



*Fig. 8.0 Concept map — Chapter 8 at a glance.*

## 1 SCOPE — SOLAR, WIND & ELECTRIC POWER ON THE FARM

Diesel and grid electricity are not always available, reliable or affordable on the farm — solar, wind and electric motors are the three renewable/electrical power routes an agricultural engineer must be able to size, select and maintain. This chapter covers solar energy from first principles through to PV systems (§2–§4), wind-electric generation (§5), and the electric motors that convert this power into farm work — pumping, threshing, processing (§6).

- ***Why grouped together*** : All three are alternatives/supplements to the IC-engine tractor power covered elsewhere in this Module — the syllabus treats them as a single 'other sources of farm power' unit.

**PREVIOUS YEAR QUESTIONS**

How is the solar energy harnessed for useful applications? Explain in detail.

[UK·PSC ACF/RFO 2025 | Q.6(ii) | 10 M]

**MODEL Q** A broad question best answered by touring §3 (thermal) and §4 (PV) in turn: collectors/cooker/dryer/still/pond for thermal harnessing, then PV cell→module→array→system for electrical harnessing, with applications named throughout.***

## 2 SOLAR ENERGY FUNDAMENTALS

### 2.1 SOLAR CONSTANT & SOLAR RADIATION

***Solar constant (Isc) :*** the intensity of solar radiation falling on a surface held normal to the sun's rays, at the mean earth–sun distance, just outside the earth's atmosphere (extraterrestrial). Accepted value: **1367 $W/m^2$** (≈ 1.94 cal/cm²·min ≈ 4.87 MJ/m²·hr). It varies about ±3.4% over the year because the earth–sun distance varies (elliptical orbit).

Of the extraterrestrial radiation reaching the atmosphere, part is scattered/absorbed and part reaches the ground directly — giving three radiation terms used throughout solar engineering:

| Term | Meaning |
|---|---|
| Beam (direct) radiation | Solar radiation received from the sun without change of direction, i.e. travelling in a straight line from the solar disc to the surface |
| Diffuse radiation | Solar radiation received after its direction has been changed by scattering in the atmosphere (by clouds, dust, water vapour) |
| Global radiation | The total radiation on a horizontal surface = beam + diffuse radiation received from the whole sky |

**PREVIOUS YEAR QUESTIONS**

- What do you understand by global radiation and diffuse radiation? [IFOS 2022 | P2/1(d) | 8 M]

**MODEL Q** *Define* beam, diffuse and global radiation as above; note global = beam + diffuse and that on an overcast day global radiation is entirely diffuse. ***

## 2.2 INSTRUMENTS FOR SOLAR RADIATION MEASUREMENT

***Pyranometer*** : measures ***global*** (beam + diffuse) solar radiation falling on a horizontal surface over a hemispherical field of view — typically a blackened, dual-metal thermopile sensor under a glass dome, whose small temperature rise (hot junction, blackened, vs cold junction, shielded) generates a millivolt signal proportional to incident radiation. Fitting a shading ring/disc to block the direct beam converts it into a diffuse-radiation measurement.

***Pyrheliometer*** : measures ***beam (direct)*** radiation only, by restricting the instrument's field of view to a narrow angle centred on the solar disc (mounted on a sun-tracking mount so it stays pointed at the sun); the collimating tube excludes diffuse sky radiation from the sensor.

- ***Other terms*** : Sunshine recorder (Campbell–Stokes) — records hours of bright sunshine via a burn-trace on a card behind a glass sphere, used to estimate average radiation when a pyranometer record isn't available.

**PREVIOUS YEAR QUESTIONS**

- What is Solar Constant? Write about the instruments that are used to measure solar energy. [IFOS 2025 | P2/1(d) | 8 M]

**MODEL Q** Define the solar constant (§2.1) and describe the pyranometer and pyrheliometer above — note the key distinguishing feature: pyranometer = hemispherical field of view (global), pyrheliometer = narrow tracking field of view (beam only). ***

# 3 SOLAR THERMAL SYSTEMS

## 3.1 FLAT-PLATE COLLECTOR

A ***flat-plate collector (FPC)*** absorbs both beam and diffuse radiation without concentrating it, and can therefore be fixed (no sun-tracking needed) — it is the workhorse of solar water/air heating.

- ***Construction*** : (i) glazing — one or two glass/plastic covers, transparent to incoming short-wave solar radiation but largely opaque to the long-wave re-radiation from the absorber (greenhouse effect), reducing convective and radiative loss; (ii) blackened absorber plate (metal, high absorptivity coating) bonded to tubes carrying the heat-transfer fluid (water or air); (iii) insulation on the back/sides to cut conduction loss; (iv) casing.


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$$Qu = Ac\,[I_t(\tau\alpha) - UL(Tp - Ta)]$$

*Useful heat-collection (energy-balance) equation. Qu = useful heat gain, W; Ac = collector area, $m^2$; $I_t$ = incident solar radiation, $W/m^2$; (τα) = transmittance–absorptance product of cover–absorber; UL = overall heat-loss coefficient, $W/m^2K$; Tp = mean absorber-plate temperature; Ta = ambient temperature.*

$$\eta = Qu / (Ac \cdot I_t)$$

*Instantaneous collection efficiency — the fraction of incident solar energy actually delivered as useful heat; falls as (Tp − Ta) rises relative to $I_t$, which is why FPC performance is usually plotted against $(Tp - Ta)/I_t$ (the Hottel–Whillier–Bliss efficiency curve).*

- ***Design parameters affecting performance*** : Number of glass covers (more covers cut convective loss but also cut transmittance); spacing between cover and absorber; selective absorber coating (high α, low emissivity ε, to cut re-radiation loss); absorber material/tube spacing/bond conductance; insulation thickness; collector tilt angle and orientation (facing true south in the northern hemisphere, tilt ≈ site latitude for year-round use).

◆ **WORKED NUMERICAL — *Useful Heat Gain & Efficiency of a Flat-Plate Collector*** **[Illustrative · verified in Python]**

**Problem.** *A 2 $m^2$ flat-plate collector receives solar radiation of 700 $W/m^2$. The transmittance-absorptance product (ta) is 0.80 and the overall heat-loss coefficient UL is 6 W/m2K. Find the useful heat gain and collection efficiency when the absorber plate runs 40C above ambient.*

**Given.** Ac = 2 m2, It = 700 W/m2, (ta) = 0.80, UL = 6 W/m2K, (Tp-Ta) = 40C.

**Formula.** Qu = Ac[It(ta) - UL(Tp-Ta)]

**Substitution.** Qu = 2 x [700x0.80 - 6x40] = 2 x [560 - 240] = 2 x 320

**Result - Qu. Qu = 640 W.**

**Efficiency.** eta = Qu/(Ac.It) = 640/(2x700) = 640/1400

**Result - eta. eta = 0.457 = 45.7% (3 s.f.).**

**Interpretation.** efficiency falls as (Tp-Ta) rises for a fixed It - at higher operating temperatures the loss term UL(Tp-Ta) consumes a larger share of the absorbed radiation, which is exactly why concentrating collectors (Section 3.2) are preferred once high temperatures are required.

### ▣ *Flat-Plate Collector — Cross-Section*

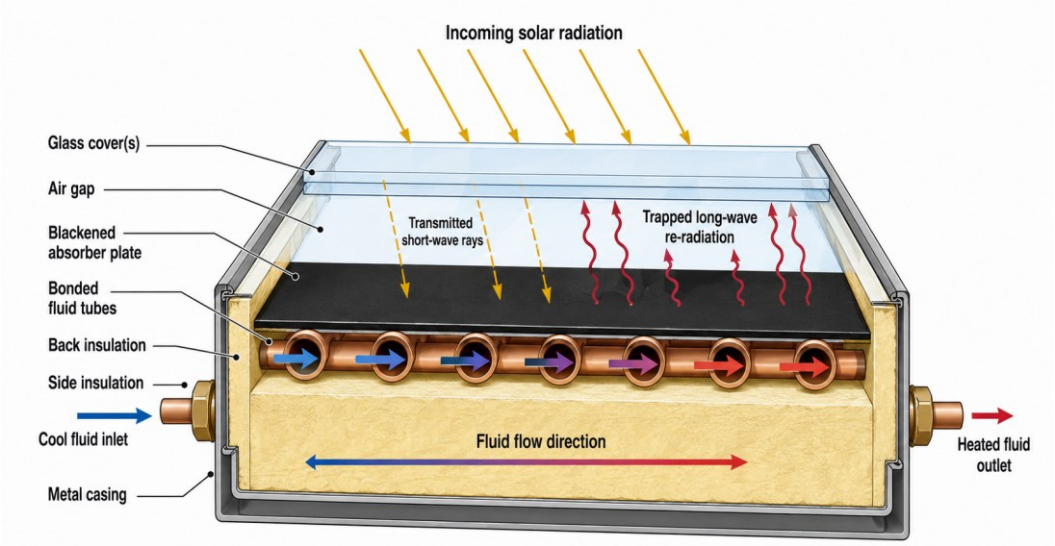



*Fig. 8.1 Flat-plate collector construction and the greenhouse-effect heat trap.*

**PREVIOUS YEAR QUESTIONS**

- What do you understand by solar thermal energy collectors? Discuss the various design parameters affecting the performance of solar flat-plate collector. [IFOS 2022 | P2/2(c) | 15 M]
- Explain the functions of different components of a solar photovoltaic system used for power generation. Write a short note on solar flat plate collector. [IFOS 2020 | P2/2(c) | 15 M]
- Discuss the different types of solar energy collectors and their applications. [IFOS 2025 | P2/2(c) | 10 M]

**MODEL Q** For IFOS 2020's flat-plate part: describe construction + energy-balance equation + design parameters above; its PV-components part is answered in §4.2. For the 'types + applications' question, tour flat-plate (§3.1: water/air heating), concentrating (§3.2: high-temperature process heat/power), cooker (§3.3), dryer (§3.4), still (§3.5) and pond (§3.6) with one application each. ***

## 3.2 CONCENTRATING (FOCUSING) COLLECTOR

A ***concentrating collector*** uses a reflecting/refracting optical system (concentrator) to focus a large collection area onto a much smaller absorber, raising the concentration ratio (aperture area ÷ receiver area) from the flat-plate's ~1 up to several thousand — delivering fluid temperatures of 500 °C or more. Because focusing only works for radiation arriving from one direction, a concentrator can use beam radiation only (not diffuse), so it usually needs sun-tracking.

| Type | Geometry | Typical use |
|---|---|---|
| Parabolic trough (line-focus) | Cylindrical parabolic mirror; absorber = a tube along the focal line, single-axis tracking | Process heat, solar thermal power plants |
| Mirror-strip reflector (line-focus) | Flat/slightly curved mirror strips angled to a common focal line | Same as trough, lower-cost construction |
| Fresnel-lens collector (line-focus) | Refracting acrylic Fresnel lens focusing onto a line receiver | Compact line-focus alternative to mirrors |
| Paraboloidal dish (point-focus) | 3-D parabolic dish focusing to a point/cavity receiver; two-axis tracking | Highest temperatures/concentration — solar furnace, Stirling-dish power |
| Compound Parabolic Concentrator (CPC) | Non-imaging trough accepting a range of incidence angles — little/no tracking needed | Medium-temperature process heat with reduced tracking cost |

| Concentrating collector | Flat-plate collector |
|---|---|
| Uses beam radiation only; needs (or benefits from) tracking | Uses beam + diffuse; usually fixed, no tracking |
| High concentration ratio → very high temperatures (500 °C+) | Low/no concentration → moderate temperatures (< 100 °C typically) |
| Higher collection efficiency at high temperature (smaller receiver → lower loss area) | Efficiency falls faster as operating temperature rises |
| More optical losses (mirror/lens reflectance, tracking imperfection); costlier, more moving parts | Simple, static, low maintenance, cheaper |
| Suited to: process heat, power generation, solar furnace | Suited to: water/space heating, drying, agriculture-scale low-grade heat |


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### ▣ *Parabolic-Trough And Paraboloidal-Dish Concentrators*

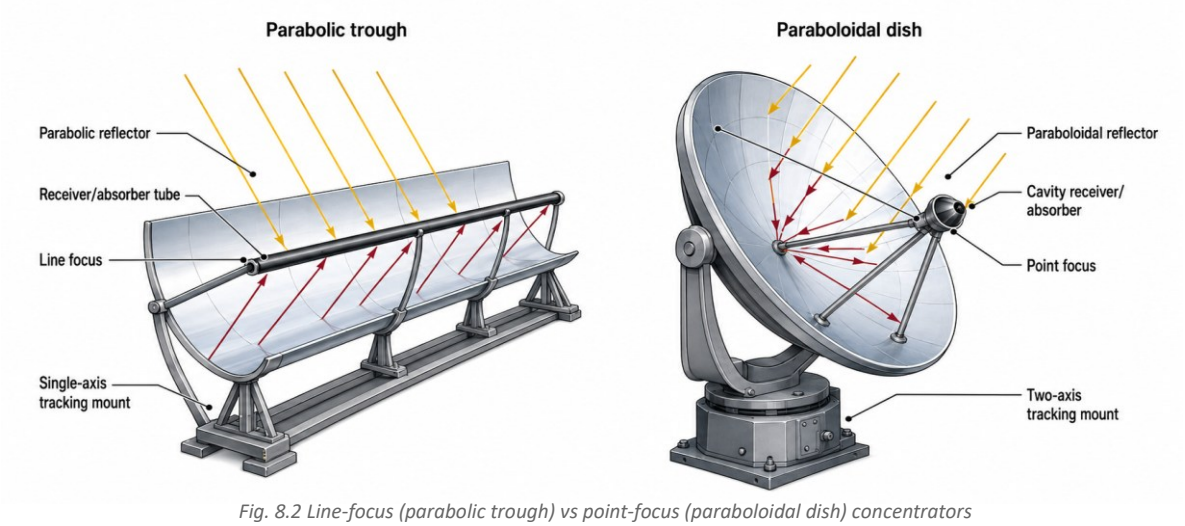



*Fig. 8.2 Line-focus (parabolic trough) vs point-focus (paraboloidal dish) concentrators*

**PREVIOUS YEAR QUESTIONS**

- Explain the principle of operation of concentrating type solar collector with a suitable diagram. What are the advantages and disadvantages of such collectors over flat plate solar collectors? [IFOS 2018 | P2/4(a) | 15 M]
- Elaborate the basic difference between solar flat plate collector and solar concentrator. Under what condition these two are recommended for various uses. [OPSC·CSE 2018–19 | Q.4(c) | 20 M]

**MODEL Q** Principle: focusing optics raise the concentration ratio, so receiver area (and thus loss area) shrinks relative to the collection area — hence higher efficiency at high temperature. Use the comparison table above directly for both PYQs; close with 'recommended when': concentrating → high-temperature/process-heat/power applications; flat-plate → moderate-temperature domestic/agricultural heating where simplicity and low cost matter more. ***

## 3.3 SOLAR COOKER

A solar cooker uses solar radiation, collected as direct/reflected/concentrated radiation and converted to heat by a blackened absorber, to cook food kept in vessels inside the cooker. Three basic designs:

| Type | Principle | Max. temperature |
|---|---|---|
| Box type (with/without reflector) | Flat blackened tray inside an insulated box under double glass covers — a hinged plane mirror can be added to boost incoming radiation | ≈ 160 °C (single reflector) |
| Multi-reflector (community) oven | 4–8 square/triangular mirrors mounted on the oven body, all reflecting radiation into the cooking zone; manually tilted to track the sun | ≈ 250–350 °C |
| Parabolic-dish (concentrator) type | Parabolic mirror concentrates radiation to a focus where the cooking vessel sits | highest — used for community/institutional cooking |

**BOX-TYPE SOLAR COOKER — CONSTRUCTION & WORKING**

Double-walled (metal/wood) insulated box, top covered by **two** glass sheets (~3 mm thick, ~20 mm apart — two covers to cut convective/re-radiation loss, same greenhouse principle as §3.1), a blackened absorber tray inside holding blackened cooking vessels, and a hinged plane mirror (adjustable via a guide) that reflects extra

radiation into the box, raising internal temperature by a further 15–25 °C. Short-wave solar radiation passes through the glass and is absorbed by the blackened tray; the resulting long-wave re-radiation cannot escape back through the glass — box temperature rises 70–110 °C above ambient, enough to cook slowly over 1–2 hours (rice: 30 min–2 h). Typical box size 60×60×20 cm, serving a family of 5–7.

- ***Advantages*** : No fuel, no attention needed during cooking, negligible maintenance, no pollution, nutrients/vitamins preserved, no charring/overflow risk.
- ***Limitations*** : Cooking depends on sunshine — no use at night or on cloudy days; meal timing must be pre-planned; cooking is slower than conventional fuels; chapatis/items needing high baking temperature and manual turning cannot be made.

### ▣ *Box-Type Solar Cooker*

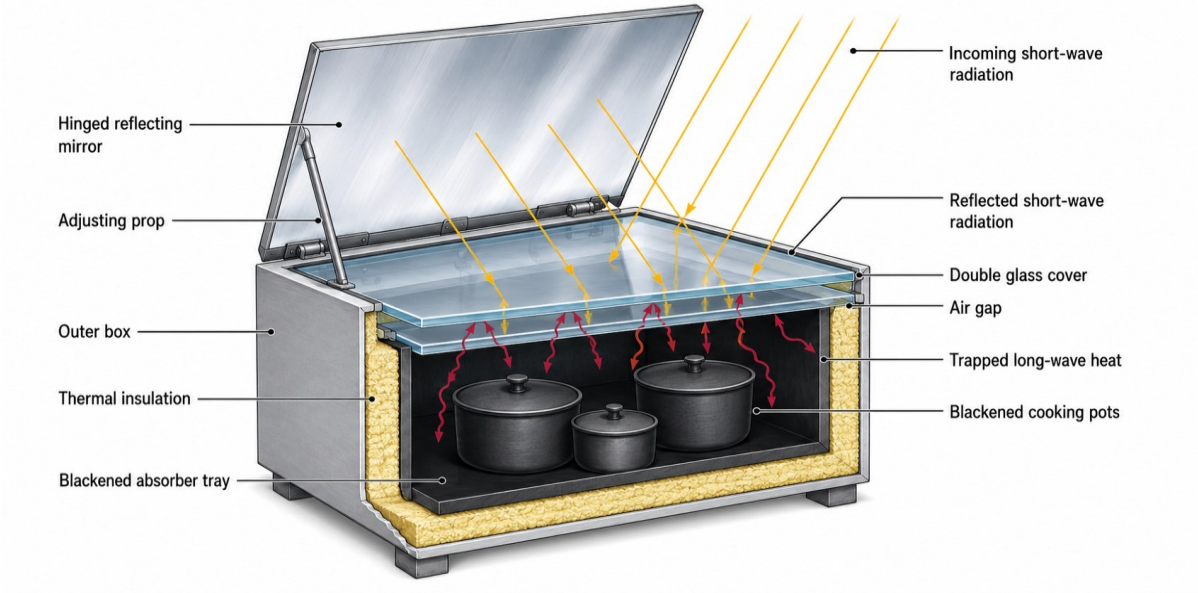



*Fig. 8.3 Box-type solar cooker with single reflector — construction.*

◆ **WORKED NUMERICAL — *Thermal Energy Required to Cook Rice*** **[Illustrative · after AgriMoon Renewable Energy Technology]**

**Problem.** *Find the heat energy required to cook 1 kg rice using 2 kg water in a 0.5 kg aluminium vessel, heated from an ambient 30 °C to a cooking temperature of 100 °C; assume ~30% extra heat is needed to sustain cooking temperature throughout.*

**Given.** $m_1$ = 1 kg rice ($cp_1$ = 3.8 kJ/kg°C), $m_2$ = 2 kg water ($cp_2$ = 4.18 kJ/kg°C), $m_3$ = 0.5 kg Al vessel ($cp_3$ = 0.90 kJ/kg°C); dt = 100 − 30 = 70°C.

**Formula.** $Q = (m_1cp_1 + m_2cp_2 + m_3cp_3) \times dt$

**Substitution.** $Q = [(1\times3.8) + (2\times4.18) + (0.5\times0.9)] \times 70 = 12.62 \times 70 = 883.4$ kJ

**Sustaining allowance (+30%).** $Q_{total} = 883.4 \times 1.3 \approx 1149$ kJ

**Result. ≈ 1.15 MJ of thermal energy is required — this is the basis for sizing a box cooker's absorber area and glazing for a given family size.**

**PREVIOUS YEAR QUESTIONS**

- Explain with the help of labelled diagram, the construction details of single reflector box solar cooker. What are the limitations of solar cookers? [IFOS 2019 | P2/1(d) | 8 M]


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**MODEL Q** Diagram + construction from the minihead above; limitations bullet list above answers the second part directly. ***

## 3.4 SOLAR DRYER

A solar (hot-air) dryer passes solar-heated air over/through a moist commodity (grain, chilli, fruit) to remove moisture — either a direct-type cabinet dryer (commodity itself absorbs radiation under a glazed cover) or an indirect-type dryer (a separate flat-plate air heater supplies hot air to a drying chamber, protecting the product from direct UV/overheating).

| Type | How it works | Product quality |
|---|---|---|
| Direct (cabinet) dryer | Product placed directly under a transparent cover and absorbs solar radiation itself, with natural/forced air circulation removing the moisture-laden air | Simple, low-cost; risk of surface case-hardening/discoloration from direct UV/overheating |
| Indirect (distributed-type) dryer | A separate solar air heater (flat-plate) heats air, which is then ducted into a shaded drying chamber holding the product | Better colour/nutrient retention (no direct radiation on product); more hardware, slightly higher cost |
| Mixed-mode dryer | Combines both — product is both exposed to some direct radiation and supplied with separately preheated air | Faster drying than pure indirect type, better quality than pure direct type |

◆ **WORKED NUMERICAL — *Solar Dryer Performance Evaluation*** [Illustrative · after AgriMoon Renewable Energy Technology]

**Problem.** *A farmer dries 100 kg of chillies in a solar dryer of collector size 2 m × 1 m, effective drying time 16 h, moisture reduced from 75% to 10% (w.b.), average solar insolation 600 W/m². Outline the performance-evaluation approach and compute the collector area.*

**Given.** l = 2 m, w = 1 m, n = 1 collector, P = 16 h, S = 600 W/m².

**Collector area.** $A_c = n \cdot l \cdot w = 1 \times 2 \times 1 = 2\ m^2$

**Parameters recorded for evaluation.** solar insolation (S), mass/initial & final moisture content of produce ($W_1$, $m_1$, $m_2$), effective drying hours (P), collector length/width/number, ambient & hot-air temperature (Ta, Th), glass transmissivity (τ), absorber absorptivity (α) — measured with a pyranometer, thermometers and an air flow meter.

**Interpretation.** performance is reported as moisture removed per unit collector area per day, and the economics compared against an equivalent electric hot-air dryer to find the payback period.

## 3.5 SOLAR STILL

***Solar still*** — a simple solar distillation device: saline/brackish water in a shallow, blackened basin absorbs solar radiation and evaporates; the vapour condenses on the underside of a sloped, transparent (glass) cover above (kept cool by ambient air), and the condensate trickles down into a collection trough — yielding fresh distilled water. Basin-type (passive) stills are simplest; active stills pump in extra solar-heated water or use a collector to boost yield.

- ***Application*** : Small-scale potable-water production from saline/brackish groundwater in areas without a reliable freshwater supply.

## 3.6 SOLAR POND

***Solar pond*** — a body of saline water in which a stable, increasing salinity (density) gradient with depth suppresses natural convection, so solar radiation absorbed near the bottom (dark-coloured floor) is trapped there as heat rather than rising and being lost — giving a bottom layer at 70–90 °C even though the surface stays near ambient. Three zones: (i) upper convective zone (thin, near-uniform low-salinity surface layer), (ii) non-convective (gradient) zone — the insulating layer, and (iii) lower convective (storage) zone — hot, high-salinity, where heat is extracted via a heat exchanger.

- ***Applications***: low-grade process/space heating, desalination, power generation (via a low-temperature Rankine/organic-fluid cycle), aquaculture pond heating.

### 3.7 SOLAR GREENHOUSE & OTHER THERMAL APPLICATIONS

A solar greenhouse is a transparent-covered structure using trapped solar radiation for controlled-environment plant growth (soil/air temperature, humidity), doubling as a passive solar collector for space heating of the growing zone; other thermal applications include solar water heating (domestic/industrial), space heating/cooling of buildings, and solar furnaces (very high-temperature process heat via large focusing arrays).

**PREVIOUS YEAR QUESTIONS**

Briefly describe the thermal applications of solar energy in agriculture and allied activities.
[HP·PSC RFO 2021 | Q.6(c) | 10 M]

**MODEL Q** Tour solar water heating → space heating/greenhouses → drying (§3.4) → cooking (§3.3) → distillation (§3.5) → pond-based process heat (§3.6) — one line of agricultural relevance each. ***

## 4 SOLAR PHOTOVOLTAIC SYSTEMS

### 4.1 PV CELL — WORKING PRINCIPLE & EFFICIENCY

A ***photovoltaic (PV) cell*** is a p–n junction semiconductor (usually silicon) that converts sunlight directly to DC electricity via the photovoltaic effect: photons with energy above the semiconductor's band-gap excite electrons across the junction, creating free electron–hole pairs; the junction's built-in electric field separates them, driving electrons around an external circuit as current before they recombine on the other side.

| Silicon PV cell type | Typical module efficiency |
|---|---|
| Monocrystalline silicon | 18–22% |
| Polycrystalline (multicrystalline) silicon | 15–18% |
| Amorphous (thin-film) silicon | 6–10% |

**PREVIOUS YEAR QUESTIONS**

Write the operating principle of a photovoltaic cell. Mention the efficiency of different types of silicon PV cells. [IFOS 2024 | P2/4(b) | 10 M]

**MODEL Q** Principle from the paragraph above; efficiency ranking mono > poly > amorphous, with the trade-off that monocrystalline costs more per watt but needs less roof area for a given power. ***

### 4.2 PV MODULE, ARRAY & SYSTEM COMPONENTS

Individual cells (~0.5 V each) are connected in series/parallel and encapsulated to form a ***module***; modules are further connected in series/parallel to form an ***array*** of the voltage/current needed for the load.


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| Component | Function |
|---|---|
| PV module/array | Converts sunlight to DC electricity |
| Charge controller | Regulates the DC output to the battery — prevents overcharging/deep discharge, protecting battery life; may also include maximum-power-point tracking (MPPT) to maximise array output |
| Battery bank | Stores DC energy for use when there is no sunshine (night/cloudy periods) |
| Inverter | Converts stored/array DC to AC for household appliances or grid-compatible loads (omitted in a DC-only system, e.g. a DC solar pump) |
| Mounting structure & tracker (optional) | Holds the array at the design tilt/orientation; a tracker (single- or dual-axis) reorients the array to follow the sun through the day for extra output |

**SUN-TRACKING FOR PV GENERATORS**

Fixed PV arrays lose output as the sun's incidence angle departs from normal; trackers recover this loss. A ***thermo-hydraulic tracker*** uses two shaded/sunlit fluid-filled canisters (or bimetallic/gas-filled actuator cylinders) mounted symmetrically on the array: uneven solar heating creates a pressure/volume difference between the canisters, driving a passive hydraulic or gas-pressure actuator that tilts the array toward the sun — no motor or electronic control needed, just the differential thermal expansion of the working fluid.

**PREVIOUS YEAR QUESTIONS**

- Name the different components required in a Solar PV system for household application and describe the function of each component. [IFOS 2021 | P2/2(b) | 10 M]
- Explain the functions of different components of a solar photovoltaic system used for power generation. [flat-plate-collector part answered in §3.1] [IFOS 2020 | P2/2(c) | 15 M]
- Briefly write about different devices and components of a solar photo-voltaic system. [solar-dryer-applications part answered in §3.4] [IFOS 2023 | P2/2(c) | 15 M]
- What is solar constant? With a neat sketch describe solar Photovoltaic system and working of solar power generators. [solar-constant part answered in §2.1] [UK·PSC RFO 2021 | Q.6(ii) | 10 M]
- Describe the features of a photovoltaic generator. What are the methods of tracking the Sun for the generator? Explain the thermo-hydraulic tracking principle. [OPSC·CSE 2024–25 | Q.6 | 15 M]

★ **MODEL Q** For all the 'PV components' PYQs: use the five-row table above (module/array → controller → battery → inverter → mounting/tracker). For the tracking-methods question: name passive (thermo-hydraulic, described above) vs active (motorised, sensor/astronomical-algorithm driven, single- or dual-axis) tracking, then detail the thermo-hydraulic principle.

**▣ PV SYSTEM COMPONENTS — HOUSEHOLD APPLICATION**

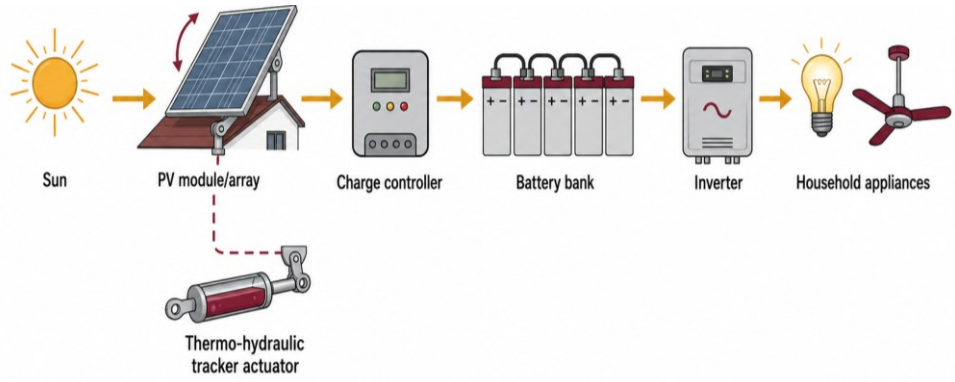



*Fig. 8.4 Solar PV system — component block diagram for a household application*

### 4.3 APPLICATIONS — HOUSEHOLD, AGRICULTURAL & SOLAR PUMP

- ***Household*** : Lighting, fans, small appliances, solar home-lighting systems (SHS), solar street lights.
- ***Agricultural*** : Solar water pumping (irrigation) — PV array drives a DC or AC-with-inverter motor-pump set, often without a battery (pumping only in daylight, matching irrigation demand to sunshine hours); solar fencing energisers; cold-storage/dryer power; crop protection lighting.

A ***solar PV water pump*** avoids diesel-fuel logistics and running cost in remote fields, but needs correct sizing (array power ≥ pump's peak power demand at the site's design solar-insolation hour) and, for steady flow through variable insolation, either a battery buffer or a variable-frequency drive matching motor speed to available array power.

## 5 WIND ENERGY

### 5.1 WIND POWER — BASIC PRINCIPLE

A wind turbine (aerogenerator) converts the kinetic energy of moving air to mechanical shaft power, which a generator then converts to electrical energy. The power available in an air stream of density ρ crossing a rotor of swept area A at wind speed V is:

$$P_{wind} = \tfrac{1}{2} \rho A V^3$$

*ρ = air density (kg/m³, ≈1.2 at sea level); A = swept area = πD²/4 (D = rotor diameter), m²; V = free wind speed, m/s. Power rises with the cube of wind speed — small speed increases give large power gains.*

$$P_{shaft} = Cp \cdot P_{wind}$$

*Cp = power coefficient (efficiency of extraction) — the fraction of wind power converted to shaft power; the theoretical (Betz) maximum is Cp,max = 16/27 ≈ 0.593, but practical modern turbines achieve Cp ≈ 0.35–0.45.*

**Why the Betz Limit is 16/27 (Derivation Outline)**

Consider wind slowing from V (far upstream) to V' (far downstream) as the rotor extracts energy, with velocity through the rotor disc taken as the average (V+V')/2 (actuator-disc theory). Writing a = (V−V')/V (the 'axial induction factor'), the extracted power works out to P = ½ρAV³ × 4a(1−a)². Maximising 4a(1−a)² with respect to a gives a = 1/3, and substituting back gives the maximum possible power fraction:

$$Cp,max = 4a(1-a)^2 \,|_{a=1/3} = 16/27 \approx 0.593$$

*The Betz limit — no horizontal-axis wind turbine, however well designed, can extract more than 59.3% of the kinetic energy in the wind passing through its swept area; gearbox, generator and blade-aerodynamic losses bring real machines down to Cp ≈ 0.35–0.45. Calculated at a = 1/3*

$$\lambda \text{ (TSR)} = V_{tip} / V = \omega R / V$$

*Tip-speed ratio — ratio of blade-tip speed to free wind speed; ω = rotor angular speed (rad/s), R = rotor radius. Every rotor design has an optimum λ at which Cp is maximum.*

- ***Cut-in and cut-out speed*** : Cut-in speed — the minimum wind speed at which the turbine starts producing usable power (below this, extraction is inefficient/uneconomic); cut-out (furling) speed — the wind speed above which the turbine is shut down/feathered to protect it from structural overload.
- ***Solidity*** : S = NC/(πD) — N = number of blades, C = average blade chord (breadth), D = rotor diameter; low-solidity, few-bladed rotors run at high TSR (electricity generation), high-solidity, many-bladed rotors run at low TSR with high starting torque (water pumping).

### 5.2 WINDMILL CLASSIFICATION & ROTOR TYPES

Wind turbines (WECS) are classified by the orientation of the rotor axis relative to the wind stream:


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| Type | Sub-types | Key feature |
|---|---|---|
| Horizontal-Axis Wind Turbine (HAWT) | Two-blade, single-blade (with counterweight), multi-blade (American farm mill), sail/Dutch type | Rotor axis parallel to wind; needs yawing to face the wind; higher Cp; dominant design for electricity generation |
| Vertical-Axis Wind Turbine (VAWT) | Savonius (S-rotor, drag type); Darrieus ('egg-beater', lift type) | Rotor axis vertical (perpendicular to wind); accepts wind from any direction — no yaw mechanism needed; simpler design |

**SAVONIUS (S-TYPE) ROTOR**

Two (or more) curved, offset half-cylindrical/S-shaped scoops mounted on a vertical shaft. It is a ***drag-type*** device — the concave face catches the wind and is pushed downwind while the convex back of the opposite scoop offers less resistance, so the rotor turns. Low TSR, high starting torque, operates well even at low wind speeds; simple and cheap, but low power coefficient — used mainly for water pumping and small-scale/low-power applications, not grid-scale generation.

**DARRIEUS ROTOR**

Curved (troposkein/'egg-beater') aerofoil blades attached at both ends to a vertical shaft. It is a ***lift-type*** device (like a HAWT blade turned vertical) suited to higher wind speeds and higher TSR/Cp than a Savonius rotor, but is not self-starting (needs an external start, e.g. a small motor or an auxiliary Savonius rotor on the same shaft) and experiences cyclic aerodynamic loading as blades pass windward/leeward.

### ▣ HAWT Vs VAWT (*Savonius & Darrieus*) Rotors

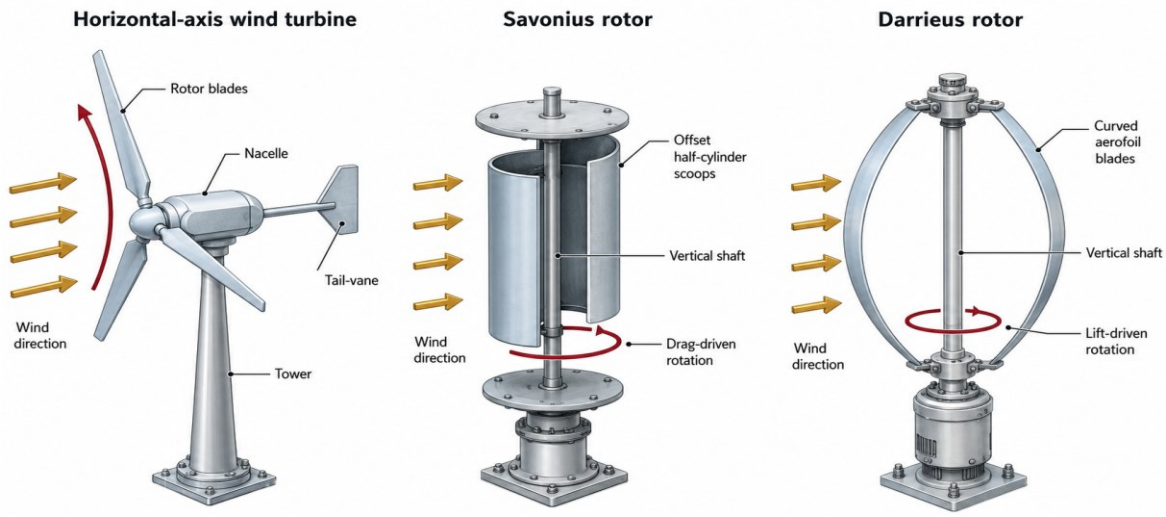



*Fig. 8.5 Windmill classification — HAWT, Savonius VAWT, and Darrieus VAWT.*

**PREVIOUS YEAR QUESTIONS**

- How do you classify the windmill? Discuss the different types of rotor blades used in the windmill. [IFOS 2022 | P2/2(c) | 15 M]
- What are different types of rotors of windmill? Describe the different components of wind-electric generating system with the help of suitable diagram. [IFOS 2019 | P2/3(b) | 15 M]
- How do you classify the windmill? Explain in detail about construction and operating principle of savonius rotor blades used in the windmill. [MH·PSC Forest 2024 | Q.6(b) | 15 M]
- Explain the characteristics of three different types of wind mill. [OPSC·CSE 2022–23 | Q.18(b) | 10 M]
- Compare and contrast in between horizontal type wind mill and vertical axis type of wind mill. [UK·PSC RFO 2015 | Q.18(b) | 10 M]

**MODEL Q** For 'three different types', use HAWT-multiblade, Savonius, and Darrieus (one HAWT + two VAWT types) — the classification table plus both mini-heads above give characteristics for all three. For 'compare HAWT vs VAWT', build a two-column table from the classification-table row content (axis orientation, yaw requirement, Cp, complexity, self-starting). ***

## 5.3 WIND-ELECTRIC GENERATING SYSTEM — COMPONENTS

| Component | Function |
|---|---|
| Rotor (blades + hub) | Captures wind kinetic energy, converts to rotational shaft power |
| Nacelle | Housing atop the tower containing the gearbox, generator, and control electronics |
| Gearbox | Steps up the rotor's low rotational speed to the higher speed needed by a standard generator (some direct-drive designs omit it) |
| Generator | Converts mechanical shaft power to electrical power (induction or synchronous) |
| Yaw mechanism (+ tail vane, HAWT only) | Rotates the nacelle/rotor to keep it facing into the wind as wind direction changes |
| Pitch/stall control | Adjusts blade pitch angle (or uses aerodynamic stall) to limit power/rotor speed above rated wind speed and to feather the blades at cut-out |
| Tower | Supports the rotor/nacelle at a height with stronger, steadier wind than at ground level |
| Controller | Starts/stops the turbine at cut-in/cut-out speed, synchronises the generator, and manages yaw/pitch |

▣ *Wind-Electric Generating System*

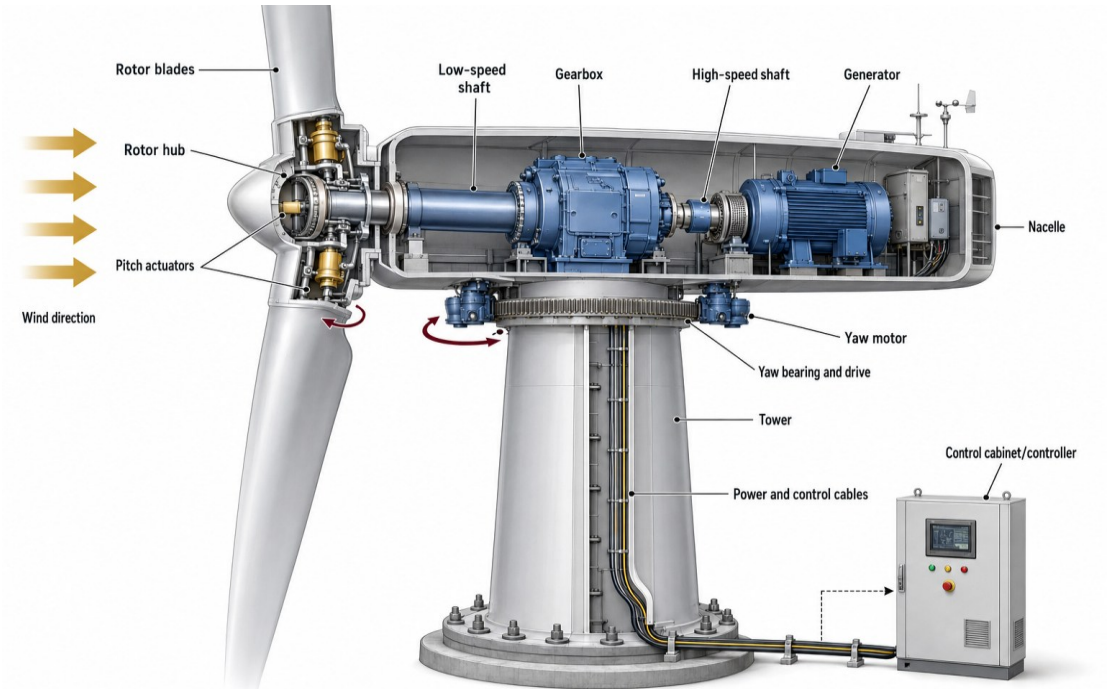



*Fig. 8.6 Wind-electric generating system — main components (nacelle cutaway).*

**PREVIOUS YEAR QUESTIONS**

- Describe the working of wind energy system with the help of a line diagram along with main components. [IFOS 2017 | P2/3(b) | 10 M]


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- Write short notes on: ...(iii) Working principle of a wind turbine. [other sub-parts are from other chapters] [IFOS 2024 | P2/2(b) | 15 M]
- Describe the functions of different parts of a horizontal-axis wind mill for water lifting and explain its working [UK·PSC RFO 2012 | Q.5(iii) | 10 M]

**MODEL Q** The water-lifting HAWT question uses the same component table above, noting that a water-pumping windmill is typically high-solidity/multi-blade (high starting torque at low wind speed, §5.1) driving a reciprocating pump rod via a crank, rather than an electrical generator. ***

## 5.4 SITE SELECTION & INDIA'S WIND-POWER STATUS

- ***Site-selection factors*** : High annual mean wind speed with acceptable turbulence; site above the cut-in speed for most of the year and rarely above cut-out; open terrain/ridge or coastal location free of large obstructions (buildings, trees) that create turbulence/wind shadow; adequate land area and spacing between turbines (to avoid wake interference); road/grid access for construction and evacuation of power; soil-bearing capacity for foundations; minimal environmental/bird-migration and land-use conflict.

**PREVIOUS YEAR QUESTIONS**

- What are the different factors to be considered for suitable site selection for a wind mill installation? Explain working of a horizontal axis wind power plant with neat diagram. [OPSC· Forest 2023–24 | Q.4(b) | 20 M]
- Write an essay on the status and scope of wind power generation in India and propose a strategy for harnessing the potential of wind energy for the country. [OPSC· Forest 2023–24 | Q.18(a) | 10 M]

**MODEL Q** Site-selection list above + HAWT working diagram from §5.3 answers the 20M question in full. For the essay question, structure as: current status (India among the world's top wind-power markets, concentrated in Tamil Nadu/Gujarat/Rajasthan/Maharashtra/Karnataka — verify latest MNRE/GWEC installed-capacity figures before the exam, as these change yearly) → scope/potential (large unexploited onshore + offshore potential, repowering of old low-capacity turbines with modern high-capacity ones) → strategy (repowering, offshore wind development, hybrid wind-solar parks, transmission/grid-evacuation investment, streamlined land acquisition and PPA policy). ***

## 5.5 WORKED NUMERICALS — WIND-TURBINE PERFORMANCE

◆ **WORKED NUMERICAL — *Overall Efficiency of a Wind-Turbine Generator*** [IFoS 2018 · P2/4(c) · 10M]

**Problem.** *The cut-in wind speed of a horizontal-axis wind generator having 8 m diameter blade span is 5.0 m/s. The wind turbine generates 4.0 kW electrical power at 6.5 m/s wind speed. Determine the overall efficiency of the wind turbine generator, taking the density of air as 1.2 kg/m³.*

**Given.** D = 8 m ⇒ R = 4 m; V = 6.5 m/s (the 5.0 m/s cut-in speed only defines the turbine's start-up threshold and is not used in the efficiency calculation itself); $P_{elec}$ = 4.0 kW; ρ = 1.2 kg/m³.

**Swept area.** $A = \pi R^2 = \pi(4)^2 = 50.27\ m^2$

**Power in the wind.** $P_{wind} = \frac{1}{2}\rho A V^3 = 0.5 \times 1.2 \times 50.27 \times 6.5^3 = 8283\ W = 8.28\ kW$

**Overall efficiency.** $\eta = P_{elec} / P_{wind} = 4.0 / 8.28$

**Result. η ≈ 0.483 = 48.3% (3 s.f.).**

**Check.** this is the turbine's combined aerodynamic + mechanical + electrical conversion efficiency; since the Betz limit caps the aerodynamic (Cp) share alone at 59.3%, a total-chain efficiency of 48.3% is physically reasonable (Cp ≈ 0.45–0.5 range, with generator/gearbox losses folded in).

◆ **WORKED NUMERICAL — *Tip-Speed Ratio, Torque Coefficient & Shaft Torque*** [OPSC·CSE 2023–24 · Q.7(b) · 15M]

**Problem.** *Consider a wind turbine with a 5 m diameter rotor. The speed of the rotor at 10 m/s wind velocity is 130 r/min and its power coefficient at this point is 0.35. Calculate the tip speed ratio and torque coefficient of the turbine. What will be the torque available at the rotor shaft? Assume the density of air to be 1.24 kg/m³.*

**Given.** D = 5 m ⇒ R = 2.5 m; N = 130 rpm; V = 10 m/s; Cp = 0.35; ρ = 1.24 kg/m³.

**Angular speed.** $\omega = 2\pi N/60 = 2\pi(130)/60 = 13.61$ rad/s

**Tip speed.** $V_{tip} = \omega R = 13.61 \times 2.5 = 34.03$ m/s

**Tip-speed ratio.** $\lambda = V_{tip}/V = 34.03/10$

**Result — TSR. $\lambda \approx 3.40$ (3 s.f.).**

**Torque coefficient.** $C_q = C_p/\lambda = 0.35/3.403$

**Result — $C_q$. $C_q \approx 0.103$ (3 s.f.).**

**Swept area.** $A = \pi R^2 = \pi(2.5)^2 = 19.63$ m²

**Power in wind & shaft power.** $P_{wind} = \frac{1}{2}\rho A V^3 = 0.5\times1.24\times19.63\times10^3 = 12{,}174$ W;

$P_{shaft} = C_p \cdot P_{wind} = 0.35\times12{,}174 = 4261$ W

**Shaft torque.** $T = P_{shaft}/\omega = 4261/13.61$

**Result — Torque. T ≈ 313 N·m (3 s.f.).**

**Check.** cross-verified via $T = C_q\cdot(\frac{1}{2}\rho A R)V^2 = 0.103\times(0.5\times1.24\times19.63\times2.5)\times10^2 = 313$ N·m — both routes agree.

**PREVIOUS YEAR QUESTIONS**

An agricultural machine has to be operated by solar energy. What should be the area of solar panel normal to Sun's rays (assuming very sunny day) in India with following parameters?

[IFOS 2017 | P2/4(b) | 10 M]

***MODEL Q** The original question's parameter table is not in the source dossier, so the following assumes standard textbook values for a small solar-operated agricultural machine on a very sunny Indian day. State any assumed value you use explicitly in the exam.* ***

*Assumed data. Required electrical power P = 1 kW = 1000 W; peak solar insolation on a clear day (panel normal to Sun) I = 1000 W/m²; overall solar-panel (PV) efficiency $\eta$ = 15% = 0.15.*

*Governing relation. Useful electrical output = I × A × $\eta$, so required panel area A = P ÷ (I × $\eta$).*

*Substitute. A = 1000 ÷ (1000 × 0.15) = 1000 ÷ 150*

*Result — Panel area. A ≈ 6.67 m² (≈ 2.6 m × 2.6 m array), oriented normal to the Sun's rays.*

*Note. Area scales linearly with the required power and inversely with both insolation and panel efficiency — e.g. at $\eta$ = 18% the same 1 kW load needs only ≈ 5.56 m². Re-work with the actual figures if the original data table is recovered.*

## 6 ELECTRIC MOTORS AS FARM POWER

### 6.1 INDUCTION MOTOR — CONSTRUCTION & CLASSIFICATION

The induction motor is the standard workhorse motor for farm pumps, mills and processing equipment: the stator's rotating magnetic field induces current in the rotor (transformer action), and the resulting rotor field


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interacts with the stator field to produce torque — the rotor always runs slightly slower than the synchronous speed (***slip***), which is why it is called ***asynchronous***.

| Basis | Classification |
|---|---|
| Supply | Single-phase (domestic/small farm loads) vs Three-phase (larger farm/industrial loads — higher efficiency, self-starting, smoother torque) |
| Rotor construction | Squirrel-cage rotor (simple, rugged, most common) vs Slip-ring (wound) rotor (external rotor resistance can be added for higher starting torque/speed control) |
| NEMA design class (starting/running behaviour) | Class A (normal torque/current, low slip — fans, pumps, low-inertia loads); Class B (normal torque, low starting current — general purpose, most common); Class C (double-cage, high starting torque, low starting current — crushers, conveyors, loaded starts); Class D (high-resistance cage, very high starting torque, high slip — punch presses, hoists, high-inertia/shock loads); Class E/F (low starting torque/current — where load is started unloaded) |

**PREVIOUS YEAR QUESTIONS**

- Write down the classification of Induction Motors. List the factors that should be considered for selecting the right type of motor [IFOS 2025 | P2/3(c) | 10 M]

**MODEL Q** Classification table above (supply / rotor construction / NEMA design class) directly answers the first part; §6.4 (motor selection criteria) answers the second. ***

## 6.2 SINGLE-PHASE INDUCTION MOTOR

A single-phase stator winding produces only a ***pulsating (alternating)*** flux, not a rotating one — so, unlike a 3-phase motor, a single-phase induction motor develops no net starting torque and is not self-starting (explained by the ***double-field revolving theory***: the alternating flux is equivalent to two equal, oppositely-rotating flux components, whose torques exactly cancel at standstill). Once started by any means, one direction's torque dominates and the motor accelerates normally.

To self-start, an auxiliary ***starting winding*** (displaced 90° from the main winding) is added, temporarily giving two-phase-like operation:

| Type | How the phase difference is created | Typical use |
|---|---|---|
| Split-phase (resistance-start) | Starting winding wound with high-resistance/fine wire (low reactance) vs main winding's low resistance/high reactance; a centrifugal switch disconnects the starting winding at ~75% speed | Fans, blowers, centrifugal pumps, small tools |
| Capacitor-start, induction-run | A capacitor in series with the starting winding gives a much larger (~80°) phase angle than split-phase (~30°), roughly doubling starting torque; capacitor + starting winding cut out at ~75% speed | Compressors, pumps needing higher starting torque than split-phase can give |
| Capacitor-start-and-run | A run-capacitor stays in circuit continuously for improved power factor and running performance, besides a start-capacitor for starting torque | Loads needing both good starting torque and good running efficiency |

- ***Other single-phase types*** : Shaded-pole (very simple, low-cost, low starting torque — small fans); AC series (universal) motor — runs on AC or DC, high speed, used in portable power tools; unexcited single-phase synchronous motor.

## 6.3 BLDC MOTOR & AC VS DC COMPARISON

**BLDC (Brushless DC) motor –** essentially a permanent-magnet synchronous motor run from a DC supply via an electronic inverter/controller that performs the commutation (switching) electronically, using rotor-position feedback (Hall sensors or sensorless back-EMF sensing) — instead of the mechanical brushes/commutator of a conventional DC motor. The permanent-magnet rotor eliminates rotor copper loss and brush wear/sparking, giving high efficiency, a long maintenance-free life, compact size and a good torque-to-weight ratio — increasingly used in small agricultural pumps/drones/precision-farm equipment.

| Aspect | AC motor (induction) | DC motor (incl. BLDC) |
|---|---|---|
| Commutation | None needed — rotating field from AC supply | Conventional DC: mechanical brush/commutator; BLDC: electronic commutation, no brushes |
| Speed control | Needs a VFD (variable-frequency drive) for smooth control | Naturally easy — proportional to armature voltage/duty cycle |
| Maintenance | Low — no brushes (induction type) | Conventional DC needs brush/commutator maintenance; BLDC needs almost none |
| Starting torque/control precision | Lower precision, needs starters for large motors | High starting torque, precise control — preferred for servo/precision drives |
| Typical farm use | Pumps, mills, threshers, conveyors (grid/3-phase supply) | Battery/solar-DC-powered small pumps, drones, precision-seeders, robotics (BLDC); older DC — traction/special drives |

**PREVIOUS YEAR QUESTIONS**

Write short notes on: (i) BLDC motor. [other sub-parts from other chapters] [IFOS 2024 | P2/2(b) | 15 M]

**MODEL Q** Use the definition box above for the BLDC short note — construction (PM rotor + electronic commutation), and the advantages (no brushes, high efficiency, compact) as the 'why it matters' close. ***

◆ *Source: Electric Motors and Drives, Hughes & Drury, Ch.9 (Synchronous & Brushless PM Machines).*

## 6.4 MOTOR SELECTION CRITERIA & MAINTENANCE

- ***Selection factors*** : (i) load type & torque-speed demand — constant load (fans/pumps, quadratic torque-speed) vs high-inertia/shock load (crushers, hoists) decides the NEMA design class (§6.1); (ii) starting torque required vs available supply capacity (a large motor's inrush current may need reduced-voltage starting, §6.5); (iii) duty cycle — continuous vs intermittent operation affects thermal rating; (iv) supply available — single- vs three-phase, voltage/frequency; (v) speed & speed-control needs; (vi) operating environment — dusty, humid, wet, corrosive (enclosure/protection class); (vii) efficiency & running cost over the motor's life; (viii) physical size/mounting and cost.
- ***Regular maintenance*** : Periodic cleaning of windings/vents to prevent dust build-up and overheating; bearing lubrication/replacement; checking insulation resistance; tightening electrical connections; checking alignment and belt/coupling condition; testing starter/overload-relay settings.
- ***Causes of overheating & rectification*** : Sustained overload → match motor rating to load or reduce load; single-phasing (one supply line lost) → protect with a phase-failure relay, repair the open line; low supply voltage → correct supply/tap settings; blocked ventilation/dust-clogged windings → clean and ensure free airflow; worn bearings increasing friction → replace/lubricate bearings; frequent starting/stopping (jogging) beyond rated duty → match motor duty-cycle rating to the actual application; unbalanced supply voltage → correct supply balance.


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**PREVIOUS YEAR QUESTIONS**

- What factors are required to be considered for selection of electric motor used in agricultural operations? Write about the regular maintenance needed by an electric motor.
  [IFOS 2020 | P2/1(e) | 8 M]
- What factors should be considered for selection of right type of electric motor for agricultural operations? What are the causes of overheating of electric motors and how it can be rectified?
  [UK·PSC RFO 2021 | Q.6(e)(i) | 10 M]

**MODEL Q** Both PYQs answered directly and in full by the three bullet lists above. ***

## 6.5 STARTERS — WHY THEY ARE NEEDED

At standstill an induction motor's rotor is stationary and the stator winding presents very low impedance to the supply, so direct-on-line switching draws a very high inrush (locked-rotor) current — typically ***5 to 7 times*** full-load current. This heavy inrush causes a large supply-voltage dip (affecting other connected loads) and heavy electrical/mechanical stress on the motor windings. A ***starter*** limits this starting current to a safe value (e.g. by applying reduced voltage, or extra rotor resistance in a slip-ring motor) and ramps the motor up to running speed smoothly, after which full supply is restored.

- ***Common starter types*** : Direct-On-Line (DOL) — for small motors only; Star-Delta starter — starts in star (reduced voltage per winding) then switches to delta for running; Auto-transformer starter — applies a reduced tapped voltage during start; rotor-resistance starter — for slip-ring motors, adds external resistance in the rotor circuit during start.

**PREVIOUS YEAR QUESTIONS**

- Why a starter is needed for an AC motor? [AP·PSC RFO 2012 | Q.1(a) | 4 M]

**MODEL Q** The inrush-current explanation above is the complete answer for this short-mark question. ***

## 7 FORMULA SHEET

$$I_{sc} = 1367\ W/m^2$$
*Solar constant (extraterrestrial, normal incidence).*

$$Q_u = A_c[I_t(\tau\alpha) - U_L(T_p - T_a)]$$
*Flat-plate collector useful heat gain.*

$$\eta = Q_u/(A_c \cdot I_t)$$
*Collector instantaneous efficiency.*

$$P_wind = \tfrac{1}{2}\rho A V^3$$
*Power available in the wind; $A = \pi D^2/4$.*

$$P_shaft = C_p \cdot P_wind$$
*Betz limit: $C_{p,max} = 16/27 \approx 0.593$.*

$$\lambda = V_{tip}/V = \omega R/V$$
*Tip-speed ratio.*

$$C_q = C_p/\lambda$$

*Torque coefficient; $T = P_{shaft}/\omega = C_q \cdot (\frac{1}{2}\rho A R) V^2$.*

$$S = NC/(\pi D)$$

*Rotor solidity.*

$$Q = \Sigma(m_i \cdot cp_i) \cdot dt$$

*Thermal energy for heating/cooking a mixed load.*

## 8 SUMMARY

- ***Solar thermal*** : flat-plate collectors use beam + diffuse radiation, no tracking, moderate temperature; concentrating collectors (trough/dish/Fresnel/CPC) use beam radiation only, need tracking, reach 500 °C+; cooker/dryer/still/pond are all direct thermal applications at agriculture scale.
- ***Solar PV*** : cell → module → array → controller → battery → inverter is the standard system chain; monocrystalline > polycrystalline > amorphous in efficiency; sun-tracking (passive thermo-hydraulic or active motorised) recovers off-normal-incidence losses.
- ***Wind*** : HAWT (multi-blade/two-blade/propeller) vs VAWT (Savonius — drag, low TSR, high starting torque; Darrieus — lift, high TSR, needs external start); power $\propto V^3$; Betz limit $C_p \leq 0.593$; site selection and India's status/strategy are current-affairs-style questions needing up-to-date figures.
- ***Motors*** : induction motors are classified by supply (1-ϕ/3-ϕ), rotor (cage/slip-ring) and NEMA design class (A–F, by starting torque/current); single-phase types need an auxiliary winding (split-phase/capacitor) to self-start; BLDC = PM synchronous motor with electronic commutation; starters exist because DOL inrush current is 5–7× full-load current.

## 9 LAST-NIGHT REVISION

| Topic | Must-remember number/fact |
|---|---|
| Solar constant | 1367 W/m² |
| Betz limit | Cp,max = 16/27 ≈ 59.3% |
| Box cooker temperature rise | 70–110 °C above ambient (single reflector) |
| Multi-reflector oven temperature | up to 250–350 °C |
| Monocrystalline / polycrystalline / amorphous Si efficiency | 18–22% / 15–18% / 6–10% |
| Savonius rotor | drag type, low TSR, high starting torque, low wind speed, water pumping |
| Darrieus rotor | lift type, high TSR, not self-starting, higher wind speed |
| Typical HAWT cut-in / cut-out | ≈ 3–5 m/s / ≈ 25 m/s |
| NEMA Class B | most common — normal torque, low starting current |
| NEMA Class D | highest starting torque — hoists, punch presses, bulldozers |
| DOL starting current | 5–7 × full-load current |
| Single-phase motor | not self-starting — pulsating flux, zero net torque at standstill |
| BLDC | PM rotor + electronic commutation, no brushes |
| Solar-panel-area numerical (2017 IFoS) | BLOCKED — need source-paper parameter table |


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CHAPTER

# 9

# BIOGAS, BIOMASS & GASIFIER

*Biomass conversion · Producer gas · Anaerobic digestion · Plant design · Engines · Clean cooking*

**SYLLABUS :** Agricultural Engineering Paper II, Section A — Agro-energy: Solar (thermal and photovoltaic), wind and bio-gas energy and their utilization in agriculture. Gasification of biomass for running I.C. engines and for electric power generation. Energy-efficient cooking stoves and alternate cooking fuels.

## Chapter Outline

1. **Chapter orientation and biomass-energy fundamentals**
2. **Biomass conversion routes, densification and pyrolysis**
3. **Gasification chemistry, controlling parameters and gas quality**
4. **Fixed-bed and fluidized-bed gasifiers**
5. **Producer-gas cleaning, engines and electric power generation**
6. **Biogas science: anaerobic digestion and process control**
7. **Biogas plants: classification, components, KVIC and fixed-dome models**
8. **Sizing and IFoS worked numericals**
9. **Biogas utilization, engines, CBG and comparisons**
10. **Energy-efficient cooking stoves and alternate fuels**
11. **Farm, environmental, employment and economic dimensions**
12. **Formula sheet, summary and last-night revision**

## 1 CHAPTER ORIENTATION AND BIOMASS-ENERGY FUNDAMENTALS

***Biomass*** : recently living organic matter of plant, animal or microbial origin that stores solar energy as chemical energy. Agricultural biomass includes crop residues, woody residues, animal dung, agro-industrial wastes and purpose-grown energy crops.

**Agro-energy logic.** A farm produces dispersed, seasonal and moisture-variable residues. A sound energy system therefore begins with resource assessment—quantity, competing uses, moisture, ash, bulk density and collection radius—and then matches conversion route to the feedstock and required energy carrier. Dry fibrous residues suit combustion, gasification or pyrolysis; wet dung and biodegradable wastes suit anaerobic digestion; oilseeds suit transesterification; sugar/starch feedstocks suit fermentation.

- ***Primary residues*** : Straw, stalk, husk, shell, cobs, bagasse, pruning and forest residues.
- ***Secondary residues*** : Rice husk, sawdust, oil cakes and food-processing wastes generated at a processing point.
- ***Animal and wet wastes***: Cattle dung, poultry litter, piggery waste, kitchen waste and market waste.
- ***Energy outputs***: Heat, shaft power, electricity, producer gas, biogas/CBG, charcoal, bio-oil, biodiesel and ethanol.

**FUEL PROPERTIES THAT DECIDE CONVERSION PERFORMANCE**

| Property | Engineering significance | Preferred direction |
|---|---|---|
| Moisture | Consumes latent heat; lowers flame/gasifier temperature; raises tar. | Drying or anaerobic digestion when very wet |
| Ash | Inert burden; clinker/slag and erosion risk. | Low ash; know ash-fusion behaviour |
| Volatile matter | Controls rapid devolatilization, flame and tar precursors. | High VM aids ignition but needs tar control |
| Fixed carbon | Char available for reduction and sustained heat. | Supports stable gasification |
| Bulk density | Controls transport, storage and reactor feeding. | Densify loose residues |
| Particle size | Controls pressure drop, heat transfer and channeling. | Uniform size matched to reactor |
| Heating value | Energy released per unit mass or gas volume. | Use LHV for practical energy balances |

HHV (Higher Heating Value, or Gross Calorific Value) = LHV (Lower Heating Value, or Net Calorific Value) + latent heat associated with water vapour

*For practical engine and gasifier balances, use LHV unless stated otherwise.*

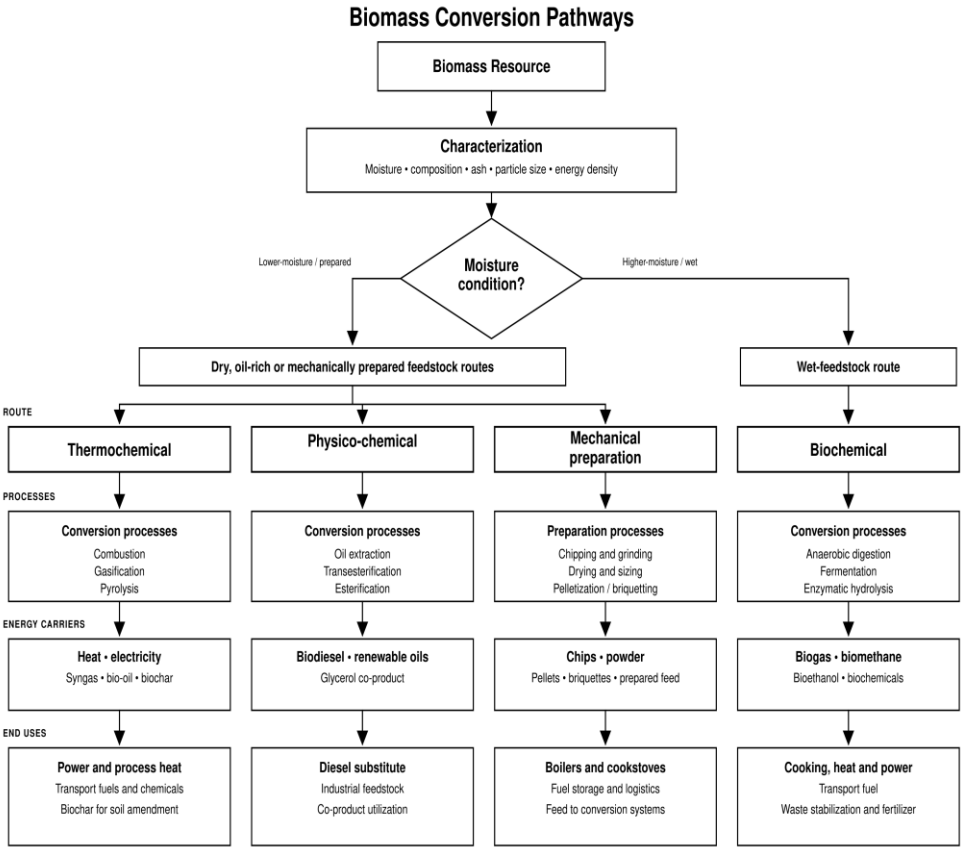
**PREVIOUS YEAR QUESTIONS**

Biomass and Biogas - Floating drum biogas plant and Fixed dome biogas plant - Beam radiation and Diffuse radiation - Solar thermal and Solar photovoltaic - With a flow diagram explain the steps followed in canning of fruits and vegetables. [HPPSC RFO 2021 | Q.7(a) | 10 M]

## 2 BIOMASS CONVERSION ROUTES

▣ ***Biomass Conversion Route Diagram***


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Biomass conversion is best written as a three-route classification. The examiner expects method → process → product → use, not an unstructured list.

| Route | Processes | Typical feed | Main products/use |
|---|---|---|---|
| Thermochemical | Combustion, gasification, pyrolysis, carbonization, liquefaction | Dry biomass, usually <15–25% moisture depending on process | Heat; producer gas/syngas; bio-oil; char |
| Biochemical | Anaerobic digestion, fermentation | Wet biodegradable waste; sugar/starch/cellulosic hydrolysate | Biogas; ethanol; digestate |
| Physico-chemical | Oil extraction + transesterification | Vegetable oils, waste cooking oil, animal fats | Biodiesel + glycerol |
| Mechanical /preparation | Size reduction, drying, pelletizing, briquetting | Loose residues | Standardized dense solid fuel; not a chemical conversion by itself |

**PREVIOUS YEAR QUESTIONS**

(i) What are the different methods of biomass conversion for energy generation? Enlist different processes of energy conversion under each method. [10 M] (ii) Name the different components of biomass gasifier-based electric power generation system. [5 M]. [IFOS 2023 | P2/3(a) | 15 M]

## 2.1 BRIQUETTING, PELLETIZATION AND CHARRING

***Briquetting*** : Mechanical densification of loose biomass into compact, regularly shaped fuel under pressure, with or without binder.

- ***Process train*** : Collection → drying → size reduction → screening/mixing → compaction → cooling → storage.
- ***Mechanisms*** : Particle rearrangement, elastic/plastic deformation, mechanical interlocking and lignin softening; binders may add adhesion.
- ***Advantages*** : Higher bulk density, easier handling and metering, more uniform combustion, lower transport cost per unit energy.
- ***Limitations*** : Power demand, die wear, moisture sensitivity, fines, capital cost and poor economics when collection radius is large.

***Charring/carbonization*** : Slow thermal decomposition of biomass with limited or no oxygen to drive off volatiles and leave carbon-rich charcoal.

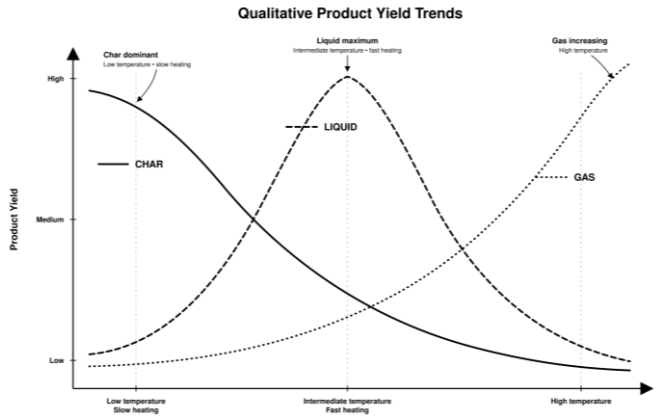
| Basis | Briquetting | Charring |
|---|---|---|
| Nature | Physical densification | Thermochemical conversion |
| Oxygen/heat | Pressure; moderate frictional heat | External heat; restricted oxygen |
| Product | Dense raw-biomass solid | Charcoal with higher fixed-carbon fraction |
| Mass/energy | Little chemical mass loss | Volatile loss; char retains only part of feed energy |
| Purpose | Handling, transport and uniform feeding | Smokeless/reducing fuel, metallurgical or soil-char uses |

## 2.2 PYROLYSIS AND PRODUCT CONTROL

Pyrolysis is thermal decomposition in the absence of externally supplied oxygen. After drying, cellulose, hemicellulose and lignin devolatilize at overlapping temperature ranges. Vapours may be condensed as bio-oil; non-condensable gases supply process heat; solid char remains.

| Mode | Heating/residence | Favoured product | Engineering note |
|---|---|---|---|
| Slow pyrolysis | Slow heating; long solids residence | Char | Traditional carbonization; maximize secondary char-forming reactions |
| Fast pyrolysis | Very rapid heating; vapour residence ≈ seconds | Bio-oil | Fine, dry feed; rapid quench required |
| Flash pyrolysis | Very high heating rate; very short contact | Gas/liquid depending temperature | Strong heat-transfer and solids-separation demand |

### ▣ *Pyrolysis Product Distribution*




*Caption: Heating rate, peak temperature and vapor residence time shift char–liquid–gas yields.*


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## 3 GASIFICATION CHEMISTRY AND PROCESS CONTROL

**Gasification :** Conversion of a solid or liquid carbonaceous fuel into a combustible gas by partial oxidation at high temperature using a sub-stoichiometric gasifying agent—air, oxygen, steam, or their mixture.

**Core distinction.** Combustion supplies excess oxygen and releases heat as the final product; gasification deliberately limits oxygen so that carbon energy remains in CO, $H_2$ and $CH_4$. Air-blown producer gas is diluted by $N_2$ and therefore has low calorific value; oxygen/steam raises gas quality but adds cost and control complexity.

**PRINCIPAL REACTIONS**

| Reaction | Equation | Heat effect / role |
|---|---|---|
| Complete oxidation | $C + O_2 \rightarrow CO_2$ | Strongly exothermic; heat source |
| Partial oxidation | $C + ½O_2 \rightarrow CO$ | Exothermic; combustible CO |
| CO oxidation | $CO + ½O_2 \rightarrow CO_2$ | Exothermic |
| Boudouard | $C + CO_2 \rightleftharpoons 2CO$ | Endothermic reduction |
| Water-gas | $C + H_2O \rightleftharpoons CO + H_2$ | Endothermic; forms $H_2$ |
| Water-gas shift | $CO + H_2O \rightleftharpoons CO_2 + H_2$ | Gas-composition adjustment |
| Methanation | $C + 2H_2 \rightleftharpoons CH_4$ | Exothermic; favoured by lower temperature |
| Steam reforming | $CH_4 + H_2O \rightleftharpoons CO + 3H_2$ | Endothermic; high-temperature $H_2$ formation |

Equivalence ratio, ER = actual air supplied / stoichiometric air for complete combustion

*Typical biomass gasification operates with ER well below 1; too low causes tar/instability, too high burns the gas and lowers LHV.*

**PREVIOUS YEAR QUESTIONS**

- (State the chemical reactions that occurs in gasifier. Explain the working of downdraft gasifier. [UKPSC RFO 2015 | Q.6(iv) | 10 M]
- Tangential flow threshing and axial flow threshing - Impact cutting and shear cutting of grasses - Write about different reactions occurring in a gasifier reactor? Describe in detail the power generation from biomass gasification. [OPSC Forest Service 2023–24 | P2/4(a) | 20 M]

### 3.1 PROCESS STAGES AND TEMPERATURE LOGIC

- ***Drying, about 100–200°C:*** Free and bound moisture is evaporated; no useful chemical conversion, but heat is consumed.
- ***Pyrolysis, about 200–600°C :*** Biomass decomposes into char, tar vapors and permanent gases.
- ***Oxidation, commonly 800–1200°C:*** Air/oxygen reacts with char and volatiles; exothermic heat drives all other zones.
- ***Reduction, commonly 700–1000°C:*** Hot char converts $CO_2$ and steam to CO and $H_2$; temperature falls along endothermic reactions.

★ ***Temperature profiles are reactor-specific*** State ranges and sequence, then relate them to flow direction. Exact boundaries depend on fuel, moisture, air rate, reactor size and measurement position; avoid presenting a single temperature as universal.

**PREVIOUS YEAR QUESTIONS**

- Enlist different types of fixed-bed biomass gasifiers and discuss different zones with temperature profiles. [IFOS 2024 | P2/1(e) | 8 M]

### 3.2 PARAMETERS AFFECTING PRODUCER-GAS GENERATION

- ***Moisture :*** high moisture absorbs heat, lowers reaction temperature, increases tar and may extinguish the oxidation zone.
- ***Particle size/shape :*** Oversize particles convert incompletely; fines cause high pressure drop, channeling or entrainment.
- ***Bulk density and porosity :*** Control bed residence time, voidage and uniformity of airflow.
- ***Ash and fusion temperature :*** High or low-fusion ash forms clinker and blocks grate/air nozzles.
- ***Volatile matter/fixed carbon :*** High volatiles increase pyrolysis gas and tar load; char sustains reduction.
- ***ER and air distribution :*** Set temperature, carbon conversion, gas LHV and tar; air leakage dilutes gas.
- ***Hearth load/residence time :*** Overloading carries char/tar; under-loading may not maintain thermal equilibrium.
- ***Reactor temperature and pressure drop :*** Indicate reaction completion, bridging, channeling, fouling and safe operation.

**PREVIOUS YEAR QUESTIONS**

- List the factors affecting the following : (i) Biogas production from cattle manure (ii) Producer gas production from agricultural crop residues (iii) Draft requirement of a tractor drawn mouldboard plough (iv) Grain losses in a power thresher. [IFOS 2021 | P2/1(e) | 8 M]
- Discuss the applications of gasifiers for the conversion of biomass and agricultural residues. What are the essential parameters affecting gasification? Describe the construction and working operation of an updraft gasifier highlighting the formation of different zones within the biomass.
  [OPSC CSE 2024–25 | P2/Q15 | 20 M]

## 4 GASIFIER TYPES AND WORKING

Gasifiers are classified by gas–solid contacting pattern: fixed/moving bed, fluidized bed, entrained flow and special designs. Agricultural-engineering answers usually classify fixed beds by relative direction of fuel, air and product gas.

| Type | Flow pattern | Tar tendency | Fuel tolerance | Best-known use |
|---|---|---|---|---|
| Updraft / counter-current | Fuel down; air and gas up | High | Good moisture and size tolerance; low pressure drop | Direct heat; gas requiring strong cleanup |
| Downdraft / co-current | Fuel and gas down through hot throat/char | Low | Needs dry, uniform, low-ash fuel | Small engine-generator systems |
| Crossdraft | Air enters side; gas exits opposite side | Low–moderate; short hot zone | Usually charcoal; sensitive to raw high-volatile biomass | Compact, rapid-response units |
| Fluidized bed | Fine solids suspended by | Moderate; good mixing | Wide fuel range, larger capacity; fines handling | Industrial heat/power and |


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| | | | | |
|---|---|---|---|---|
| | upward gas | | needed | scale-up |

**PREVIOUS YEAR QUESTIONS**

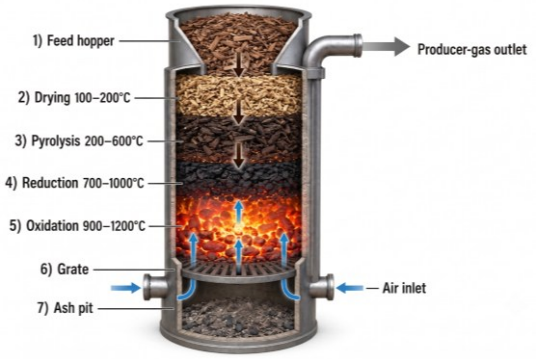
- Give the classification of gasifiers as per the direction of the gas flow. Explain the working principle of updraft type gasifier with neat sketch. [MHPSC Forest Services 2024 | Q.5(b) | 8 M]
- What are the various constituents present in the producer gas? Explain the different types of gasifier with the help of suitable diagram. [OPSC CSE 2018–19 | P2/4(b) | 20 M]
- what is gasifire? Whar are the gases obtained during gasification in gasifire?

[APPSC RFO 2012 |Q.1(L) | 4 M]

## 4.1 UPDRAFT GASIFIER

Air enters below the grate and product gas leaves at the top, counter-current to descending fuel. The bottom oxidation zone produces heat; gas passes upward through reduction, pyrolysis and drying zones. Rising hot gas preheats and dries fresh fuel, giving high thermal efficiency and low exit temperature. The penalty is high tar: pyrolysis vapours leave without passing through a sufficiently hot char bed.

### ▣ *Updraft Gasifier—Construction And Zones*




*Counter-current updraft gasifier: efficient heat recovery but tar-rich*

- ***Advantages*** : Simple construction, high carbon conversion, high cold-gas efficiency, low pressure drop and tolerance to moist/coarse fuel.
- ***Limitations*** : High tar and condensate; unsuitable for engines without extensive cooling and cleaning; channeling and clinker remain possible.

**PREVIOUS YEAR QUESTIONS**

- What is gasification? Explain the working of up-draft type gasifier with a neat diagram.

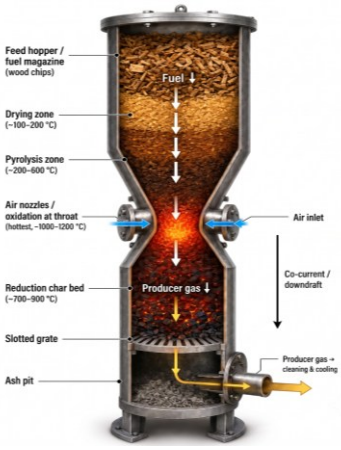
[IFoS 2020 | P2/1(d) | 8 M]

## 4.2 DOWNDRAFT GASIFIER

Air is admitted near the oxidation throat and gas flows downward with fuel. Pyrolysis vapors are forced through the high-temperature oxidation zone and hot char reduction bed, so much of the tar is cracked. The gas exits hot from below the grate and must be cooled and cleaned before an engine.

### ▣ *Downdraft Gasifier—Construction And Zones*

- ***Advantages*** : Lower tar than updraft, compact, good load response and proven engine compatibility after cleanup.
- ***Limitations*** : Narrow fuel-size/moisture range, throat bridging, high gas-exit temperature, fines/char carry-over and scale-up limitation.




*Co-current downdraft gasifier: low-tar gas suited to small IC-engine systems.*

**PREVIOUS YEAR QUESTIONS**

- Explain the working principle of a downdraft type gasifier with a suitable diagram.

[IFoS 2018 | P2/1(e) | 8 M]

- Explain the working principle of updraft and downdraft gasifiers and draw the diagram for updraft and downdraft gasifiers [OPSC CSE 2023–24 | P2/8(a) | 15 M]

### 4.3 CROSSDRAFT AND FLUIDIZED-BED GASIFIERS

**Crossdraft.** Air enters through a high-velocity side tuyere and gas leaves from the opposite side. The compact reaction zone gives fast start and response, but intense local temperature demands refractory and normally favours charcoal.

**Fluidized bed.** Air/steam suspends an inert bed (commonly sand) and biomass particles. Vigorous mixing produces near-uniform temperature, high heat/mass transfer and flexible scale. Bubbling beds operate just above minimum fluidization; circulating beds use higher velocity and recycle entrained solids. Disadvantages are auxiliary power, bed agglomeration, dust carry-over and more elaborate feeding/cyclones..

## 5 PRODUCER GAS, CONTAMINANTS AND CLEANUP

***Producer gas :*** Low-calorific-value fuel gas obtained by air/air–steam gasification, consisting mainly of CO, $H_2$, $CH_4$, $CO_2$ and $N_2$, with water vapour and contaminants. Composition is feedstock- and reactor-dependent.

| Constituent | Indicative air-blown range (vol.%, dry) | Role |
|---|---|---|
| CO | 15–25 | Major combustible; toxic |
| $H_2$ | 10–20 | Fast-burning combustible |
| $CH_4$ | 1–5 | High-heating-value minor component |
| $CO_2$ | 8–15 | Non-combustible; dilution |
| $N_2$ | 40–55 | Major inert dilution from air |
| LHV | about 4–6 MJ/Nm$^3$ | Roughly one-sixth to one-fifth of natural gas |

***Use ranges, not a universal recipe*** Producer-gas composition varies with biomass, moisture, ER, gasifying agent, temperature and sampling basis.***

### 5.1 TAR AND PARTICULATE MATTER

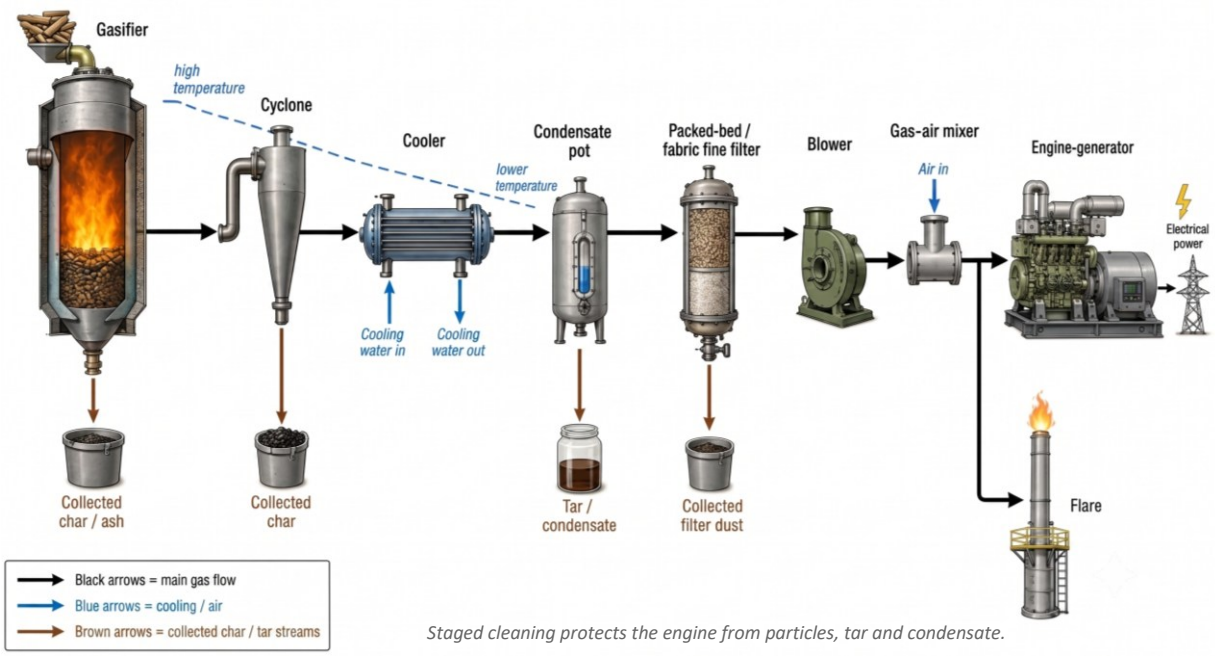
| Basis | Tar | Particulate matter |
|---|---|---|
| Nature | Condensable organic vapours/aerosols from incomplete cracking | Entrained ash, char, soot, bed material and dust |
| Phase behaviour | Vapour at reactor temperature; sticky liquid/solid on cooling | Solid particles over operating range |
| Damage | Fouls coolers, valves and intake; gums piston rings; blocks pipes | Erodes blower/engine; abrades rings; deposits and blocks filters |
| Control | High-temperature cracking, catalytic bed, thermal management, wet scrubber/condensation | Cyclone, settling, hot filter, fabric/packed-bed filter, scrubber |
| Measurement | Mass of condensable organics per normal volume | Gravimetric particle loading and size distribution |


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**A PRACTICAL CLEANUP TRAIN**

Reactor → cyclone (coarse solids) → hot/guard filter → gas cooler/heat exchanger → condensate trap → fine filter or scrubber → safety filter → gas–air mixer → engine. Sequence matters: first remove hot coarse dust, then cool/condense tar, then polish. Provide drains, flare, pressure-relief and CO-safe ventilation.

▣ ***Producer-Gas Cleaning Train***




*Staged cleaning protects the engine from particles, tar and condensate.*

## 5.2 PERFORMANCE INDICES

Cold-gas efficiency, $\eta cg = (Vg \times LHVg) / (mf \times LHVf)$

*Use consistent time basis; Vg is normal-volume gas flow and mf is biomass consumption.*

Specific gas yield = Vg / mf ; Specific fuel consumption = mf / electrical energy

*Quote gas at stated reference conditions and include auxiliary loads.*

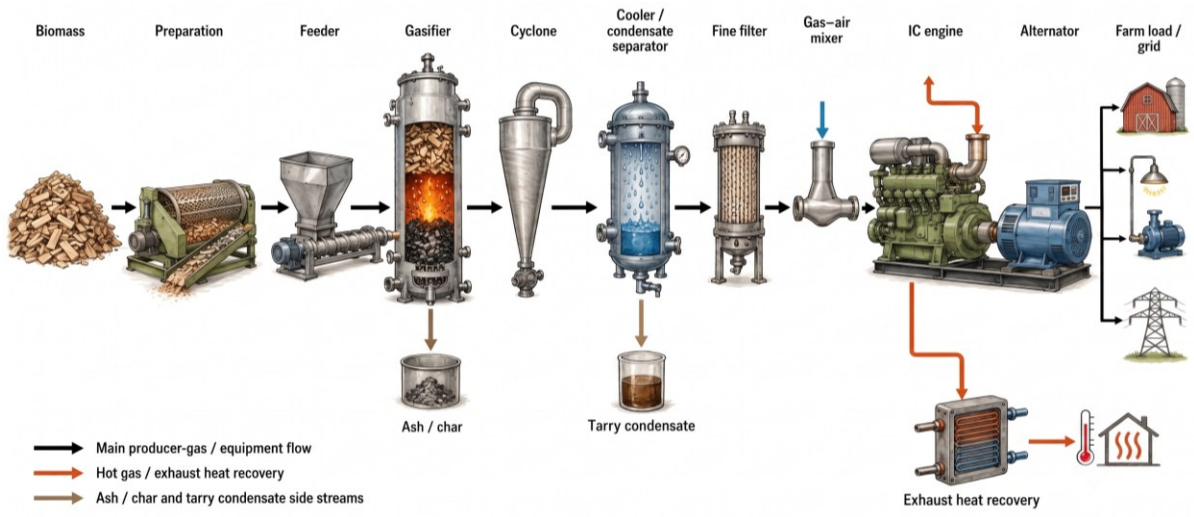
## 6 GASIFIER-BASED ENGINES AND ELECTRIC POWER

A dependable biomass power plant is a chain, not merely a reactor. Feedstock logistics and preparation govern availability; the reactor governs conversion; cleanup governs engine life; controls and load management govern power quality.

**SYSTEM COMPONENTS AND ENERGY FLOW**

1. ***Fuel reception*** : Weighing, covered storage, size reduction, screening and drying.
2. ***Metered feeding*** : Hopper, lock-hopper/rotary valve and anti-bridging device prevent air leakage.
3. ***Gasification*** : Reactor, air nozzles/blower, grate, ash/char handling and temperature/pressure instrumentation.
4. ***Cooling and cleaning*** : Cyclone, cooler, condensate separator, scrubber or filters and safety filter.
5. ***Power island*** : gas–air mixer, spark-ignition gas engine or dual-fuel diesel engine, governor, alternator and control panel.
6. ***Safety/environment*** : Flare, CO detector, flame arrestor, pressure relief, wastewater/tar management and earthing.

### ▣ *Biomass Gasifier Power System*




*Components of a gasifier-based electric power-generation system.*

**PREVIOUS YEAR QUESTIONS**

- Explain how the producer gas and biogas is used for running I. C. engines and for electric power generation. [OPSC CSE 2017–18 | P2/1(b) | 20 M]
- Producer gas and bio gas for running I. C, engines. [OPSC CSE 2020–21 | P2/4(c)(iv) | 5 M]
- How bio gas and producer gas is used for running I. C. engines? [OPSC CSE 2016–17 | P2/4(d) | 15 M]

## 6.1 ENGINE OPTIONS

| Mode | Ignition and control | Practical implication |
|---|---|---|
| 100% gas spark-ignition | Spark plug; throttle/gas–air mixer; compression ratio chosen to avoid knock | No liquid pilot; clean gas and stable mixture essential |
| Dual-fuel compression-ignition | Small diesel pilot auto-ignites premixed producer gas/biogas–air | Retains diesel capability; diesel substitution falls at low load |
| Converted diesel to SI | Lower/appropriate compression ratio, spark plug and ignition system, gas carburetion | More extensive modification; dedicated gas operation |

**Producer-gas derating.** Low LHV and the volume occupied by gas reduce inducted air and mixture energy per cycle, so maximum power is lower than on liquid fuel. A governor must coordinate gas and pilot-fuel racks. Never feed dirty, wet gas: tar, dust and corrosive condensate rapidly destroy valves, liners and lubricating oil.

## 6.2 APPLICATIONS AND SUSTAINABLE AGRICULTURE

- ***Thermal*** : Crop drying, tea/tobacco curing, boilers, kilns and process heat; tar tolerance may be higher than engines.
- ***Mechanical/electric*** : Irrigation pumping, milling, cold storage, dairy loads and village mini-grids.
- ***Circularity*** : use local residues, return clean ash/biochar appropriately, recover engine heat and integrate seasonal load.
- ***Innovations*** : Sensor-based ER/temperature control, automated feeding, modular throatless reactors, improved ceramic/catalytic filters, CHP, remote monitoring and hybrid solar–biomass microgrids.
- ***Caution*** : Sustainability requires residue-retention limits, no diversion of fodder, safe tar disposal, fair feedstock pricing and realistic collection radius.


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**PREVIOUS YEAR QUESTIONS**

How does producer gas technology align with sustainable agricultural practices and what advancements or innovations are being made in this field? [OPSC CSE 2023–24 | P2/8(b) | 15 M]

## 7 BIOGAS AND ANAEROBIC DIGESTION

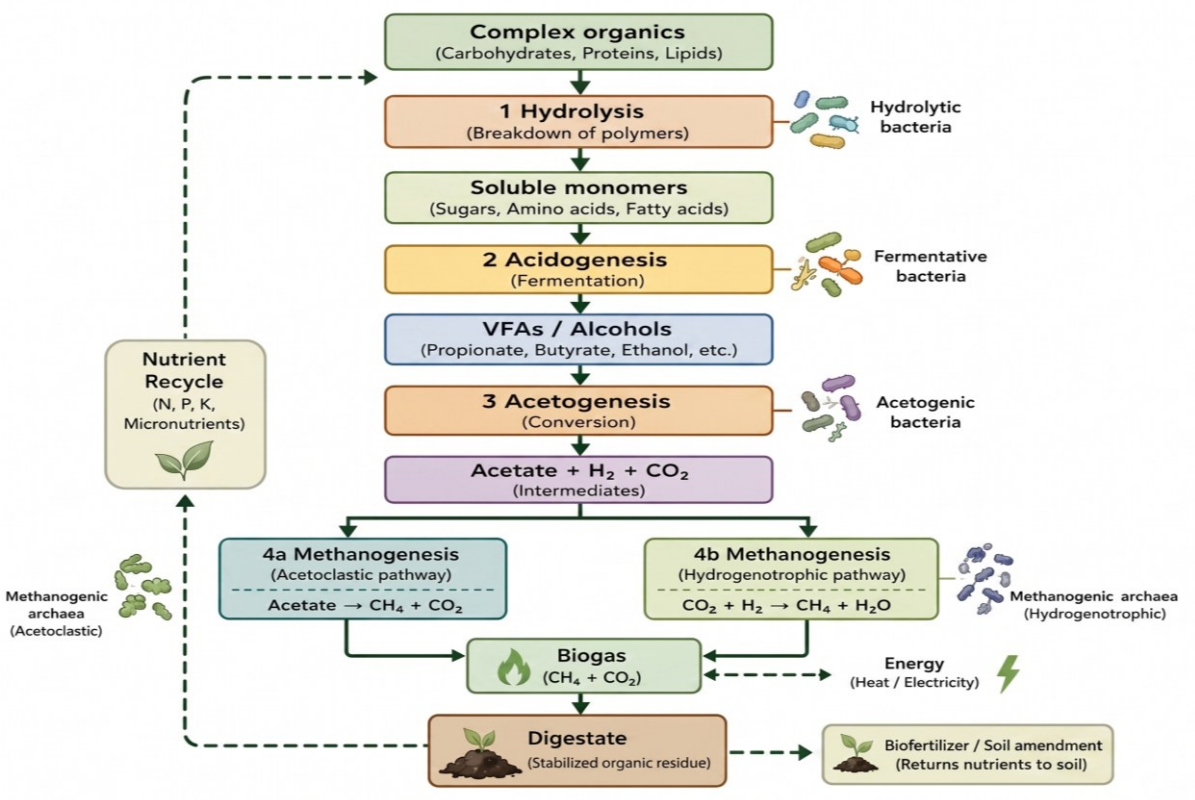
**Biogas :** The combustible gas produced when microorganisms decompose biodegradable organic matter without molecular oxygen. It commonly contains about 55–65% $CH_4$, 35–45% $CO_2$ and traces of $H_2S$, water vapour, $NH_3$, $H_2$ and $N_2$.

**Energy and co-product.** Methane provides energy; stabilized digestate retains most mineral nutrients and part of the organic matter. Thus a biogas plant is simultaneously a waste-treatment, sanitation, renewable-energy and nutrient-recycling system.

**FOUR BIOLOGICAL PHASES**

1. ***Hydrolysis :*** Extracellular enzymes split carbohydrates, proteins and lipids into sugars, amino acids and long-chain fatty acids.
2. ***Acidogenesis :*** Fermenters convert soluble monomers to volatile fatty acids (VFAs), alcohols, $CO_2$, $H_2$, $NH_3$ and other intermediates.
3. ***Acetogenesis :*** Syntrophic bacteria convert higher VFAs/alcohols mainly to acetate, $CO_2$ and $H_2$; low hydrogen partial pressure is crucial.
4. ***Methanogenesis :*** Strict anaerobic archaea form $CH_4$ chiefly from acetate and from $H_2 + CO_2$; this slow, sensitive step often controls stability.

### ▣ *Anaerobic Digestion Pathway*




*Coupled microbial consortia convert wet biomass into methane-rich biogas.*

**PREVIOUS YEAR QUESTIONS**

- What are the different phases of anaerobic digestion for bio-gas production? What are the advantages of anaerobic digestion? [IFoS 2018 | P2/3(a) | 10 M]

## 7.1 ANAEROBIC VERSUS AEROBIC TREATMENT

| Basis | Anaerobic | Aerobic |
|---|---|---|
| Oxygen | Excluded; sealed digester | Continuously supplied |
| Energy balance | Produces methane; low mixing/aeration demand | Consumes substantial aeration energy |
| Biomass/sludge yield | Low | High |
| Rate/start-up | Slower; long start-up and HRT | Faster |
| Odour/pathogens | Controlled only with good sealing and adequate digestion | Generally good oxidation; aerosols/odour possible |
| Nutrient fate | Digestate rich in available nutrients; $NH_4^+$ retained | Some N lost/converted; large sludge stream |
| Sensitivity | Methanogens sensitive to pH, toxins, temperature and overload | More robust to some shocks but oxygen-dependent |

**PREVIOUS YEAR QUESTIONS**

- Differentiate between the following in brief : (i) Gas engine and Dual fuel engine (ii) CNG and Bio-CNG (iii) Anaerobic process and Aerobic process (iv) Active solar heating and Passive solar heating. [IFoS 2016 | P2/1(c) | 8 M]

## 7.2 MERITS, LIMITATIONS AND SAFEGUARDS

- ***Merits :*** Renewable cooking/power fuel, methane capture, odour and fly reduction, pathogen reduction, lower BOD/COD, nutrient-rich slurry and women's time savings.
- ***Limitations :*** Capital and masonry quality, regular water/feed requirement, temperature sensitivity, scum/sediment, $H_2S$ corrosion, leakage, slow start-up and digestate-management need.
- ***Safeguards :*** Gas-tight construction, water trap and $H_2S$ removal, no flame near plant, good ventilation, pressure relief, no confined-space entry, fenced slurry pits and gloves/hygiene.

◆ *Source: FAO, Biogas Technology: A Training Manual for Extension, Sessions 1, 4 and 9; Nijguna, Biogas Technology for India.*

# 8 FACTORS GOVERNING BIOGAS PRODUCTION

A high-scoring answer links each factor to microbial kinetics, mass transfer or toxic inhibition and states the direction of effect.

| Factor | Favourable practice | If outside range |
|---|---|---|
| Manure : water ratio | Commonly 1:1 by mass for fresh cattle dung; make pumpable ≈8–10% ts slurry | Too thick: poor mixing/scum; too dilute: larger digester and low volumetric yield |
| Temperature | Stable mesophilic operation, roughly 30–38°c; 35°c often used in design | Low: slow kinetics/long hrt; sudden change shocks consortia |
| Ph/alkalinity | Near neutral, about 6.8–7.5; adequate buffering | Acidification suppresses methanogens; excessive alkalinity/free $nh_3$ can inhibit |
| Hrt | Long enough for temperature/feed biodegradability | Too short washes out methanogens; too long increases cost |


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| | | |
|---|---|---|
| Organic loading rate | Gradual, uniform loading matched to active biomass | Overload → vfa accumulation, ph fall and gas collapse |
| C:n ratio | Balanced substrate; often about 20–30:1 as a guide | Low c:n → ammonia; high c:n → n limitation |
| Ammoniacal nitrogen | Nutrient at moderate level; acclimatize | High free $nh_3$ is toxic, especially at high ph/temperature |
| Mixing | Break scum, distribute microbes and heat without excessive shear | No mixing → stratification; excess mixing wastes energy |
| Toxicants | Exclude disinfectants, antibiotics, heavy metals, salts and pesticides | Microbial inhibition or death |
| Particle size/inoculum | Reasonable size reduction and active digested slurry at start-up | Slow hydrolysis and delayed commissioning |

**PREVIOUS YEAR QUESTIONS**

- Write the effect of the following on biogas production from a cow manure-based biogas plant : (i) manure-water ratio (ii) ambient temperature (iii) total solid content in manure (iv) ph of slurry (v) ammoniacal nitrogen in slurry. [IFoS 2024 | P2/4(a) | 15 M]
- Discuss various factors which affect the generation of biogas production. [IFoS 2012 | Q.4(e) | 10 M]

## 8.1 TOTAL SOLIDS, VOLATILE SOLIDS AND LOADING

**Total solids (TS) :** Residue remaining after drying a representative slurry sample; TS = fixed solids + volatile solids.

**Volatile solids (VS) :** Fraction of TS lost on controlled ignition; a practical estimate of biodegradable/organic matter, though not all VS is equally degradable.

TS (%) = dry residue mass / wet sample mass × 100 ; VS (%) = ignition mass loss / dry residue mass × 100

**Design implication.** Fresh cattle dung near 18% TS diluted 1:1 gives roughly 9% TS, a pumpable concentration suited to many household plants. Daily VS loading determines biological demand; slurry volume and HRT determine digester size.

**PREVIOUS YEAR QUESTIONS**

- Write the major differences between the following : (i) Tar and Particulate matter (ii) Briquetting and Charring (iii) Wind mill and Water mill (iv) Mechanical efficiency and Thermal efficiency (v) Total solids and Volatile solids. [IFoS 2016 | P2/4(c) | 10 M]

# 9 BIOGAS-PLANT CLASSIFICATION, COMPONENTS AND SITE

**CLASSIFICATION**

- ***By construction/material :*** Masonry/concrete, steel, ferrocement, prefabricated plastic/FRP or flexible tubular/bag plants.
- ***By gas storage :*** floating gas holder, fixed dome, separate external gas holder, flexible membrane/bag.
- ***By feeding :*** batch, semi-continuous or continuous.
- ***By solids regime :*** Wet digestion, dry/high-solids digestion; plug-flow or completely mixed.

- ***By temperature :*** Psychrophilic/ambient, mesophilic and thermophilic.
- ***By stage :*** Single-stage or two/multi-stage separation of acid and methane phases.

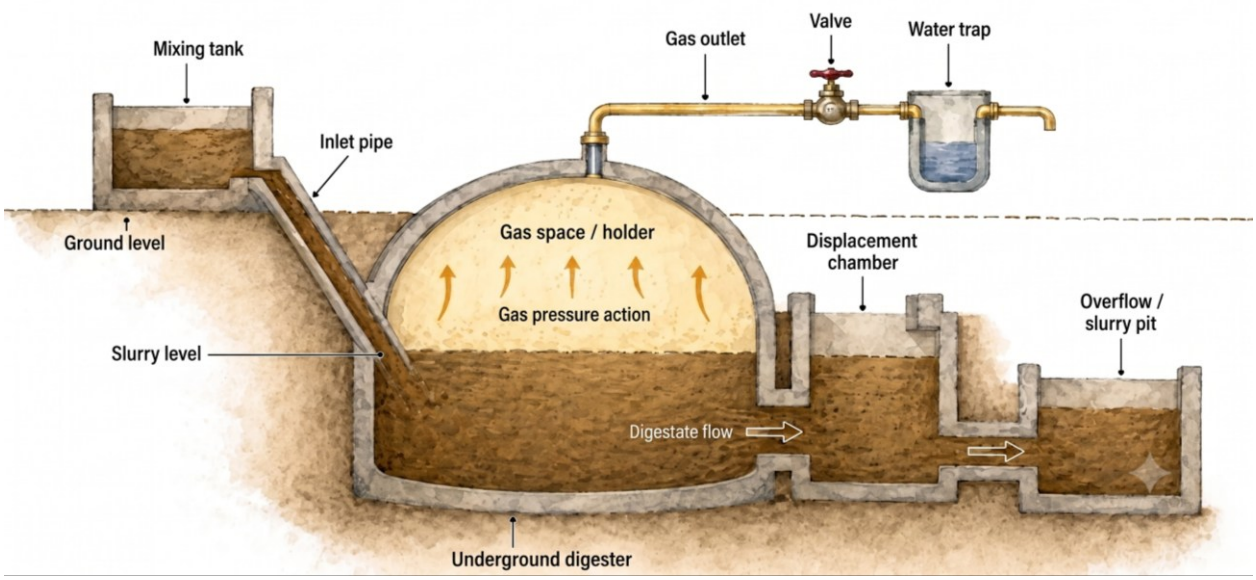
**PREVIOUS YEAR QUESTIONS**

- Classify the digester of a biogas plant on the basis of construction as well as on the basis of gas storage. Also, discuss the utilization of biogas for different applications. [IFoS 2025 | P2/4(a) | 15 M]
- What are the main components of a biogas plant? On what basis biogas plants can be classified? [UKPSC ACF/RFO/Logging Officer 2025 | Q.6(iii) | 10 M]

## 9.1 FUNCTIONAL COMPONENTS

| Component | Function/design point |
|---|---|
| Mixing tank | Homogenizes dung and water; screens stones, straw and grit |
| Inlet pipe/chamber | Transfers daily feed below slurry level; prevents gas escape |
| Digester | Gas-tight anaerobic reaction volume; resists soil/water pressure |
| Gas holder/dome | Stores gas and develops pressure |
| Outlet/displacement chamber | Accommodates slurry displaced by gas and maintains hydraulic level |
| Slurry pit/channel | Collects digestate for composting, drying or field application |
| Gas line | Main valve, pressure gauge, water trap, $H_2S$ filter, flame arrestor and appliance valves |
| Manhole | Inspection/desludging; must remain gas-tight and never be entered without confined-space controls |

▣ ***Generic Biogas Plant—Functional Layout***




*Common functional parts of household and farm biogas plants.*

**PREVIOUS YEAR QUESTIONS**

- List the factors to be considered for the design of biogas plant. Briefly discuss the components of a biogas plant with the help of neat sketch. [IFoS 2017 | P2/1(c) | 8 M]
- Compare floating gas holder and fixed-dome types of biogas units. [UKPSC ACF/RFO/Logging Officer 2025 | Q.6(iv) | 10 M]


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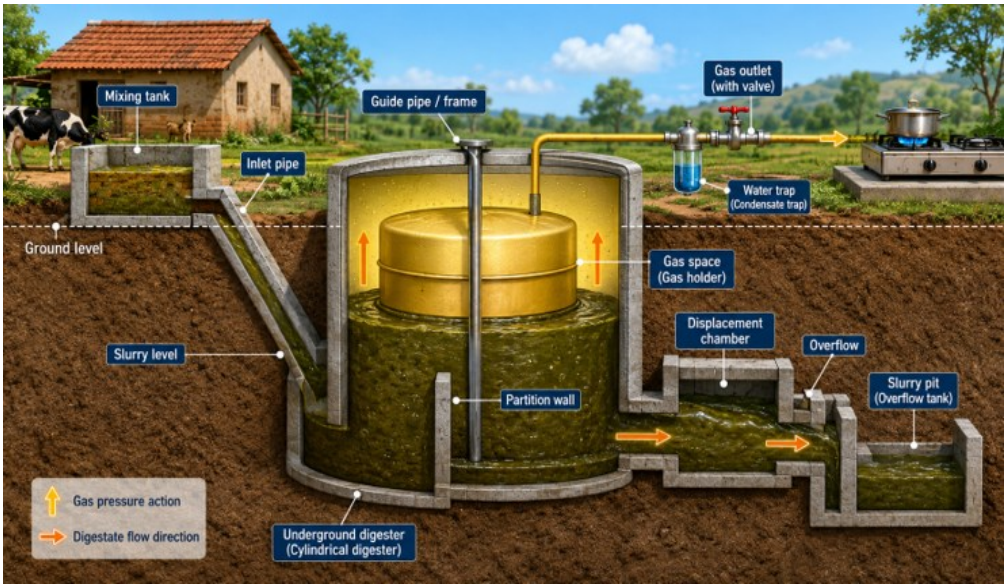
## 9.2 SITE SELECTION

- ***Feed and water :*** Close to cattle shed and reliable water; short, level feeding route.
- ***Use point :*** Near kitchen/engine to reduce gas-pipe loss, yet with fire-safe separation and ventilation.
- ***Ground :*** Firm, well-drained, outside flood path; groundwater below excavation where possible.
- ***Sun and climate :*** Sunny exposure helps ambient-temperature plants; protect piping and appliances.
- ***Sanitation :*** Away from drinking-water wells and runoff to water bodies; safe slurry handling.
- ***Construction/O&M :*** Space for excavation, future repair, slurry storage and access; no heavy vehicle load over digester.

## 10 KVIC FLOATING-DRUM BIOGAS PLANT

The KVIC model has an underground cylindrical masonry digester and a mild-steel gas holder that floats on the slurry, commonly guided by a central or external frame. Gas lifts the drum; consumption lowers it. The drum weight delivers nearly constant pressure, while its movement indicates stored gas.

### ▣ *KVIC Floating-Drum Plant*




*KVIC model: floating gas holder gives visible storage and nearly constant gas pressure*

**CONSTRUCTION AND WORKING—ANSWER SEQUENCE**

1. ***Charging :*** Fresh dung is mixed, usually 1:1 with water, and fed through the inlet.
2. ***Digestion :*** Slurry remains for design HRT while microbial phases generate biogas.
3. ***Storage/pressure :*** Gas collects under the drum; the drum rises and its weight pressurizes the gas.
4. ***Displacement :*** New feed and gas pressure displace digested slurry to the outlet/overflow.
5. ***Utilization :*** Gas passes through valve, water trap and optional $H_2S$ filter to stove or engine.
   - ***Merits :*** Almost constant pressure, visible gas volume, easy scum breaking by drum rotation, accessible holder.
   - ***Demerits :*** Steel corrosion, painting/maintenance, higher cost, heat loss and drum jamming/tilting.

**PREVIOUS YEAR QUESTIONS**

Using a neat diagram, explain the construction and working of KVIC-type biogas plant.

[IFoS 2023 | P2/4(b) | 15 M]

With the help of suitable diagram, show the different components of floating dome type biogas plant. Compare the advantages and disadvantages of floating dome and fixed dome type digesters in a biogas plant. [IFoS 2019 | P2/4(b) | 15 M]

## 11 FIXED-DOME PLANTS: JANATA AND DEENBANDHU

### 11.1 JANATA MODEL

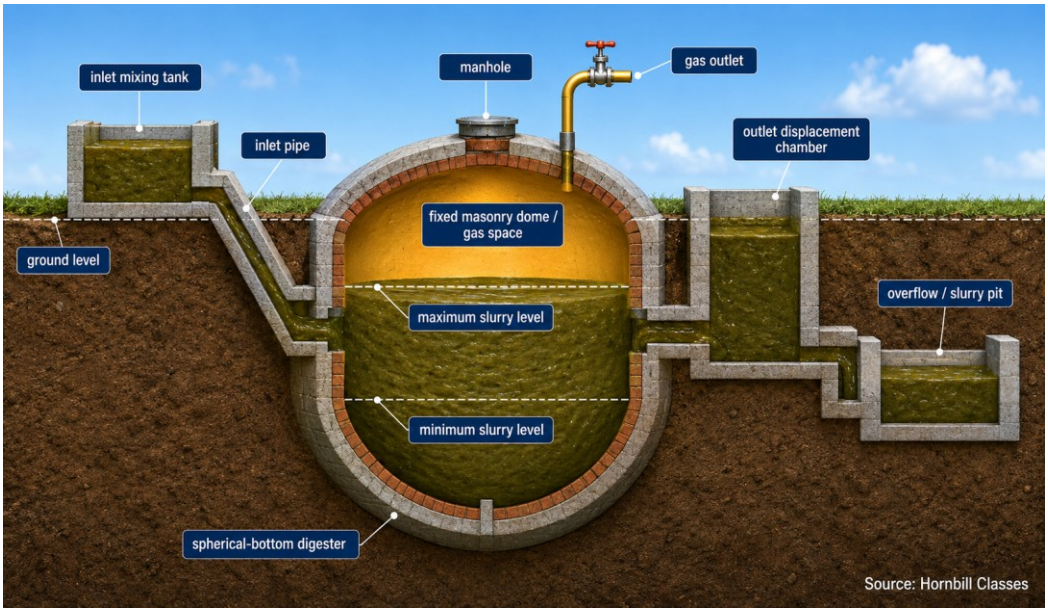
The Janata plant is a fixed-dome masonry design. The digester and gas-storage dome form a rigid gas-tight structure; gas pressure displaces slurry into an outlet/compensation chamber. Pressure varies with stored gas and slurry-level difference. It eliminates a steel drum but demands excellent masonry, plastering and crack control.

- ***Merits :*** Low maintenance, no corrosion-prone moving holder, underground thermal insulation and long life if well built.
- ***Demerits :*** Variable pressure, no direct indication of gas volume, hidden leakage/cracks, skilled construction and scum access difficulty.

### 11.2 DEENBANDHU MODEL

Deenbandhu is a cost-reduced fixed-dome plant whose digester floor, spherical/segmental walls and dome distribute loads efficiently and reduce masonry compared with older fixed-dome geometry. Inlet and outlet chambers are integrated with the underground digester. Gas accumulation increases pressure, displacing slurry to the outlet; gas use allows slurry to return.

***Deenbandhu Fixed-Dome Plant***




*Deenbandhu: structurally efficient fixed dome, low maintenance and variable gas pressure.*

- ***Farmer suitability :*** Lower material cost, locally available brick/cement, underground temperature stability, no steel-holder maintenance and small land footprint.
- ***Construction keys :*** Correct templates/curvature, sound foundation, rich gas-tight plaster, curing, backfilling only after checks and leak testing before commissioning.
- ***O&M :*** Uniform daily feeding, remove grit, protect gas line, drain condensate, monitor pressure/flame and use digestate promptly.


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**PREVIOUS YEAR QUESTIONS**

- Draw a neat figure showing the different components of a Deenbandhu Biogas plant and describe its working. [IFoS 2021 | P2/4(b) | 15 M]
- Explain the characteristic features of a 'Deenbandhu' biogas plant suitable for a farmer. [OPSC CSE 2022–23 | P2/10(a) | 10 M]
- State merits and demerits of anaerobic digestion of biogas waste. Describe the constructional feature of fixed Dome Janta type Biogas plant [UKPSC RFO 2015 | Q.7(i) | 10 M]

## 11.3 KVIC VERSUS FIXED DOME

| Basis | KVIC floating drum | Janata/Deenbandhu fixed dome |
|---|---|---|
| Holder | Movable steel/FRP drum | Rigid masonry gas space |
| Pressure | Nearly constant from drum weight | Variable with gas volume/slurry head |
| Gas indication | Drum height visibly indicates storage | Not directly visible |
| Cost | Higher due to holder and guide | Lower, especially Deenbandhu |
| Maintenance | Corrosion/painting and guide movement | Low moving-part maintenance; cracks/leakage may be hidden |
| Heat | Exposed drum loses heat | Underground dome gives better insulation |
| Scum | Drum movement/rotation can help break scum | Scum removal more difficult |
| Construction skill | Drum fabrication/anti-corrosion critical | Gas-tight masonry curvature/plaster critical |

**PREVIOUS YEAR QUESTIONS**

- Explain bio-digestion process in a biogas plant. Also, mention the functions of various parts of Khadi and Village Industries Commission (KVIC) model of biogas plant and compare it with Janata model. [UKPSC RFO 2012 | Q.6(i) | 10 M]

## 12 BIOGAS-PLANT SIZING AND DESIGN EQUATIONS

Separate three volumes: daily slurry volume, working digester volume and gas-storage/freeboard volume. The most common error is to multiply dung mass directly by HRT without converting it to slurry volume.

Daily dung mass, $m_d$ = number of animals × recoverable dung per animal per day

Daily slurry mass, $m_s = m_d$ + added water ; Daily slurry volume, $Q_s = m_s / \rho_s$

Working digester volume, $V_w = Q_s \times HRT$

Actual constructed volume, $V_a = V_w$ / useful-volume fraction

*For 10% freeboard, useful fraction = 0.90; alternatively $V_a = 1.10V_w$ only when the convention explicitly says 'add 10%'.*

Cylinder volume, $V = (\pi/4)D^2H$ ; if $H = kD$, $D = [4V/(\pi k)]^{1/3}$

Daily biogas, $V_b$ = substrate mass × specific gas yield

Useful energy/day = $\eta_u \times x_{CH_4} \times V_b \times LHV_{CH_4}$ ; continuous power = energy/day ÷ 86,400

***Design assumptions must be declared*** HRT depends mainly on temperature and feed biodegradability; gas-storage fraction depends on demand pattern. If a PYQ omits HRT or H:D ratio, state the omission, give a parametric result and then adopt a defensible design assumption.***

◆ **WORKED NUMERICAL — *Known cylindrical digester and daily gas*** [IFoS 2021 · P2/3(c) · 10M]

**Problem.** A cattle manure-based biogas plant has diameter and height of digester as 2 m and 5 m respectively. The plant is charged daily with 100 kg fresh manure mixing it in equal proportion with water. If the input slurry has density of 1.05 g/cc, calculate the volume of digester of the plant and also the daily biogas production from the plant if 50 l biogas is produced from one kilogram of fresh manure.

**Given** $D = 2$ m; $H = 5$ m; fresh manure = 100 kg $d^{-1}$; water = 100 kg $d^{-1}$; $\rho s = 1.05$ g $cm^{-3} = 1050$ kg $m^{-3}$; gas yield = 50 L $kg^{-1}$.

**Find** Digester volume and daily biogas production. The slurry-volume/HRT check is also shown.

**Formula** $V = (\pi/4)D^2H$;

$Qs = (md + mw)/\rho s$;

$Vb = md \times$ yield.

**Substitution** $V = (\pi/4)(2)^2(5) = 15.708\ m^3$.

**Substitution** $Qs = (100 + 100)/1050 = 0.190476\ m^3\ d^{-1}$;

implied HRT $= 15.708/0.190476 = 82.47$ d.

**Result** Digester volume = 15.7 $m^3$. Daily biogas $= 100 \times 50 = 5000\ L\ d^{-1} = 5.00\ m^3\ d^{-1}$.

**Unit check** $m^2 \times m = m^3$; $kg \div (kg\ m^{-3}) = m^3$; $kg \times L\ kg^{-1} = L$.

◆ **WORKED NUMERICAL — *Dairy herd—diameter and height*** [IFoS 2017 · P2/3(c) · 10M]

**Problem.** Find out height and diameter of the digester of a biogas plant, whose design is to be matched with input feed from dairy of 80 cows and 40 calves. Following assumptions may be made: Calves produce half gobar (dung) compared to cows. Average gobar (dung) available per cattle per day = 10 kg. Average biogas available per kg gobar (dung) per day = 0.03 $m^3$. Average content of solid in gobar (dung) = 18%. Average bulk density of gobar (dung) = 1100 kg/$m^3$. Optimum ratio of gobar (dung) : water in slurry = 1 : 1.

**Given** 80 cows; 40 calves = 0.5 cow each; dung = 10 kg cow-equivalent$^{-1}$ $d^{-1}$; water:dung = 1:1; $\rho s = 1100$ kg $m^{-3}$; gas yield = 0.03 $m^3\ kg^{-1}$.

**Data issue** The printed question does not state HRT or H:D. First retain them symbolically; then use HRT = 30 d, 10% freeboard and H:D = 1, consistent with standard mesophilic design examples.

**Equivalent herd** $Neq = 80 + 0.5(40) = 100$;

$md = 100 \times 10 = 1000\ kg\ d^{-1}$.

**Gas** $Vb = 1000 \times 0.03 = 30.0\ m^3\ d^{-1}$.

**Slurry** $ms = 1000 + 1000 = 2000\ kg\ d^{-1}$;

$Qs = 2000/1100 = 1.818\ m^3\ d^{-1}$.

**Solids check** At 18% solids in dung and 1:1 dilution, slurry TS ≈ 18/2 = 9%, a suitable pumpable concentration.

**Working volume** $Vw = 1.818 \times 30 = 54.545\ m^3$;

$Va = 54.545/0.90 = 60.606\ m^3$.

**Geometry** For $H = D$: $V = \pi D^3/4$, so $D = (4V/\pi)^{⅓} = (4 \times 60.606/\pi)^{⅓} = 4.258$ m; $H = 4.258$ m.


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**Result** Adopt digester diameter ≈ 4.26 m and liquid/structural height ≈ 4.26 m under the stated assumptions; daily gas = 30.0 $m^3$.

**Unit check** $(m^3)^{1/3} = m$; $m^3\ d^{-1} \times d = m^3$.

◆ **WORKED NUMERICAL — *Digester volume and useful power*** [IFoS 2016 · P2/4(a) · 15M]

**Problem.** Calculate the volume of a biogas digester and power available from it assuming the following: Number of animals = 8; Retention time = 20 days; Temperature of digestion = 35°C; Dry matter consumed per animal per day = 2 kg; Burner efficiency = 70%; Methane content in biogas = 70%; Density of dry matter in slurry = 50 kg/$m^3$; Biogas yield per unit dry mass = 0.2 $m^3$/kg; Heat of combustion of methane = 28 MJ/$m^3$ at STP.

**Given** 8 animals; dry matter = 2 kg $animal^{-1}\ d^{-1}$; HRT = 20 d; ρDM in slurry = 50 kg $m^{-3}$; gas yield = 0.2 $m^3\ kg^{-1}$ DM; $CH_4$ = 0.70; $HCH_4$ = 28 MJ $m^{-3}$; η = 0.70.

**Dry matter** $mDM = 8 \times 2 = 16$ kg $d^{-1}$.

**Slurry flow** $Qs = 16/50 = 0.320\ m^3\ d^{-1}$.

**Digester** $Vd = Qs \times HRT = 0.320 \times 20 = 6.40\ m^3$.

**Biogas** $Vb = 16 \times 0.2 = 3.20\ m^3\ d^{-1}$.

**Useful energy** $Eu = 0.70 \times 0.70 \times 28 \times 3.20 = 43.904$ MJ $d^{-1}$.

**Power** $P = 43.904 \times 10^6 / 86{,}400 = 508.148$ W = 0.508 kW.

**Result** Digester working volume = 6.40 $m^3$; useful continuous power equivalent = 0.508 kW.

**Unit check** kg $d^{-1}$ ÷ kg $m^{-3}$ = $m^3\ d^{-1}$; MJ $d^{-1}$ ÷ s $d^{-1}$ = MW, then $\times 10^6$ gives W.

## 13 BIOGAS UTILIZATION, PURIFICATION AND ENGINES

### FARM APPLICATIONS

- ***Direct heat*** : Cooking, water heating, milk pasteurization, brooders, crop drying and small boilers; use a biogas-designed burner.
- ***Lighting*** : Mantle lamps are possible but generally less efficient and less convenient than generating/using electricity.
- ***Shaft power*** : Irrigation pumps, chaff cutters, mills and dairy equipment through gas or dual-fuel engines.
- ***Electricity/CHP*** : Engine-generator with recovery of exhaust and jacket heat; viable where heat and power loads coincide.
- ***Upgraded gas*** : Remove $H_2S$, moisture, $CO_2$ and contaminants; compress biomethane as CBG or inject where standards/infrastructure permit.
- ***Digestate*** : Fertilizer/soil amendment after safe handling, storage and nutrient-based field application.

**PREVIOUS YEAR QUESTIONS**

What are the potential uses of biogas in a farm? [OPSC CSE 2022–23 | P2/10(b) | 5 M]

### 13.1 GAS CONDITIONING

For cooking, remove condensate and control $H_2S$ where needed. Engines require stronger $H_2S$ and moisture control because acid corrosion and lubricating-oil degradation are serious. Upgrading to biomethane uses

combinations of water/chemical scrubbing, pressure-swing adsorption, membranes or cryogenic separation, followed by drying and compression. Methane slip must be minimized.

## 13.2 BIOGAS ENGINE AND DUAL-FUEL DIESEL

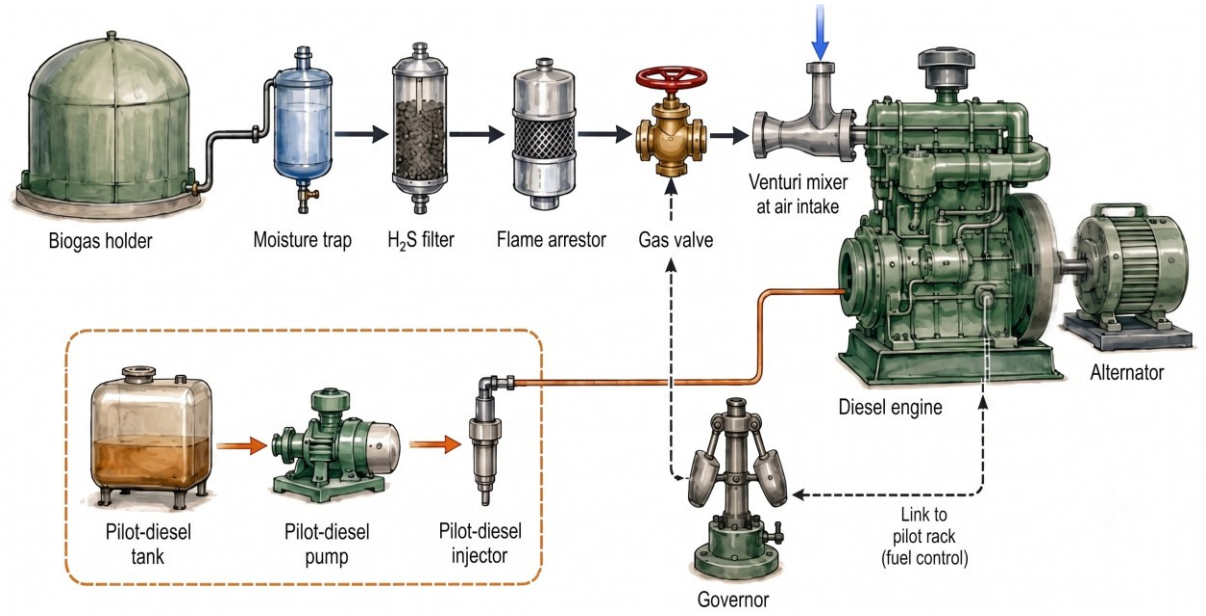
***Gas engine*** : Spark-ignition engine designed or converted to operate on a premixed gaseous fuel–air charge.

***Dual-fuel engine*** : Compression-ignition engine in which a small liquid-diesel pilot initiates combustion of the inducted biogas/producer-gas–air mixture.

**CONSTANT-SPEED DIESEL MODIFICATIONS FOR BIOGAS + DIESEL**

- ***Gas admission*** : Fit gas–air mixer/venturi upstream of intake, gas control valve, non-return valve and flame arrestor.
- ***Governing*** : Link gas valve and diesel rack to maintain rated speed/frequency; retain pilot diesel to provide ignition.
- ***Compression/ignition*** : Normally retain diesel compression ratio and injector; optimize pilot timing/quantity to avoid knock and misfire.
- ***Safety*** : Install gas shut-off solenoid, overspeed/low-pressure interlocks, crankcase ventilation, leak test and $H_2S$/moisture removal.
- ***Reason*** : Biogas has high auto-ignition temperature and cannot reliably ignite by compression at normal diesel conditions; gas displaces air and has slower combustion, so mixture and timing require control.

▣ ***Dual-Fuel Biogas–Diesel Engine***




*Pilot diesel ignites the inducted biogas–air mixture while governing maintains constant speed.*

**PREVIOUS YEAR QUESTIONS**

- What are the modifications required to run a constant speed diesel engine on dual fuel (biogas + diesel) mode and why? [IFoS 2016 | P2/3(c) | 10 M]
- Write short notes on: (i) Solar lantern (ii) Solar cooker (iii) Gas engines. [IFoS 2016 | P2/4(b) | 15 M]

## 13.3 FREQUENTLY TESTED GAS COMPARISONS


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| Basis | Biogas | Producer gas | Natural gas/CBG |
|---|---|---|---|
| Origin | Anaerobic digestion of wet organics | Partial oxidation of solid biomass/coal | Fossil reservoir / upgraded renewable biogas |
| Main combustibles | $CH_4$ | CO + $H_2$ + little $CH_4$ | Predominantly $CH_4$ |
| Major diluent | $CO_2$ | $N_2$ + $CO_2$ | Small impurities after processing |
| LHV, indicative | ≈18–23 MJ/$m^3$ | ≈4–6 MJ/$Nm^3$ | ≈35–40 MJ/$m^3$; CBG close to standard biomethane |
| Raw cleanup issue | $H_2S$, moisture, $CO_2$ | Tar, particles, moisture | Meets pipeline/vehicle specification after processing |
| Feed/process | Wet, low-temperature biological | Dry, high-temperature thermochemical | Extraction or upgrading + compression |

| Basis | CNG | CBG / Bio-CNG |
|---|---|---|
| Source | Geological natural gas | Biogas upgraded to biomethane |
| Chemistry at specification | Predominantly methane | Predominantly methane; intended to meet applicable fuel standard |
| Carbon character | Fossil carbon | Biogenic carbon; climate benefit depends on leakage and feedstock baseline |
| Processing | Gas treatment + compression | Digestion → $H_2S$/moisture/$CO_2$ removal → compression |
| Use | Vehicle, industrial and piped fuel | Same end-use class where quality/pressure standards are met |

**PREVIOUS YEAR QUESTIONS**

Distinguish between the following in brief : (i) Biogas and Producer Gas (ii) Compressed Natural Gas and Compressed Biogas (iii) AC Motor and DC Motor (iv) Solar Cell and Dry Cell.

[IFoS 2021 | P2/1(d) | 8 M]

## 14 ENERGY-EFFICIENT COOKING STOVES AND ALTERNATE FUELS

An improved cookstove is a fuel–air–heat-transfer system. Efficiency alone is insufficient: the design must also reduce incomplete-combustion emissions, vent smoke, accept local cookware and fuel, remain stable and safe, and fit cooking practices.

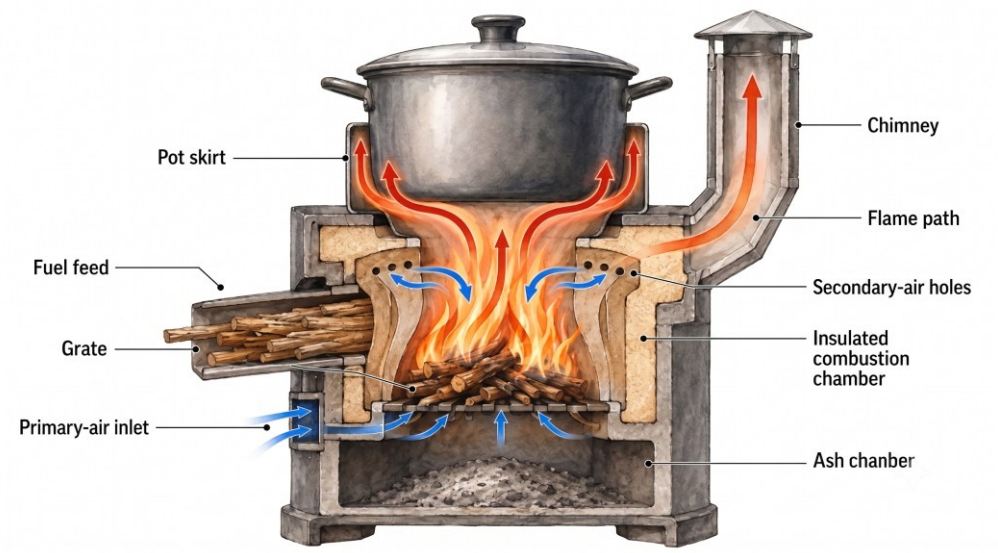
**DESIGN PRINCIPLES**

- ***Combustion :*** Insulated, correctly sized chamber; controlled primary air below/through fuel and secondary air above the fuel bed.
- ***Draft :*** Grate and chimney or fan create adequate flow; avoid excessive air that cools the flame.
- ***Heat transfer :*** Small pot-to-flame gap, pot skirt/baffles and short hot-gas path maximize convective/radiative transfer.
- ***Emissions ;*** High temperature, adequate residence time and turbulence complete oxidation; dry uniform fuel reduces smoke.

- ***User and safety :*** Stable pot rest, cool-touch handles, chimney sealing, easy ash removal, durable local materials and no indoor CO accumulation.

| Stove/fuel | Principle and merit | Constraint |
|---|---|---|
| Improved natural-draft biomass | Insulated chamber/chimney improves draft and pot heat transfer | Performance depends on fuel and chimney maintenance |
| Forced-draft gasifier stove | Fan stages primary/secondary air; burns pyrolysis gas cleanly | Needs electricity/fan and trained operation |
| Biogas stove | Premixed gas–air burner; clean controllable flame | Requires daily plant feed and gas-pressure matching |
| LPG/PNG | High heat rate, clean point-of-use, convenient | Fossil cost/supply and cylinder safety |
| Ethanol/methanol | Clean liquid-fuel burner with easy metering | Fuel availability, toxicity/flammability and stove compatibility |
| Electric/induction | Very high point-of-use efficiency and no kitchen combustion | Grid reliability, cookware and upstream electricity source |
| Solar cooker | No purchased fuel during sunshine | Intermittent, slower, requires outdoor solar access |
| Pellet/briquette | Uniform dense biomass enables controlled feeding | Fuel supply chain and ash/clinker management |

▣ ***Improved Biomass Cookstove***




*Efficient combustion combines controlled air, insulation, residence time and close pot heat*

**PREVIOUS YEAR QUESTIONS**

- Describe in brief various energy efficient cooking stoves and alternate cooking fuels. [IFoS 2017 | P2/3(a) | 10 M]
- Explore the concept of energy-efficient cooking stoves and their significance in the context of sustainable agriculture. [OPSC CSE 2023–24 | P2/12(b) | 15 M]
- Describe the energy efficient cooking stoves and alternate cooking fuels. [OPSC CSE 2016–17 | P2/12(c) | 15 M]


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## 15 BIODIESEL AND BIOETHANOL

| Basis | Biodiesel | Bioethanol |
|---|---|---|
| Chemical nature | Fatty-acid alkyl esters | Ethyl alcohol, $C_2H_5OH$ |
| Feedstock | Vegetable oils, waste cooking oil, animal fat, algal oil | Sugar/starch crops; cellulosic hydrolysate |
| Conversion | Extraction / pretreatment + transesterification with alcohol / catalyst | Hydrolysis where needed + fermentation + distillation/dehydration |
| Engine family | Compression-ignition diesel blends / engines | Spark-ignition petrol blends; special high-blend engines |
| Key property | High cetane and lubricity; oxygenated, near-zero sulphur | High octane; oxygenated; lower volumetric energy than petrol |
| Issues | Cold flow, oxidation stability, $NO_x$ tendency, glycerol/wash-water quality | Water affinity, material compatibility, vapour pressure and food / feed / land concerns |
| Co-product | Glycerol | $CO_2$ and distillers grains depending feed/process |

**Exam line.** Biodiesel substitutes the diesel fraction through an oil-to-ester route; bioethanol substitutes petrol through a sugar-to-alcohol route. Sustainability depends on life-cycle land, water, fertilizer, residue and by-product management.

**PREVIOUS YEAR QUESTIONS**

- Discuss the major differences between the following : (i) Biogas and Producer gas (ii) Biodiesel and Bio-ethanol (iii) Single phase electric motor and Three phase electric motor (iv) Downdraft gassifier and Updraft gassifier. [IFoS 2016 | P2/1(e) | 8 M]

## 16 RURAL SYSTEMS, ENVIRONMENT AND ECONOMICS

A farm-energy answer should extend beyond hardware. The relevant unit is the local resource–enterprise–nutrient system: who supplies feedstock, who operates the asset, who uses the energy and how the co-products are returned.

| Dimension | Potential benefit | Condition/risk to mention |
|---|---|---|
| Waste management | Controlled collection of dung and wet organic wastes; lower odour, flies and open decomposition | Segregation, regular feeding, pathogen-safe digestate and no water contamination |
| Energy | Clean cooking, heat, pumping and decentralized electricity | Seasonal feed, storage, backup and appliance compatibility |
| Climate/air | Captures methane; displaces traditional fuel and some fossil energy | Methane leakage, incomplete combustion, unsustainable residue removal and tar disposal can erase benefits |
| Soil/nutrients | Digestate recycles N-P-K and carbon; ash/biochar may have appropriate uses | Nutrient testing, application timing/rate and contaminant control |
| Employment | Masonry, fabrication, feedstock aggregation, O&M, slurry enterprise and local energy services | Training, dependable revenue and safe formal work rather than unpaid labour transfer |

| | | |
|---|---|---|
| Gender/health | Less fuelwood collection and indoor smoke; time available for education/income | Actual benefit depends on reliable gas and women's role in design/ownership |
| Economics | Fuel savings, fertilizer value, processing income and avoided waste costs | Capital, finance, downtime, collection distance and co-product market determine viability |

**PREVIOUS YEAR QUESTIONS**

- How do biogas plants address environmental and energy challenges in rural areas and what are the key benefits they offer in terms of waste management, renewable energy generation and economic development? [OPSC CSE 2023–24 | P2/7(a) | 15 M]

## 16.1 FREQUENTLY

Annual net benefit = energy savings + energy sales + digestate/by-product value + avoided disposal cost − annual O&M − feedstock/logistics cost

Simple payback = initial investment / annual net cash benefit

Use discounted measures—NPV, IRR or levelized cost—for larger projects. Include capacity factor, parasitic power, replacement of engine/filters/holder, operator wage, financing and downtime. For biomass gasification, collection radius and seasonal covered storage can dominate. For biogas, a local digestate market and dependable daily feed are as important as rated gas output.

**INSTITUTIONAL AND PROGRAMME LINKAGE**

- ***Small/farm biogas :*** MNRE's Biogas Programme links clean cooking, sanitation, organic manure, women's empowerment and rural employment; always verify the current scheme guidelines before quoting subsidy figures.
- ***Waste-to-wealth :*** GOBARdhan promotes convergence around biodegradable waste, biogas/CBG and organic manure; quote current portal statistics only after checking the latest dashboard.
- ***Delivery model :*** Individual household, dairy cluster, cooperative/FPO, panchayat, entrepreneur or energy-service company—selected by feed concentration, demand and management capacity.

◆ *Source: MNRE, Biogas Programme (accessed July 2026); GOBARdhan Unified Registration Portal (accessed July 2026; latest figures to be verified); FAO socioeconomic sessions.*

## 17 OPERATIONS, TROUBLESHOOTING AND SAFETY

| Symptom | Likely cause | Corrective action |
|---|---|---|
| Low biogas | Cold slurry, low feed, short HRT, toxicity, leak or overload collapse | Leak-test; restore stable feed/temperature; check pH/VFA; reduce load and re-inoculate if needed |
| Gas burns poorly | High $CO_2$ during start-up/acidification; low $CH_4$; air in line | Flare initial gas safely; stabilize digestion; purge under safe procedure |
| Scum | Long fibres, high solids, poor mixing | Screen/chop feed, correct dilution, controlled mixing; safe mechanical removal |
| $H_2S$ corrosion | Sulphur-rich feed and no treatment | Iron-based/biological desulfurization; drain water; use compatible materials |
| Gasifier high tar | Wet/oversize fuel, low temperature, air maldistribution, overload | Dry/grade fuel; correct ER/nozzles; remove bridging; restore hot stable hearth |


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| | | |
|---|---|---|
| Gasifier pressure drop | Fines, clinker, blocked filters or bed compaction | Screen fuel; ash removal; clean filters; verify pressure profile |
| Engine power loss | Low-LHV gas, dirty filter, wrong mixture, high gas temperature | Service cleanup, cool gas, tune mixture/governor; check leakage |

***Non-negotiable safety*** CO is colourless and lethal; methane is flammable; $H_2S$ is toxic. Ventilate gasifier/engine rooms, fit CO detection and shut-offs, prohibit confined-space entry into digesters, keep ignition sources away during leak tests, provide flare/pressure relief, and manage tarry condensate as a pollutant—not as drain water.***

## 18 FORMULA SHEET

| Quantity | Equation | Use |
|---|---|---|
| Slurry flow | $Qs = (md + mw)/\rho s$ | Daily feed volume |
| Working digester | $Vw = Qs \times HRT$ | Biological liquid volume |
| Constructed volume | $Va = Vw/\text{useful fraction}$ | Allows gas/freeboard space |
| Cylinder | $V = \pi D^2H/4$ | Convert volume to dimensions |
| Gas yield | $Vb = mfeed \times \text{specific yield}$ | Daily gas production |
| Useful biogas energy | $Eu = \eta u\ xCH_4\ Vb\ LHVCH_4$ | Cooking/power equivalent |
| Continuous power | $P(W) = E(MJ\ d^{-1})\times10^6/86{,}400$ | Energy-to-power conversion |
| Equivalence ratio | ER = actual air/stoichiometric air | Gasifier air control |
| Cold-gas efficiency | $\eta cg = VgLHVg/(mfLHVf)$ | Gasification efficiency |
| TS | TS% = dry residue/wet sample ×100 | Slurry concentration |
| VS | VS% = ignition loss/dry residue ×100 | Organic fraction |
| Simple payback | Investment/annual net benefit | Screening economics |

***Unit discipline*** Convert g $cm^{-3}$ to kg $m^{-3}$ (1 g $cm^{-3}$ = 1000 kg $m^{-3}$), litres to $m^3$ (1000 L = 1 $m^3$), MJ to J ($10^6$), and day to seconds (86,400). Carry at least one extra digit and report the final answer to three significant figures.***

## 19 PYQ-READY COMPARISONS AT A GLANCE

| Pair | Fast discriminator 1 | Fast discriminator 2 |
|---|---|---|
| Updraft vs downdraft | Counter-current; gas exits top | Co-current; gas passes hot throat/char |
| Updraft vs downdraft | High tar, cool exit, tolerant fuel | Low tar, hot exit, strict fuel preparation |
| Biogas vs producer gas | Wet biological; $CH_4 + CO_2$ | Dry thermochemical; $CO + H_2 + N_2$ |
| Tar vs particles | Condensable organics | Entrained solids |
| Briquetting vs charring | Physical densification | Thermochemical carbonization |
| TS vs VS | All dry residue | Ignitable organic fraction of TS |
| Aerobic vs anaerobic | Consumes aeration energy | Produces methane; slower |
| Gas engine vs dual fuel | Spark ignition; gaseous fuel | Diesel pilot ignites gas–air charge |
| CNG vs CBG | Fossil natural gas | Upgraded biogas; both methane-rich at specification |

| | | |
|---|---|---|
| Biodiesel vs ethanol | Oil → ester; CI engine | Sugar → alcohol; SI engine |
| Floating vs fixed dome | Constant pressure; visible; corrosion | Variable pressure; hidden storage; masonry |

## 20 CHAPTER SUMMARY

- ***Route selection*** : dry residues favour thermochemical routes; wet biodegradable feed favours anaerobic digestion; densification solves handling but not chemistry.
- ***Gasification*** : partial oxidation preserves energy in CO, $H_2$ and $CH_4$; ER, moisture, particle size, ash and hearth load govern gas quality.
- ***Gasifiers*** : updraft is efficient and tolerant but tar-rich; downdraft cracks tar and suits engines; fluidized beds scale with better mixing but more solids control.
- ***Power system*** : preparation, feeding, reactor, staged cleanup, engine-generator, controls, flare and waste streams form one system.
- ***Digestion*** : hydrolysis → acidogenesis → acetogenesis → methanogenesis; stable temperature, neutral pH, balanced loading and adequate HRT protect methanogens.
- ***Plants*** : KVIC offers nearly constant pressure with steel-holder maintenance; fixed domes reduce cost but give variable pressure and require gas-tight masonry.
- ***Sizing*** : convert daily feed to slurry volume, multiply by HRT, add storage/freeboard convention, then obtain geometry; declare missing assumptions.
- ***Use*** : biogas supports cooking, heat, engines, power and CBG; digestate closes nutrient loops.
- ***Clean cooking*** : controlled air, insulation, residence time, heat transfer and user fit jointly determine performance.
- ***Sustainability*** : count methane leakage, residue competition, tar/digestate management, operator jobs, collection radius and co-product markets.

## 21 LAST-NIGHT REVISION—ONE PAGE

**TEN RECALL HOOKS**

1. ***Biomass routes*** : thermochemical, biochemical, physico-chemical; mechanical densification is preparation.
2. ***Gasifier reactions*** : oxidation supplies heat; Boudouard and water-gas form CO/$H_2$; shift and methanation adjust composition.
3. ***Zone order*** : drying → pyrolysis → oxidation → reduction; map order to gas-flow direction.
4. ***Updraft*** : counter-current, high efficiency, high tar.
5. ***Downdraft*** : co-current, vapours cross hot zone, low tar, strict fuel quality.
6. ***Biogas phases*** : H-A-A-M: hydrolysis, acidogenesis, acetogenesis, methanogenesis.
7. ***Stable digestion*** : ≈1:1 dung–water, ≈8–10% TS, mesophilic stability, pH near 7, balanced OLR/HRT.
8. ***Plant choice*** : KVIC: constant pressure/steel drum; fixed dome: variable pressure/low maintenance.
9. ***Sizing*** : daily slurry × HRT; then freeboard/storage and geometry.
10. ***Answer value-add*** : draw flow arrows/zones, state assumptions/units, add safety, jobs, nutrient loop and lifecycle caveat.


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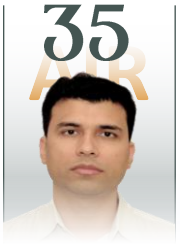

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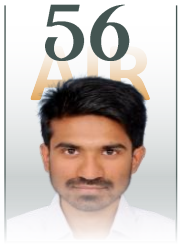

**B Jaya Aswantha Reddy**

Comprehensive Forestry Course 2022




**Sanskar Bharti**

Test Series




**Sachin Datt**

Test Series + CIGP




**Anusha Srinivas**

Comprehensive Forestry Course + Test Series



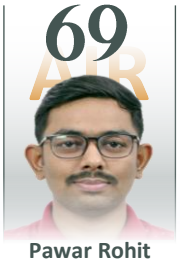

**Ashish**

Comprehensive Forestry Course + Test Series




**Saurabh Singh**

Comprehensive Forestry Course




**Pawar Rohit Sanjay**

Comprehensive Interview Guidance Program (CIGP)




**Omkar Kumar**

Comprehensive Forestry Course 2024




**Manav Gupta**

Comprehensive Forestry Course + CIGP




**Prityesh Raj**

Comprehensive Interview Guidance Program (CIGP)




**Reshma Nivetha R**

Comprehensive Forestry Course + CIGP




**Pawar Akshay Haribhau**

Comprehensive Interview Guidance Program (CIGP)




**Sambhav Kumar Jain**

Test Series




**Rajat Kataria**

Comprehensive Interview Guidance Program (CIGP)

*Congratulations*

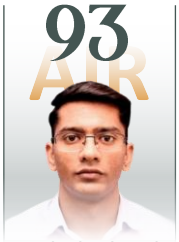
To all our successful candidates in

# INDIAN FOREST SERVICE (IFOS) 2025



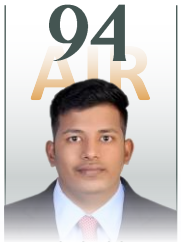

**Rajat Kumar**

Comprehensive Forestry Course + CIGP



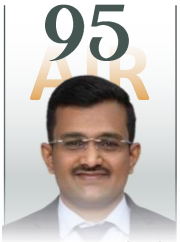

**Kailash Chand Yadav**

Comprehensive Forestry Course + CIGP




**Patil Shubham Jaysing**

Comprehensive Forestry Course



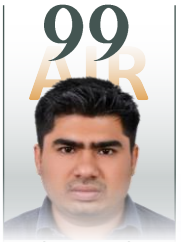

**Hinge Harshad Pandurang**

Comprehensive Forestry Course (2023) + Test Series + CIGP




**Pawar Onkar Mahesh**

Comprehensive Interview Guidance Program (CIGP)




**Dharmendra Choudhary**

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**Kushare Pratik Chandrashekhar**

Comprehensive Interview Guidance Program (CIGP)




**Venkatesh M**

Comprehensive Forestry Course + CIGP




**K Sai Goutham**

Comprehensive Forestry Course




**Kritika Negi**

Comprehensive Forestry Course 2023 + CIGP 2025



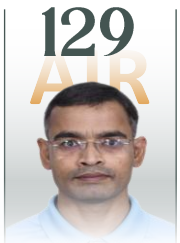

**Himanshu Kumar**

Comprehensive Forestry Course 2023 + CIGP




**Satyam Shivam Sundaram**

Comprehensive Interview Guidance Program (CIGP)




**Satya Pal Arya**

Comprehensive Interview Guidance Program (CIGP)



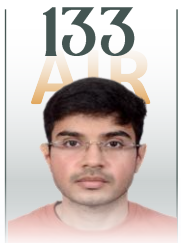

**Aakash Verma**

Comprehensive Forestry Course




**Ajay Kumar Ushara**

Comprehensive Forestry Course + CIGP




**Vikalp Mandawaria**

Comprehensive Forestry Course + Test Series + CIGP




**Prateek Kumar Meena**

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