

Power Engineering (315371)

Model Question Paper — Set A · Model Answers

Q.1

a) Tonne of refrigeration.

2 M

One tonne of refrigeration (1 TR) is the refrigerating effect (rate of heat removal) needed to freeze one ton of water at 0 °C into ice at 0 °C in 24 hours. The unit comes from the American ton (2000 lb ≈ 907 kg).

$$1 \text{ TR} = 907 \times 335 / (24 \times 60) = 211.0 \text{ kJ/min} \approx \mathbf{210 \text{ kJ/min} = 3.5 \text{ kW}}$$
 (value used in practice).

(Definition 1 M, value 1 M)

b) DBT and WBT.

2 M

Dry bulb temperature (DBT): The temperature of air measured by an ordinary thermometer whose bulb is dry, i.e. not affected by the moisture in air.

Wet bulb temperature (WBT): The temperature recorded by a thermometer whose bulb is covered by a wet wick and exposed to moving air. Evaporation from the wick cools the bulb, so $\text{WBT} \leq \text{DBT}$ (equal only for saturated air).

(1 M each)

c) BP and mechanical efficiency.

2 M

Brake power (BP): The net power available at the crankshaft of the engine, measured by a dynamometer (brake). $\text{BP} = 2\pi NT/60000 \text{ kW}$.

Mechanical efficiency (η_m): Ratio of brake power to indicated power: $\eta_m = \text{BP}/\text{IP}$. It accounts for friction power, $\text{FP} = \text{IP} - \text{BP}$.

(1 M each)

d) Volumetric efficiency and FAD.

2 M

Volumetric efficiency: Ratio of the actual volume of free air delivered (reduced to suction / atmospheric conditions) per stroke to the swept volume of the cylinder: $\eta_{\text{vol}} = (V_1 - V_4)/V_s$.

Free air delivery (FAD): The actual volume of air delivered by the compressor per minute, expressed at the free (atmospheric) intake conditions of pressure and temperature, in m³/min. It is the capacity of the compressor.

(1 M each)

e) Pollutants regulated under BS-VI.

2 M

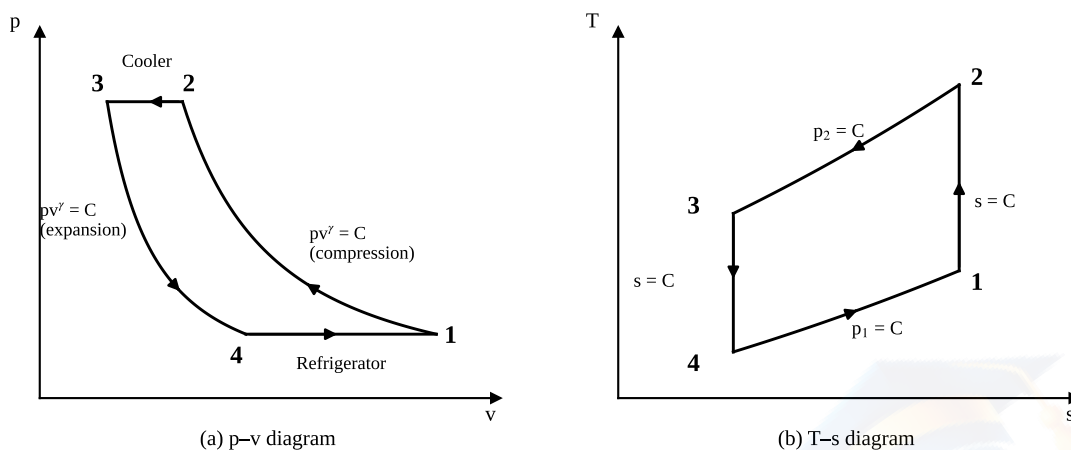
1. Carbon monoxide (CO)
2. Unburnt hydrocarbons (HC) / non-methane HC
3. Oxides of nitrogen (NO_x) — also combined HC + NO_x for diesel
4. Particulate matter (PM) and particle number (PN) — mainly for diesel / GDI engines

BS-VI (Bharat Stage VI, from April 2020) sharply reduced NO_x and PM limits, especially for diesel vehicles.

(Any four, ½ M each)

f) Bell-Coleman cycle on p–v and T–s.

2 M



Bell-Coleman (reversed Brayton) air refrigeration cycle

1–2 isentropic compression, 2–3 constant-pressure cooling, 3–4 isentropic expansion, 4–1 constant-pressure heat absorption (refrigeration).

(Each diagram 1 M)

g) Desirable properties of a refrigerant.

2 M

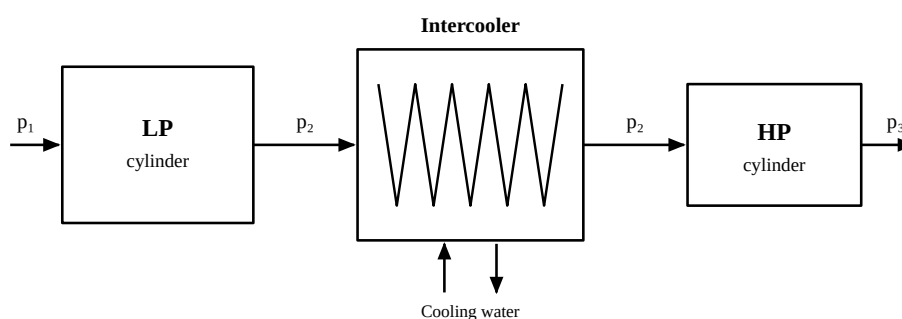
1. Low boiling point and high latent heat of vaporisation (large refrigerating effect per kg).
2. Moderate condensing pressure and evaporator pressure slightly above atmospheric (no air leak-in).
3. Non-toxic, non-flammable and non-explosive.
4. Zero ozone depletion potential (ODP) and low global warming potential (GWP).
5. Chemically stable, non-corrosive, easy leak detection, cheap.

(Any four, ½ M each)

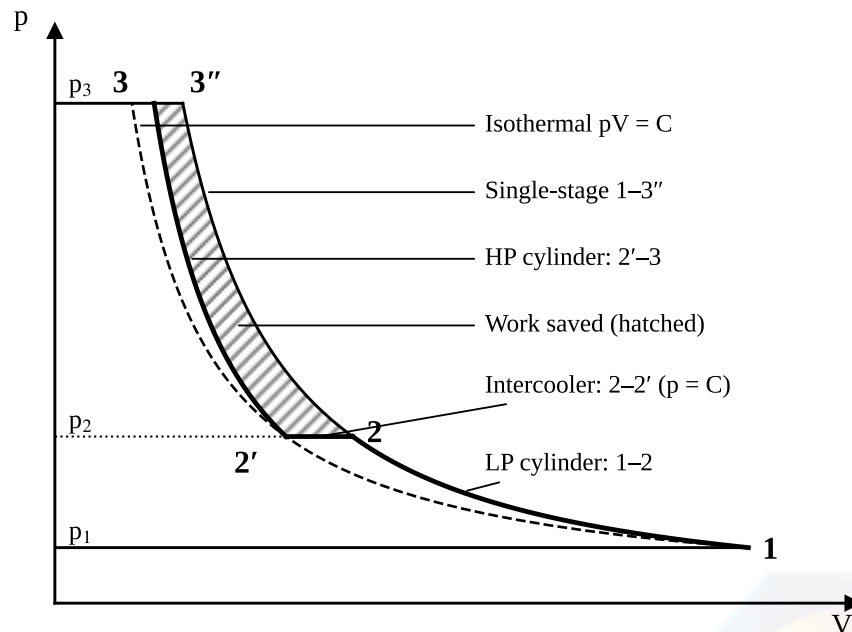
Q.2

a) Effect of intercooling in two-stage compression.

4 M



Two-stage reciprocating compressor with intercooler



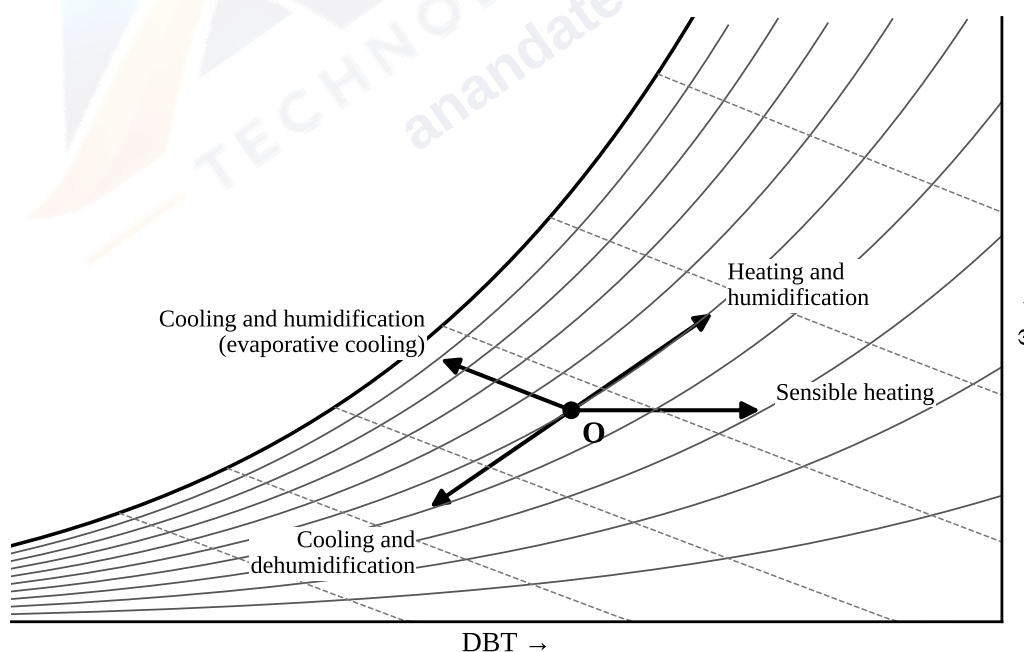
Two-stage compression with perfect intercooling: work saved (hatched area)

- Air is compressed in the LP cylinder along 1–2 to the intermediate pressure p_2 .
- It is then cooled in the intercooler at constant pressure (2–2'). With **perfect intercooling** the air is cooled back to the initial temperature T_1 , so point 2' lies on the isothermal through 1.
- The HP cylinder compresses it along 2'–3 to the delivery pressure p_3 .
- Without intercooling, single-stage compression would follow 1–3''. The **hatched area 2–2'–3–3''** is the work saved by intercooling; the overall process comes nearer to isothermal.
- Other effects: lower delivery temperature, better volumetric efficiency, less lubrication trouble, and minimum work when $p_2 = \sqrt{p_1 p_3}$.

(Diagram 2 M, explanation 2 M)

b) Psychrometric processes.

4 M



Psychrometric processes shown from an initial state O

- **Sensible heating (O → right):** DBT increases at constant ω ; RH falls. Example: air over a heating coil.
- **Cooling and dehumidification (O → down-left):** DBT and ω both fall; air is passed over a coil colder than its dew point (summer AC).
- **Heating and humidification (O → up-right):** DBT and ω both rise; air heated and steam / water spray added (winter AC).
- **Evaporative cooling (O → up-left along constant WBT line):** DBT falls, ω rises, enthalpy $\approx$ constant (desert cooler).

(Each process 1 M)

c) Need of heat balance sheet; format.

4 M

Need: The heat balance sheet shows how the heat supplied by the fuel is distributed — useful work (BP), cooling water, exhaust gas and unaccounted losses. It shows where losses occur, helps to judge engine condition, to improve performance, to design the cooling system and to recover waste heat.

Heat supplied	kJ/min	%	Heat distributed	kJ/min	%
Heat by fuel = $m_f \times CV$	...	100	1. Heat equivalent of BP	...	...
			2. Heat to cooling water = $m_w c_w(t_2 - t_1)$	...	...
			3. Heat to exhaust = $m_g c_{pg}(t_g - t_r)$	...	...
			4. Unaccounted (by difference)	...	...
Total	...	100	Total	...	100

Items to be measured: fuel consumption and CV; brake load / torque and speed (for BP); mass of cooling water and its inlet and outlet temperatures; air consumption (air box / orifice) or A/F ratio; exhaust gas temperature and room temperature; specific heats of water and exhaust gas.

(Need 1 M, format 2 M, items 1 M)

d) VCR vs VAR.

4 M

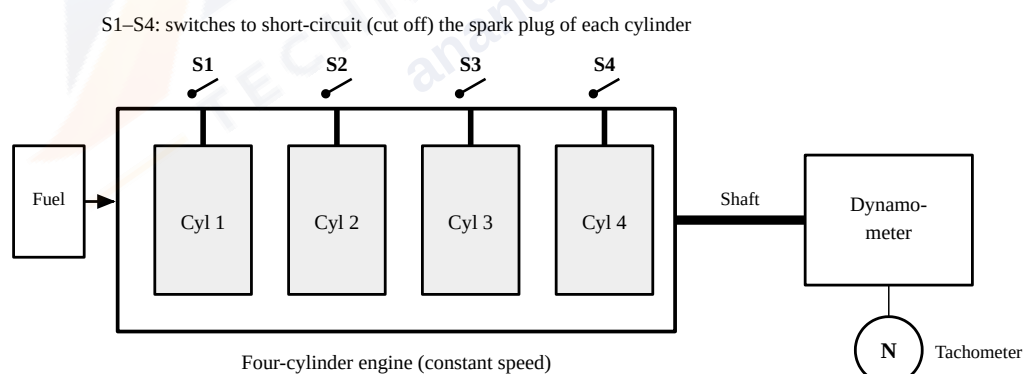
Parameter	Vapour compression (VCR)	Vapour absorption (VAR)
Components	Compressor, condenser, expansion valve, evaporator.	Generator, absorber, pump, condenser, expansion valve, evaporator (+ heat exchanger).
Refrigerant used	R-134a, R-32, R-410A, R-600a, NH ₃ etc.	NH ₃ (with water as absorbent) or water (with LiBr as absorbent).
Energy input	High-grade energy: mechanical work / electricity to the compressor.	Low-grade energy: heat (steam, exhaust gas, solar, waste heat); small pump work.
COP	High (about 3 to 5).	Low (about 0.4 to 1.2).
Noise and maintenance	Noisy and more wear because of the compressor; more maintenance.	Quiet; only the pump moves, so less wear and maintenance.
Capacity flexibility / part load	COP falls at part load; capacity control by compressor speed / on-off.	Works well at part load; capacity changed by changing heat input.
Pressure ratio	Compressor produces the pressure difference; higher pressure ratio.	Pump raises pressure of liquid solution; lower pressure ratio (for LiBr-water system, vacuum).
Application	Domestic refrigerators, ACs, water coolers, cold storage.	Large central plants with waste heat, hotels, hospitals, Electrolux (gas) refrigerator.

(Any eight points, ½ M each)

Q.3

a) Morse test.

4 M



Morse test set-up on a four-cylinder SI engine

1. The multi-cylinder engine is coupled to a dynamometer and run at the required constant speed N . BP with all cylinders working is measured: $BP = \Sigma IP - \Sigma FP$.
2. One cylinder (say No. 1) is cut off by short-circuiting its spark plug. The speed falls; the load is reduced to bring the speed back to N , and BP_1 is measured. Since friction power remains the

same at the same speed, $IP_1 = BP - BP_1$.

3. The cylinder is restored and the test is repeated for every cylinder in turn: $IP_n = BP - BP_n$.

4. IP of the engine = $IP_1 + IP_2 + IP_3 + IP_4$; $FP = IP - BP$; $\eta_m = BP/IP$.

Limitations: applicable only to multi-cylinder engines; assumes friction and pumping losses do not change when a cylinder is cut off; cutting a cylinder changes exhaust / intake flow (and in carburettor engines the mixture distribution), so results are approximate; speed must be held exactly constant.

(Sketch 1 M, procedure 2 M, limitations 1 M)

b) Factors affecting human comfort.

4 M

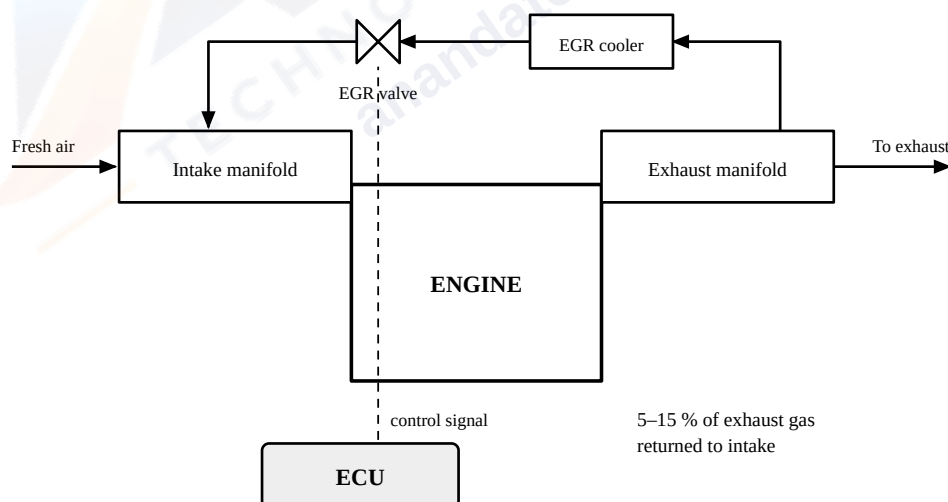
- **Temperature:** Comfortable dry-bulb temperature is about 22–26 °C in summer and 19–22 °C in winter; the body loses heat easily only within this range.
- **Humidity:** Relative humidity of 40–60 % is comfortable; high humidity prevents evaporation of sweat, low humidity dries the skin and throat.
- **Air motion (velocity):** Air velocity of about 6–9 m/min (0.1–0.15 m/s) in the occupied zone removes heat and moisture from the body without causing draught.
- **Purity of air:** Air must be free from dust, odour, bacteria and CO₂ — fresh air ventilation and filters are provided.
- **Effective temperature / radiation:** Effective temperature combines DBT, humidity and air motion; hot or cold surfaces (radiation) also affect comfort.

(Any four, 1 M each)

c) Purpose and working of EGR.

4 M

Purpose: To reduce NO_x emission. NO_x forms at high combustion temperature; recirculating a part of the exhaust gas dilutes the fresh charge with inert gas (CO₂, H₂O, N₂) of higher heat capacity, which lowers the peak combustion temperature and oxygen concentration.



Exhaust gas recirculation (EGR) system

Working: A pipe connects the exhaust manifold to the intake manifold through an **EGR valve** (and in diesel engines an **EGR cooler**). The ECU opens the valve at part load and cruising (not at idle or

full load) so that about 5–15 % of exhaust gas mixes with the intake air. At idle and full power the valve is closed to keep smooth running and maximum power.

(Purpose 1 M, sketch 2 M, working 1 M)

d) Reciprocating vs centrifugal compressor.

4 M

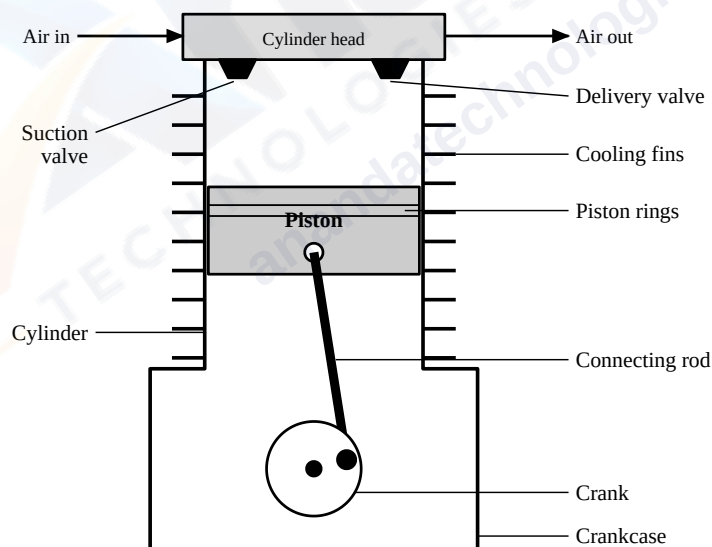
Parameter	Reciprocating compressor	Centrifugal compressor
Pressure range	High pressure ratio; single stage up to about 8–10 bar, multistage above 100 bar.	Low pressure ratio per stage (about 2–4); used for large volume at moderate pressure.
Mechanical efficiency	Lower — many rubbing parts (piston, rings, crank, valves).	Higher — no rubbing parts other than bearings; balanced rotating impeller.
Capacity control	Easy: unloading of suction valve, clearance pockets, start–stop, speed control; good at part load.	By inlet guide vanes, throttling or speed; narrow range — surging at low flow.
Applications	Workshops, garages, pneumatic tools, spray painting, refrigeration, high-pressure gas filling.	Large plants, gas pipelines, process industries, turbochargers, gas turbines, large AC plants.

(Each parameter 1 M)

Q.4

a) Single-stage single-acting reciprocating compressor.

4 M



Single-stage single-acting reciprocating air compressor

Construction: It has a cylinder (with cooling fins), a piston with rings, connecting rod and crank driven by a motor / engine, and a cylinder head carrying a spring-loaded **suction valve** and **delivery valve**. Air acts on one side of the piston only (single acting).

- **Suction stroke:** the piston moves down; pressure in the cylinder falls below atmospheric, the suction valve opens and air is drawn in at p_1 .
- **Compression stroke:** the piston moves up; both valves are closed and the air is compressed ($pV^n = C$).
- **Delivery:** when the pressure slightly exceeds the receiver pressure p_2 , the delivery valve opens and air is pushed to the receiver for the rest of the stroke.
- The cycle repeats once per revolution; air left in the clearance space expands at the start of the next suction stroke.

(Sketch 2 M, working 2 M)

b) Factors affecting efficient management of compressed air system.

4 M

1. Air leaks in pipes, joints, valves, hoses and couplings (often 20–30 % of output is wasted).
2. Pressure drop due to small / long distribution pipes, clogged filters and dryers.
3. Generating air at a pressure higher than required by end-uses.
4. High intake air temperature and dusty intake air (1 °C rise in intake temperature $\approx$ 0.33 % more power).
5. Poor intercooling / aftercooling and moisture in the air.
6. Inappropriate use of compressed air (cleaning, cooling) and running compressors during idle periods.
7. Wrong compressor size / capacity control (unloading, VFD) and poor maintenance (worn valves, belts).

Measures to reduce leakage: (1) regular leak survey using ultrasonic leak detector / soap solution and prompt repair of joints, hoses and couplings; (2) fit solenoid valves to isolate idle machines and sections, and reduce the system pressure to the minimum required.

(Factors 3 M, two measures 1 M)

c) Energy-saving checklist for AC of a computer laboratory.

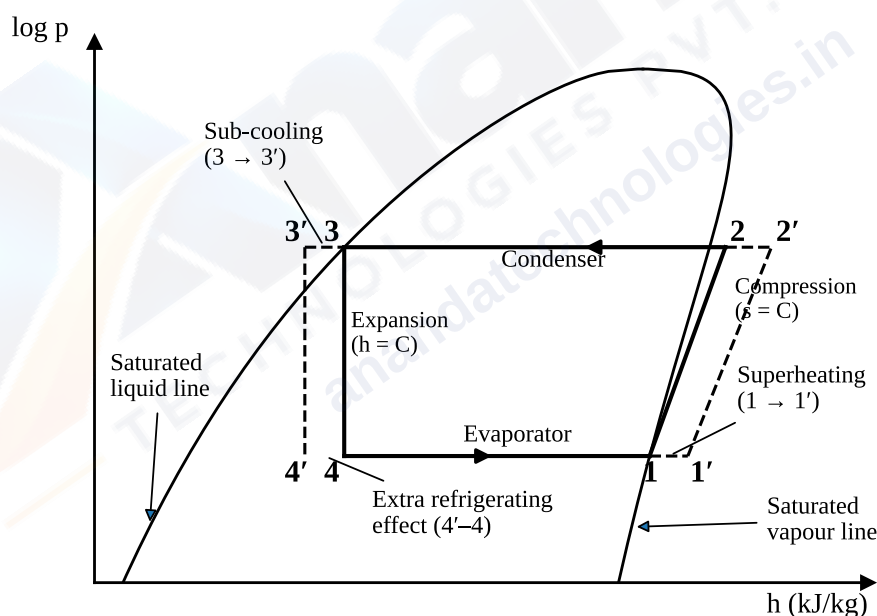
4 M

No.	Check point	Yes / No
1	Set thermostat at 24–26 °C (each 1 °C rise saves about 3–5 % energy); use timers / occupancy sensors so units switch off when the room is empty.	☐
2	Clean air filters every 2–4 weeks and clean evaporator / condenser coils regularly; dirty coils raise condensing pressure and power.	☐
3	Keep doors and windows closed; seal gaps; provide door closers, air curtains and false ceiling / roof insulation to reduce heat gain.	☐
4	Shade the outdoor unit and give free air flow around it; avoid hot-air recirculation.	☐
5	Use window films, blinds or curtains to cut solar heat; switch off unused lights and computers (internal heat).	☐
6	Replace old units by BEE 5-star / inverter units; use energy-efficient (EC / BLDC) fan motors.	☐
7	Check refrigerant charge, insulation of suction line and duct leakage during maintenance.	☐
8	Maintain proper sizing — avoid over-sized units that cycle on-off frequently; use a log book of power, temperature and running hours.	☐

(Any eight relevant points, ½ M each)

d) Sub-cooling and superheating.

4 M



VCR cycle on p - h diagram (1-2-3-4 simple cycle; dashed: with superheating and sub-cooling)

Sub-cooling (under-cooling): cooling of the liquid refrigerant below the condensing (saturation) temperature at constant condenser pressure ($3 \rightarrow 3'$), e.g. by extra condenser surface or a liquid–suction heat exchanger.

Effect: the throttling line moves left ($4 \rightarrow 4'$); refrigerating effect increases by $(h_4 - h_{4'})$ while compressor work is unchanged $\Rightarrow$ **COP increases**; also less flash gas.

Superheating: heating of the vapour above its saturation temperature at evaporator pressure before entering the compressor ($1 \rightarrow 1'$).

Effect: if superheating takes place inside the evaporator (useful superheat) the refrigerating effect increases; compressor work and discharge temperature also increase. COP may rise slightly or fall depending on the refrigerant. It prevents liquid entering the compressor (no slugging).

(Sub-cooling $1\frac{1}{2}$ M, superheating $1\frac{1}{2}$ M, diagram 1 M)

e) Single-stage compressor numerical.

4 M

Given: $p_1 = 1 \text{ bar} = 100 \text{ kPa}$, $T_1 = 27^\circ\text{C}$, $p_2 = 6 \text{ bar}$, $V_1 = 3.5 \text{ m}^3/\text{min} = 0.05833 \text{ m}^3/\text{s}$, $n = 1.3$

Pressure ratio $p_2/p_1 = 6.0000$; $(n-1)/n = 0.2308$; $(p_2/p_1)^{(n-1)/n} = 1.5121$

$$IP = [n/(n-1)] \cdot p_1 V_1 \cdot [(p_2/p_1)^{(n-1)/n} - 1]$$

$$IP = 4.3333 \times 100 \times 0.05833 \times (1.5121 - 1) = \mathbf{12.94 \text{ kW}}$$

$$\text{Isothermal power} = p_1 V_1 \ln(p_2/p_1)$$

$$= 100 \times 0.05833 \times \ln(6.0000) = 100 \times 0.05833 \times 1.7918 = \mathbf{10.45 \text{ kW}}$$

$$\text{Isothermal efficiency } \eta_{\text{iso}} = \text{Isothermal power} / \text{Indicated power} = 10.45 / 12.94 = \mathbf{80.7 \%}$$

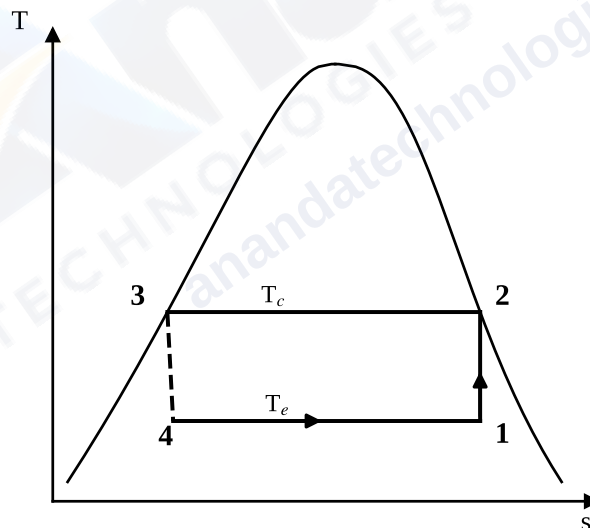
$$(\text{Delivery temperature } T_2 = T_1(p_2/p_1)^{(n-1)/n} = 300.15 \times 1.5121 = 453.8 \text{ K} = 180.7^\circ\text{C}.)$$

(Formula 1 M, IP $1\frac{1}{2}$ M, isothermal power 1 M, efficiency $\frac{1}{2}$ M)

Q.5

a) Ammonia refrigerator: COP, capacity, power.

6 M



Cycle 1-2-3-4 on T-s diagram: 1 wet vapour at compressor inlet, 2 dry saturated after compression

Given: $T_c = 30^\circ\text{C} = 303.15 \text{ K}$, $T_e = -15^\circ\text{C} = 258.15 \text{ K}$, $\dot{m} = 4 \text{ kg/min}$. Point 2 (after compression) is dry saturated at T_c ; point 1 (before compression) is wet at T_e ; 1-2 is isentropic.

$$s_2 = s_{f(c)} + h_{fg(c)}/T_c = 1.2017 + 1144.59/303.15 = 4.9774 \text{ kJ/kg}\cdot\text{K}$$

$$s_1 = s_{f(e)} + x_1 \cdot h_{fg(e)}/T_e = 0.4566 + x_1 \times 1312.73/258.15 = 0.4566 + 5.0851 x_1$$

$$s_1 = s_2 \Rightarrow x_1 = (4.9774 - 0.4566) / 5.0851 = \mathbf{0.8890}$$

$$h_1 = h_{f(e)} + x_1 h_{fg(e)} = 112.33 + 0.8890 \times 1312.73 = 1279.36 \text{ kJ/kg}$$

$$h_2 = h_{f(c)} + h_{fg(c)} = 322.63 + 1144.59 = 1467.22 \text{ kJ/kg}$$

$$h_3 = h_4 = h_{f(c)} = 322.63 \text{ kJ/kg (throttling, no under-cooling)}$$

$$\text{Refrigerating effect RE} = h_1 - h_4 = 1279.36 - 322.63 = 956.73 \text{ kJ/kg}$$

$$\text{Compressor work } W = h_2 - h_1 = 1467.22 - 1279.36 = 187.86 \text{ kJ/kg}$$

$$\text{(i) COP} = \text{RE}/W = 956.73/187.86 = \mathbf{5.09}$$

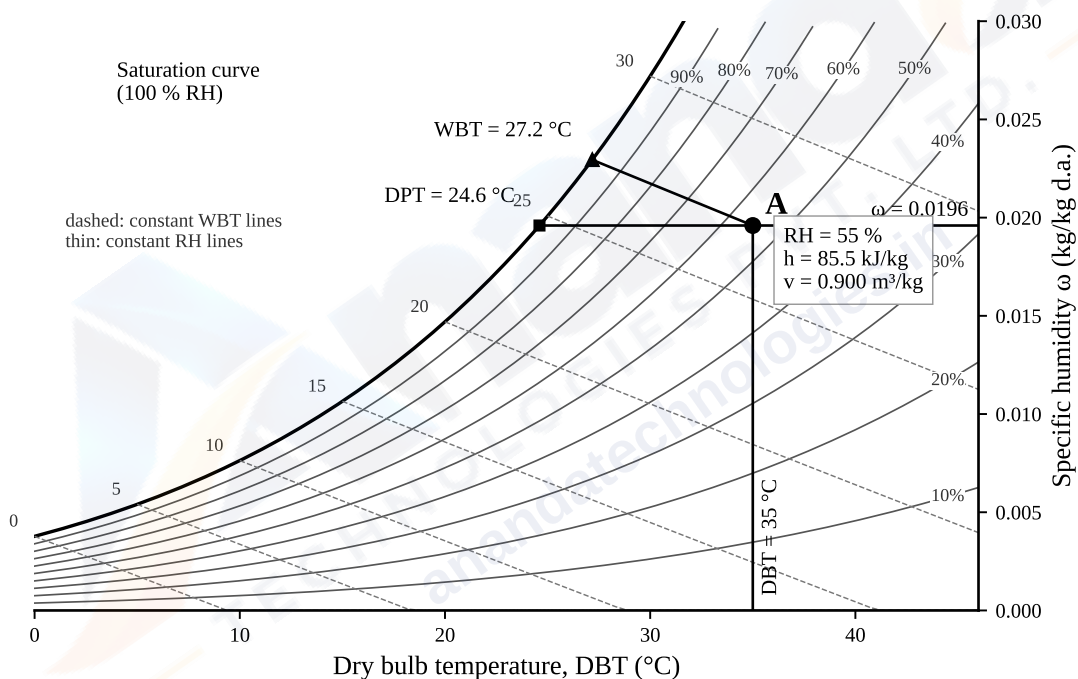
$$\text{(ii) Capacity} = \dot{m} \times \text{RE} = 4 \times 956.73 = 3826.9 \text{ kJ/min} = 3826.9/210 = \mathbf{18.22 \text{ TR}} \text{ (1 TR = 210 kJ/min)}$$

$$\text{(iii) Power} = \dot{m} \times W/60 = 4 \times 187.86/60 = \mathbf{12.52 \text{ kW}}$$

(Check: Carnot COP between the same limits = $T_e/(T_c - T_e) = 5.74$, higher than the actual cycle, as expected.)

(x_1 2 M, enthalpies 1 M, COP 1 M, capacity 1 M, power 1 M)

b) Properties of air at 35 °C DBT, 55 % RH.



Psychrometric chart ($p = 1.01325 \text{ bar}$) showing the given state A and the read-off properties

- Saturation pressure at 35 °C (steam table): $p_s = 5.6278 \text{ kPa}$
- Vapour pressure $p_v = \phi p_s = 0.550 \times 5.6278 = 3.0953 \text{ kPa}$
- Specific humidity $\omega = 0.622 p_v/(p - p_v) = 0.622 \times 3.0953/(101.325 - 3.0953) = \mathbf{0.01960 \text{ kg/kg d.a.}}$
- Dew point temperature = saturation temperature at $p_v = \mathbf{24.6 \text{ °C}}$
- Enthalpy $h = 1.005 t + \omega(2500 + 1.88 t) = 1.005 \times 35 + 0.01960(2500 + 1.88 \times 35) = \mathbf{85.46 \text{ kJ/kg d.a.}}$
- Specific volume $v = R_a T/(p - p_v) = 0.287 \times 308.15/(101.325 - 3.0953) = \mathbf{0.9003 \text{ m}^3/\text{kg d.a.}}$

- Wet bulb temperature (from chart, along constant-WBT line through the state) = **27.2 °C**

Property	Value
Dew point temperature	24.6 °C
Wet bulb temperature	27.2 °C
Specific humidity ω	0.0196 kg/kg d.a. (19.6 g/kg)
Enthalpy	85.5 kJ/kg d.a.
Specific volume	0.900 m ³ /kg d.a.

Values are calculated from psychrometric relations at $p = 1.01325$ bar (saturation pressures from steam tables); readings taken from the chart will agree within about ± 0.5 °C and ± 1 kJ/kg.

(Sketch with state point 1 M, each property 1 M)

c) Engine trial and heat balance sheet.

6 M

$A = (\pi/4) D^2 = (\pi/4) \times 0.2^2 = 0.031416$ m²; for a four-stroke engine $n = N/2 = 200$ cycles/min

$$IP = p_m L A n / 60 \text{ (kW, } p_m \text{ in kPa)}$$

$$IP = 650 \times 0.28 \times 0.031416 \times 200/60 = \mathbf{19.06 \text{ kW}}$$

$$BP = (W - S) \pi (D_{\text{drum}} + d_{\text{rope}}) N / 60000$$

$$BP = 600 \times \pi \times (1.2 + 0.02) \times 400/60000 = \mathbf{15.33 \text{ kW}}$$

$$\text{Mechanical efficiency } \eta_m = BP/IP = 15.33/19.06 = \mathbf{80.44 \%}$$

$$\text{BSFC} = m_f/BP = 4.2/15.33 = \mathbf{0.2740 \text{ kg/kWh}}$$

$$\text{Heat supplied} = \dot{m}_f \times CV = (4.2/3600) \times 43,000 = 50.17 \text{ kW}$$

$$\text{Indicated thermal efficiency} = IP/(\dot{m}_f CV) = 19.06/50.17 = \mathbf{37.99 \%}; \text{ brake thermal efficiency} = 15.33/50.17 = 30.56 \%$$

Heat balance (per minute):

- Heat supplied = $(4.2/60) \times 43,000 = \mathbf{3010.00 \text{ kJ/min}}$
- Heat equivalent of BP = $15.331 \times 60 = \mathbf{919.86 \text{ kJ/min}}$
- Heat to cooling water = $m_w c_w \Delta t = 9 \times 4.187 \times 20 = \mathbf{753.66 \text{ kJ/min}}$
- Mass of exhaust gas = $(m_a + m_f)/60 = (180 + 4.2)/60 = 3.0700$ kg/min; heat to exhaust = $3.0700 \times 1.1 \times (320 - 27) = \mathbf{989.46 \text{ kJ/min}}$
- Unaccounted heat (radiation, friction etc.) = $3010.00 - (919.86 + 753.66 + 989.46) = \mathbf{347.02 \text{ kJ/min}}$

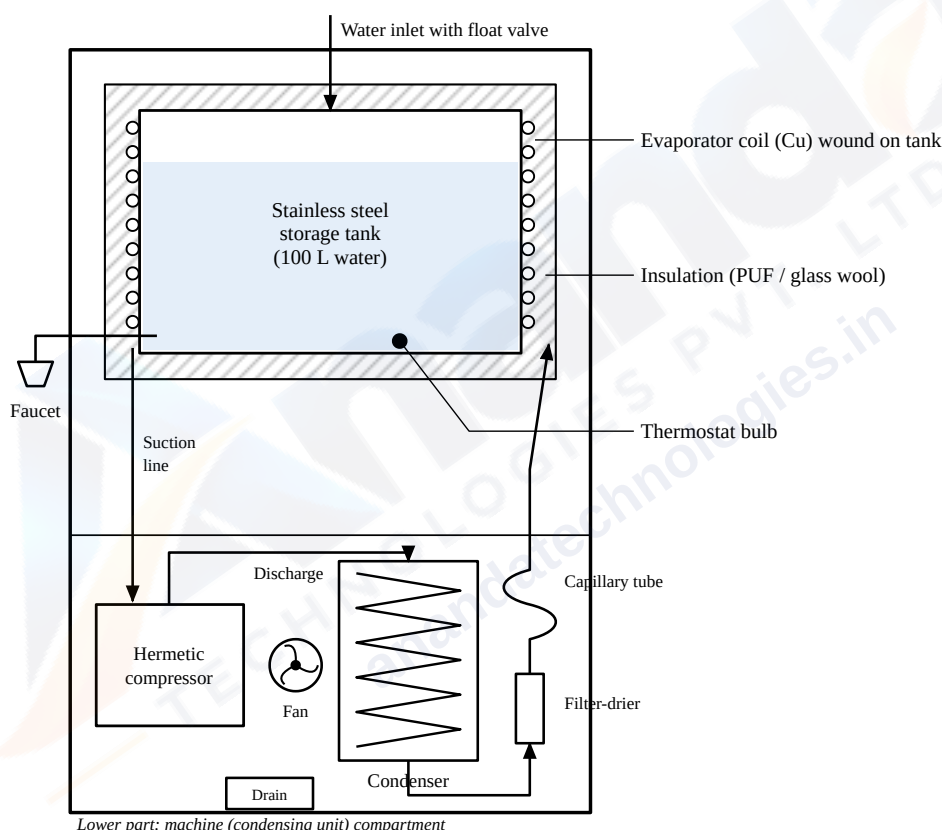
Heat supplied (kJ/min)			Heat distributed (kJ/min)		
Item	kJ/min	%	Item	kJ/min	%
Heat supplied by fuel ($m_f \times CV$)	3010.00	100.00	Heat equivalent of BP	919.86	30.56
			Heat carried by cooling water	753.66	25.04
			Heat carried by exhaust gases	989.46	32.87
			Heat unaccounted (by difference)	347.02	11.53
Total	3010.00	100.00	Total	3010.00	100.00

(IP, BP, η_m 2 M; BSFC and η_{lith} 1 M; heat balance sheet 3 M)

Q.6

a) Storage-type water cooler.

6 M



Storage type water cooler — construction (sectional sketch)

Construction: A stainless-steel storage tank is surrounded by the evaporator coil (copper tube wound and soldered on the outer surface) and insulated with PUF. Water enters through a float valve and is drawn from faucets at the front. The lower compartment contains the hermetic compressor, an air-cooled condenser with fan, filter-drier and capillary tube. A thermostat with its bulb in the tank controls the compressor.

Working: The compressor sends hot high-pressure R-134a vapour to the condenser, where the fan-cooled air condenses it. The liquid passes through the filter-drier and the capillary tube, where its

pressure and temperature fall. The cold refrigerant evaporates in the coil round the tank, taking heat from the water. The vapour returns to the compressor. When the water reaches the set temperature (about 10–12 °C) the thermostat stops the compressor and restarts it when the temperature rises.

Typical specifications (example; actual values depend on make and model):

Item	Typical value
Storage capacity	100 litres
Cooling capacity	about 50 L/h from 35 °C to 12 °C (≈ 1.34 kW of cooling)
Refrigerant	R-134a (newer models R-290 / R-600a)
Compressor	Hermetically sealed reciprocating / rotary
Expansion device	Capillary tube
Condenser	Air-cooled, fan-forced
Thermostat range	about 8 °C to 15 °C
Tank / body	SS 304 tank; PUF insulation; SS / powder-coated body
Power supply	230 V, 1-phase, 50 Hz
Taps	2 to 4 push-type faucets

(Sketch 2 M, construction 1 M, working 2 M, specifications 1 M)

b) Morse test numerical.

6 M

When one cylinder is cut off, the speed is brought back to the original value by reducing the load. The drop in BP equals the indicated power of the cylinder that was cut off: $IP_n = BP - BP_n$.

Cylinder	$IP = BP - BP_n$	IP (kW)
1	22.5 – 15.9	6.60
2	22.5 – 16.0	6.50
3	22.5 – 15.8	6.70
4	22.5 – 16.1	6.40
	Total IP	26.20

(i) IP of engine = **26.20 kW**

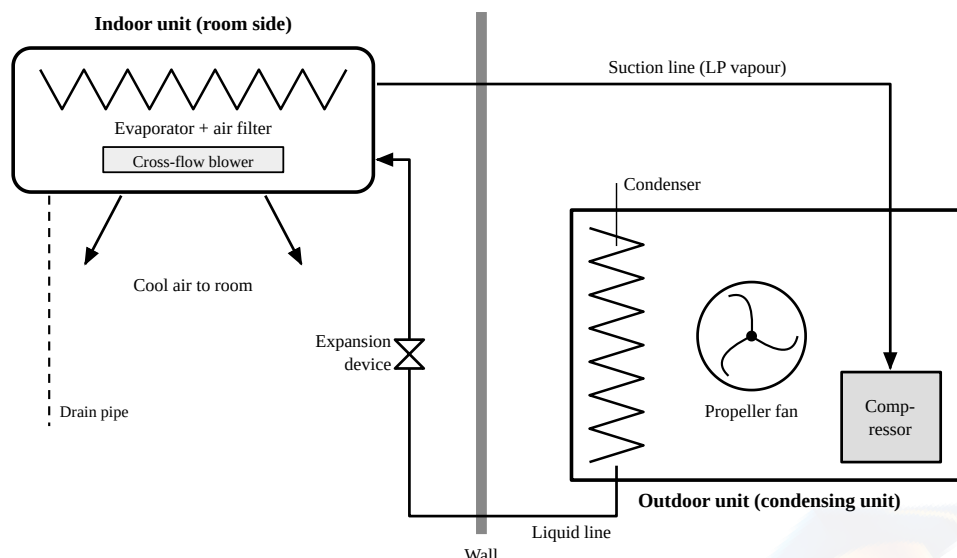
(ii) $\eta_m = BP/IP = 22.5/26.20 = 85.88 \%$; friction power = $26.20 - 22.5 = 3.70$ kW

(iii) Heat supplied = $(7.2/3600) \times 44,000 = 88.00$ kW

$\eta_{bth} = 22.5/88.00 = 25.57 \%$; $\eta_{ith} = 26.20/88.00 = 29.77 \%$; BSFC = $7.2/22.5 = 0.3200$ kg/kWh

(IP 3 M, η_m 1 M, efficiencies 2 M)

c) Split air conditioner.



Split air conditioner: indoor and outdoor units

Construction: A split AC has two units joined by copper refrigerant pipes (liquid line and suction line) and electric cables:

- **Indoor unit** (on the room wall): evaporator coil, air filter, cross-flow blower, louvers, drain tray and pipe, remote-controlled electronic controls.
- **Outdoor unit** (outside the room): hermetic compressor, air-cooled condenser coil, propeller fan and the expansion device (capillary / EEV).

Working: The compressor sends high-pressure hot vapour to the condenser, where the outdoor fan removes heat and the vapour condenses. The liquid goes through the expansion device to the indoor evaporator at low pressure and temperature. The indoor blower draws room air through the filter and over the cold evaporator; the air is cooled and dehumidified and returned to the room. The condensed moisture drains out. The vapour returns to the compressor through the suction line. The thermostat (in the indoor unit) controls the compressor.

Advantages over window AC: (1) Very quiet indoors because the compressor and condenser fan are outside. (2) No need to cut a large opening in the wall; indoor unit can be placed at the best position for air distribution and looks better.

(Sketch 2 M, construction 1 M, working 2 M, advantages 1 M)

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