DETAILED SOLUTIONS

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ESE 2026 : Prelims Exam
CLASSROOM TEST SERIES

MECHANICAL ENGINEERING

Test 4

Section A : Production Engineering & Material Science [All Topics]
Section B : Thermodynamics-1 [Part Syllabus]
Section C : Refrigeration and Air-Conditioning-1 [Part Syllabus]

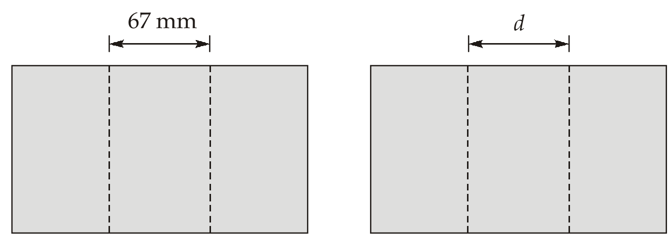
Answer Key

1.	(b)	16.	(d)	31.	(c)	46.	(c)	61.	(c)
2.	(b)	17.	(c)	32.	(a)	47.	(c)	62.	(d)
3.	(c)	18.	(d)	33.	(a)	48.	(b)	63.	(b)
4.	(d)	19.	(d)	34.	(d)	49.	(b)	64.	(b)
5.	(d)	20.	(d)	35.	(c)	50.	(a)	65.	(d)
6.	(c)	21.	(c)	36.	(a)	51.	(d)	66.	(b)
7.	(d)	22.	(c)	37.	(a)	52.	(c)	67.	(b)
8.	(a)	23.	(a)	38.	(d)	53.	(c)	68.	(d)
9.	(c)	24.	(d)	39.	(a)	54.	(a)	69.	(c)
10.	(c)	25.	(d)	40.	(d)	55.	(a)	70.	(b)
11.	(c)	26.	(c)	41.	(d)	56.	(d)	71.	(a)
12.	(b)	27.	(d)	42.	(c)	57.	(c)	72.	(a)
13.	(c)	28.	(b)	43.	(a)	58.	(b)	73.	(c)
14.	(b)	29.	(d)	44.	(c)	59.	(d)	74.	(c)
15.	(b)	30.	(b)	45.	(b)	60.	(b)	75.	(d)

Section A : Production Engg. & Material Science

1. (b)

Given, Product dimension = 67 mm



$$\text{Pattern dimension} = 67 - 2 \times 1.5 = 64 \text{ mm}$$

2. (b)

Given : $p = 3.5 \text{ g/cm}^2$; $T = 2 \text{ min } 6\text{s} = 2 + \frac{6}{60} = 2.1 \text{ min}$, $PN = \frac{V \times W}{\rho A T}$

$$\text{Permeability number, } P = \frac{501.28}{pT} = \frac{501.28}{3.5 \times 2.1} = \frac{501.28}{7.35}$$

$$P = 68.20$$

3. (c)

The term fluidity is normally used in a foundry to designate the casting material's ability to fill the mould cavity. Fluidity depends on the casting as well as the mould. Lower the coefficient of viscosity of the molten metal, higher would be the fluidity since the melt will be able to flow freely. In general, the alloys which have a narrow freezing range, have a higher fluidity compared to the wide freezing range once. In wide freezing range alloys, during the process of solidification, the dendrites are spread over a much larger part of the mould and thus reduce the flow of the metal, decreasing the fluidity.

4. (d)

Given $\omega_m = 78000 \text{ N/m}^3$; $\omega_c = 18000 \text{ N/m}^3$; $d_i = d_c = 12 \text{ cm} = 0.12 \text{ m}$; $L_c = 150 \text{ cm} = 1.5 \text{ m}$

$$\text{Buoyancy force} = \rho_m \times V_c g$$

$$F_{net} = (\rho_m - \rho_c) g V_c$$

$$F_{net} = \frac{\pi}{4} \times 0.12^2 \times 1.5(78000 - 18000)$$

$$= \frac{\pi}{4} \times 0.12 \times 0.12 \times 1.5 \times 60000$$

$$= 324 \pi \text{ N}$$

5. (d)

	x	y	z
Intercept	1	1/2	1/2
Reciprocals	1	2	2
Miller indices	1	2	2

6. (c)

$$\text{Number of groups} = \frac{\text{Process capability}}{\text{Tolerance desired}} = \frac{0.9}{0.3} = 3$$

7. (d)

$$E_m = 3.4 \text{ GPa},$$
$$V_m = 0.6$$
$$E_f = 69 \text{ GPa},$$
$$V_f = 0.4$$

$$E_{ct} = \frac{E_m \times E_f}{V_m E_f + V_f E_m} = \frac{3.4 \times 69}{0.6 \times 69 + 0.4 \times 3.4} = 5.48 \text{ GPa}$$

8. (a)

Fettling

- The complete process of cleaning of casting, called fettling, involves the removal of the cores, gates and risers, cleaning of the casting surface and chipping of any of the unnecessary projections.
- The dry sand cores can simply be removed by knocking off with an iron bar, by means of a core vibrator, or by means of hydro blasting. The method depends on the size, complexity and the core material used.
- For cleaning of sand particles, sand blasting is used. The casting is kept in a closed box and a jet of compressed air with a blast of sand grains or steel grit is directed against the casting surface, which thoroughly cleans the casting surface. The typical shot speeds reached are of the order of 80 m/s.
- Another useful method for cleaning the casting surface is tumbling. One precaution to be taken for tumbling is that the casting should be all rigid with no frail or overhung segments which may get knocked off during the tumbling operation.

9. (c)

Given, $P = 2(50 + 100) = 300$ mm; $p = 0.4$, $t = 6$ mm; $s = 5$ mm

$$pt = 6 \times 0.4 = 2.4 \text{ mm}$$

$$\text{Working without shear} = F_{\max}\,(pt)$$

$$F_{\max} = Pt\tau$$

$\because$ $$s > pt$$

$\therefore$ $$\text{Workdone} = F_s \cdot s$$

$\therefore$ $$F_s = Pt\tau \cdot \frac{pt}{s}$$

$$= 300 \times 6 \times 500 \times \frac{2.4}{5} = 432 \text{ kN}$$

10. (c)

Ironing is the operation of thinning the side walls and increasing the height. The die and punch set used is similar to that of drawing operation except that the clearance between the die and punch is smaller than that used in the drawing operation. The wall thickness can be reduced to as much as 50% in a single ironing operation. In ironing, the objective is only to reduce the wall thickness of the cup, and hence no blank holding is required because the punch is fitted closely inside the cup.

11. (c)

Given, d = 50 mm, h = 59.5 mm, r = 4 mm

$$10\,r = 40 \text{ mm}, 15\,r = 60 \text{ mm}$$

$\because$ $$10\,r \le d \le 15\,r$$

$\therefore$ $$D = \sqrt{d^2 + 4dh - r}$$

$$= \sqrt{50^2 + 4 \times 50 \times 59.5 - 4}$$

$$= \sqrt{14400 - 4} \qquad \left\{\because \sqrt{14400} = 120\right\}$$

$$= 119.98 \text{ mm}$$

12. (b)

Pressure is constant. Use Gibbs phase rule: $P + F = C + 1$

Given: $$F = 1, C = 2$$

$$P + 1 = 2 + 1$$

$\Rightarrow$ $$P = 2$$

13. (c)

Eutectic reaction : $L \underset{\text{heating}}{\rightleftharpoons} S_1 + S_2$

e.g. $L \rightarrow \gamma + Fe_3C$

Peritectic reaction: $S_1 + L \rightleftharpoons S_2$

Eutectoid reaction: $S_1 \rightleftharpoons S_2 + S_3$

e.g. $\gamma \rightarrow \alpha + Fe_3C$

Congruent transformation: $\gamma \rightarrow \alpha$

When there is no composition alteration.

14. (b)

Given, R = 250 mm, w = 280 mm

$$h_o - h_f = 26 - 23.5 = 2.5 \text{ mm}$$

$$N = 120 \text{ rpm}, \sigma_{avg} = 200 \text{ MPa}$$

$$L = \sqrt{R\left(h_o - h_f\right)} = \sqrt{250 \times 2.5} = 25 \text{ mm}$$

$$F = \sigma_{avg}\ (L\omega)$$

$$P = 2Fv = \frac{2\pi FLN}{60000} \text{ kW}$$

$$P = \frac{2\pi \times (200 \times 25 \times 280) \times 25 \times 10^{-3} \times 120}{60000}$$

$$\Rightarrow \quad P = 140\,\pi \text{ kW}$$

15. (b)

- **Shape rolling :** Straight and long structural shapes (such as channels, I-beams, rails and solid bars) are formed at elevated temperatures by shape rolling (profile rolling).
- **Skew Rolling :** It is used for making ball bearings.
- **Ring rolling :** Typical applications of ring rolling are large rings for rockets, and turbines, jet engine cases, gearwheel rims, ball-bearing and roller bearing races, flanges, and reinforcing rings for pipes.
- **Tube rolling :** The diameter and thickness of pipes and tubing can be reduced by tube rolling, which utilizes shaped rolls.

16. (d)

Isothermal forging, also known as hot forging, this process heats the dies to the same temperature as that of hot workplace. Because the workplace remains the hot, its flow strength and high ductility are maintained during forging. The dies for hot forging of high temperature alloys are usually made of nickel or molybdenum alloys, but steel dies can be used for aluminium alloys. Isothermal forging, is expensive and the production rate is low.

17. (c)

Given, R = 3, d_o = 120 mm, k = 250 MPa

$$F = kA_o \ln(\text{R})$$

$$= 250 \times \frac{\pi}{4}(120)^2 \ln(3)\,\text{N} = 900000\,\pi \ln(3) \text{ N}$$

$$\Rightarrow \quad F = 900\,\pi \ln(3) \text{ kN}$$

$$\text{or} \quad F = 450\,\pi \ln(9) \text{ kN}$$

18. (d)

We know that,

$$\text{Maximum possible reduction in area} = 63.2\%$$

or
$$\frac{A_o - A_f}{A_o} = 0.632$$

$$\Rightarrow \quad \frac{A_f}{A_o} = 0.368$$

$$\Rightarrow \quad \frac{d_f}{d_o} = 0.607$$

$$\Rightarrow \quad 1 - \frac{d_f}{d_o} = 0.393$$

$$\Rightarrow \quad \left(\frac{d_o - d_f}{d_o}\right) \simeq 39.3\%$$

19. (d)

Tempering is accomplished by heating a martensitic steel to a temperature below eutectoid for a specified time period.

The single phase BCT martensite, which is supersaturated with carbon, transforms to the tempered martensite, composed of stable ferrite and cementite phase.

Ductility is improved and strength is reduced relative to the martensite.

20. (d)

Given : $V = 40\text{ mm}^3$; $\rho_s = 7500\text{ kg/m}^3 = 0.0075\text{ g/mm}^3$; $H_m = 1500\text{ J/g}$; $R = 100\ \mu\Omega$

$T = 0.2\text{s}$; $I = 6000\text{ A}$

$$\begin{aligned}\text{Heat required for melting} &= mH_m\\ &= (0.0075 \times 40) \times 1500\\ &= 450\text{ J}\end{aligned}$$

21. (c)

Given : $V = 40\text{ mm}^3$; $\rho_s = 7500\text{ kg/m}^3 = 0.0075\text{ g/mm}^3$; $H_m = 1500\text{ J/g}$; $R = 100\ \mu\Omega$

$T = 0.25\text{s}$; $I = 6000\text{ A}$

$$\begin{aligned}\text{Heat supplied} &= I^2RT = (6000)^2 \times 0.2 \times 100 \times 10^{-6}\\ &= 720\text{ J}\\ \text{Heat dissipated to surrounding} &= 720 - 450 = 270\text{ J}\\ \%\text{Heat dissipated} &= \frac{270}{720} \times 100 = 37.5\%\\ &= 1055.83\text{ mm}^2 \text{ ; } 1056\text{ mm}^2\end{aligned}$$

22. (c)

$$\text{Vickers hardness, HV} = \frac{1.854P}{L^2}$$

$$\text{Knoop hardness, HK} = \frac{14.2P}{L^2}$$

23. (a)

- CIM integrates all functional areas of manufacturing through computer system and data communication.
- It links CAD, CAM, and business functions such as inventory control and production scheduling.
- CIM in not intended to eliminate people from the manufacturing environment but to integrate the human element with machines and computers in an organized information system.
- Since, Databases are used for a variety of purposes and by many people, databases must be flexible and responsive to the needs of different users.

24. (d)

Killed Steel: Killed steel is a fully deoxidized steel; that is, oxygen is removed and the associated porosity is thus eliminated. In the deoxidation process, the dissolved oxygen in the molten metal is made to react with elements such as aluminum, silicon, manganese, and vanadium that have been added to the melt. These elements have an affinity for oxygen and form metallic oxides. If aluminum is used, the product is called aluminium-killed steel. The term killed comes from the fact that the steel lies quietly after being poured into the mold.

If they are sufficiently large, the oxide inclusions in the molten bath float out and adhere to (or are dissolved in) the slag. A fully killed steel thus is free of any porosity caused by gases; it also is free of any blowholes (large spherical holes near the surfaces of the ingot). Consequently, the chemical and mechanical properties of a killed-steel ingot are relatively uniform throughout. Because of shrinkage during the solidification, however, an ingot of this type develops a pipe at the top (also called a shrinkage cavity). It has the appearance of a funnel-like shape. This pipe can take up a substantial volume of the ingot, as it has to be cut off and scrapped.

25. (d)

The tendency to BUE formation can be reduced by one or more of at the following:

- Increase the cutting speeds.
- Decrease the depth of cut.
- Increase the rake angle.
- Use a sharp tool.
- Use an effective cutting fluid.
- Use a cutting tool that has lower chemical affinity for the workplace material.

26. (c)

Given : $r = 0.6$; $\alpha = 8°$; $F_c = 400$ N; $F_t = 300$ N

$$R = \sqrt{F_c^2 + F_t^2} = 500 \text{ N}$$

$$\therefore \quad F_c = R\cos(\phi - \alpha)$$

$$\Rightarrow \quad \cos(\phi - 8) = 0.8$$

$$\Rightarrow \quad \phi = 45°$$

$$\text{Frictional force, } F = R\sin\phi = 500 \sin 45°$$

$$\Rightarrow \quad F = \frac{500}{\sqrt{2}} = 250\sqrt{2} \text{ N}$$

27. (d)

Given : $r = 0.6$; $\alpha = 8°$; $F_c = 400$ N; $F_t = 300$ N

$$R = \sqrt{F_c^2 + F_t^2} = 500 \text{ N}$$

$$\therefore \quad F_c = R\cos(\phi - \alpha)$$

$$\Rightarrow \quad \cos(\phi - 8) = 0.8$$

$$\Rightarrow \quad \phi = 45°$$

$$\text{Friction energy} = FV_c$$

$$\text{Total energy} = F_cV$$

$$\therefore \quad \frac{\text{Friction energy}}{\text{Total energy}} = \frac{FV_c}{F_cV} = \frac{Fr}{F_c}$$

$$\% = \frac{Fr}{F_c} \times 100 = \frac{250\sqrt{2} \times 0.6}{400} \times 100 \simeq 53\%$$

28. (b)

Given : $VT^{0.25} d^{0.25} f^{0.45} = C$

Let $\quad V_1 = V, \; T_1 = T, d_1 = d, f_1 = f$

$$V_2 = \frac{V_1}{2}, \; d_2 = 2d, f_2 = f$$

$$\therefore \quad V_1T_1^{0.25}d_1^{0.25}f_1^{0.45} = V_2T_2^{0.25}d_2^{0.25}f_2^{0.45}$$

$$\Rightarrow \quad V(T_1d)^{0.25} f^{0.45} = \left(\frac{V}{2}\right)(2T_2d)^{0.25} f^{0.45}$$

$$\Rightarrow \quad \left(\frac{2T_2d}{T_1d}\right)^{0.25} = 2$$

$$\Rightarrow \qquad \frac{T_2}{T_1} = \frac{(2)^4}{2} = 8$$

$$\Rightarrow \qquad \left(\frac{T_2 - T_1}{T_1}\right) \times 100 = (8 - 1) \times 100 = 700\%$$

29. (d)

Phosphorus in steels has two major effects: High strength of the ferrite, causing increased hardness and resulting in better chip formation and surface finish, and it increase hardness and thus causes the formation of short-chips instead of continuous stringy ones, thereby improving machinability. Near that soft steels can be difficult to machine because of their tendency for built-up edge formation and the resulting poor surface finish.

The presence of aluminium and silicon in steels is always harmful, because these elements combine with oxygen to form an aluminum oxide and silicate, which are hard and abrasive. As a result, tool wear increases and machinability is reduced.

Carbon and manganese have various effects on the machinability of steels, depending on their composition. Plain low-carbon steels (less than 0.15% C) can produce poor surface finish by forming a built-up edge. Cast steels are more abrasive, although their machinability is similar to that of wrought steels. Tool and die steels are very difficult to machine and usually require annealing prior to machining. The machinability of most steels is improved by cold working, which hardens the material and reduces the tendency for built-up edge formation.

Other alloying elements (such as nickel, chromium, molybdenum, and vanadium) that improve the properties of steel generally reduce machinability. The effect of boron's negligible. Gaseous elements such as hydrogen and nitrogen can have particularly detrimental effects on the properties of steel. Oxygen has been shown to have a strong effect on the aspect ratio of the manganese sulfide inclusions. The higher the oxygen content, the lower the aspect ratio, and the higher the machinability.

30. (b)

Effects of Cutting Fluids on Machining

Since the cutting fluid is a good lubricant, the following chain of events will take place after the fluid is shut off:

- Friction at the tool-chip interface will increase.
- The shear angle will decrease.
- The shear strain will increase.
- The chip will become thicker.
- A built-up edge is likely to form.

As a result of these changes, the following events will occur:

- The shear energy in the primary zone will increase.
- The frictional energy in the secondary zone will increase.
- The total energy will increase.
- The temperature in the cutting zone will rise, causing greater tool wear.

- Surface finish will begin to deteriorate and dimensional tolerances may be difficult to maintain because of the increased temperature and thermal expansion of the workpiece during machining.

31. (c)

Given, N = 400 rpm, d_i = 14 mm, d_f = 13 mm, f_m = 160 mm/min

$$\text{MRR} = \frac{\pi}{4}\left(d_i^2 - d_f^2\right)(f\,N)$$

$$= \frac{\pi}{4}\left(14^2 - 13^2\right)(160)\ \text{mm}^3/\text{min}$$

$$= 1080\,\pi\ \text{mm}^3/\text{min}$$

$$= 18\,\pi\ \text{mm}^3/\text{s}$$

32. (a)

To reduce the rate of galvanic attack, anode area should be as large as possible.

The reason for this is that corrosion rate depends on current density, i.e. the current per unit area of corroding surface, and not simply the current. Thus, this results in high current density for the anode when its area is small relative to that of cathode.

33. (a)

Process	Characteristics	Process Parameters and typical material removal rate or cutting speed
Electrochemical Machining (ECM)	Complex shapes with deep cavities; highest rate of material removal among other nontraditional processes; expensive tooling and equipment; high power consumption; medium-to-high production quantity.	V: 5–25 DC; A: 1.5–8 A/mm^2; 2.5–12 mm/min, depending on current density.
Electron-Beam Machining (EBM)	Cutting and hole making on thin materials; very small holes and slots; heat-affected zone; requires a vacuum; expensive equipment.	1–2 mm^3/min.
Laser-Beam Machining (LBM)	Cutting and hole making on thin materials; heat-affected zone; does not require a vacuum; expensive equipment; consumes much energy.	0.50–7.5 m/min.
Abrasive-Jet Machining (AJM)	Cutting, slotting, deburring, etching, and cleaning of metallic and nonmetallic materials; tends to round off sharp edges; can be hazardous.	Varies considerably with material.

34. (d)

35. (c)

Angle measurement devices

- Level protractor
- Sine bar
- Surface plates
- Combination square is used to measuring 45° to 90° angles.

Linear Measurement

- Rules
- Calipers
- Digital Calipers
- Micrometers

36. (a)

Plastic deformation in metals take place by a slip mechanism. Although the theoretical shear stress required to cause slip is very high, actual stresses are much lower because of the presence of dislocations (edge or screw type). The deformed metal exhibit higher strength, because of the entanglement of dislocations with grain boundaries and with each other.

Dislocations are the defects in the orderly arrangement of the metal's atomic structure. Because a slip plane containing a dislocation requires less shear stress to allow slip than does a plane in a perfect lattice, dislocations are the most significant defects that explain the discrepancy between the actual and theoretical strengths of metals.

37. (a)

Effect of sulphur quantity in plane carbon steel.

Iron forms with sulphur, iron sulphide, FeS, which solidifies along the grain boundaries making the steel brittle and lowers its hot working properties. If equal amount of manganese present in steel, MnS forms and harmful effects of sulphur are reduced.

Section B : Thermodynamics-1

38. (d)

Thermocouples are based on the principle that when two dissimilar metals are joined, an electromotive force (emf) that is primarily a function of temperature will exist in a circuit. In certain thermocouples, one thermocouple wire is platinum of a specified purity and the other is an alloy of platinum and rhodium. Thermocouples also utilize copper and constantan (an alloy of copper and nickel), iron and constantan, as well as several other pairs of materials.

Electrical resistance sensors are another important class of temperature measurement devices. These sensors are based on the fact that the electrical resistance of various materials changes in a predictable manner with temperature. The materials used for this purpose are normally conductors (such as platinum, nickel, or copper) or semiconductors. Devices using conductors are known as resistance temperature detectors. Semiconductor types are called thermistors.

39. (a)

In view of the limitations of empirical means for measuring temperature, it is desirable to have a procedure for assigning temperature values that does not depend on the properties of any particular substance or class of substances. Such a scale is called a thermodynamic temperature scale. The Kelvin scale is an absolute thermodynamic temperature scale that provides a continuous definition of temperature, valid over all ranges of temperature. The unit of temperature on the Kelvin scale is the kelvin (K). The kelvin is the SI base unit for temperature. To develop the Kelvin scale, it is necessary to use the conservation of energy principle and the second law of thermodynamics. However, we note here that the Kelvin scale has a zero of 0 K, and lower temperatures than this are not defined.

By definition, the Rankine scale, the unit of which is the degree rankine (°R), is proportional to the Kelvin temperature according to

$$°R = 1.8\text{ K}$$

As evidenced by above equation, the Rankine scale is also an absolute thermodynamic scale with an absolute zero that coincides with the absolute zero of the Kelvin scale.

40. (d)

Relation between temperatures in Rankine Scale (°R) and Kelvin Scale (K) is given by

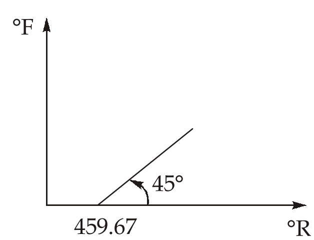
$$°R = 1.8\text{ K}$$

$$°R = 1.8\,(130) = 234$$

41. (d)

Relation between temperatures in Fahrenheit and Rankine Scale (°R) is given by

$$°F = °R - 459.67$$



42. (c)

Given : $m = 2$ kg; $P_1 = 100$ kPa; $T_1 = 27°C = 300$ K; $V_1 = 10\text{ m}^3$; $V_2 = 27.1828\text{ m}^3$

Process is isothermal (T = constant)

$$W = PV\ln\left(\frac{V_2}{V_1}\right) = 100 \times 10 \times \ln\left(\frac{27.1828}{10}\right)$$

$$\simeq 1000\ln(e) = 1000\text{ kJ}$$

43. (a)

Steady state expansion

$\Rightarrow$ Open flow system

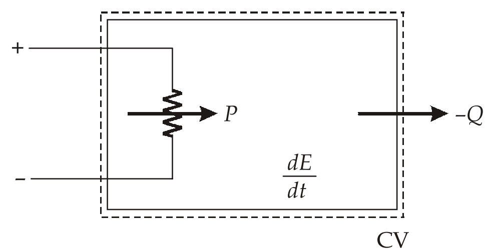
$$Pv^{-1} = 0.5$$

$$v = 2P$$

$$w = -\int_1^2 v\,dP = -\int_1^2 2P\cdot dP$$

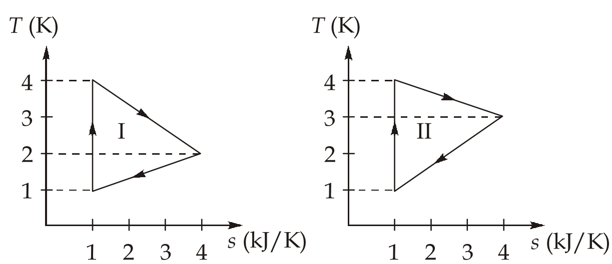
$$= -\left(P_2^2 - P_1^2\right) = (P_1 + P_2)(P_1 - P_2)$$

44. (c)



$$\frac{dE}{dt} = -Q + P$$

45. (b)



Cycle work $= W_{\text{I}} = W_{\text{II}} =$ Area enclosed by cycle on T-s diagram

$$= \frac{1}{2}(4-1)(4-1) = 4.5 \text{ kJ}$$

Heat supplied, $Q_{S,\text{I}} = \frac{1}{2}(3)(4+2) = 9$ kJ

$$Q_{S,\text{II}} = \frac{1}{2}(3)(4+3) = \frac{21}{2} \text{ kJ}$$

Efficiency ratio $\left(\frac{\eta_I}{\eta_{II}}\right) = \dfrac{\frac{W_I}{Q_{S,I}}}{\frac{W_{II}}{Q_{S,II}}} = \frac{Q_{S,II}}{Q_{S,I}} = \frac{21}{2\times 9} = \frac{7}{6}$

46. (c)

(i) Expansion work by gas can be evaluated using $\int_1^2 \left(P_{gas,\,at\,piston}\right) dV$ for both actual and quasi equilibrium expansion.

(ii) Energy transfer in a closed system can be induced as a result of temperature difference between system and surrounding or work transfer or mass transfer.

(iii) If the system undergoes a process involving work transfer but no heat with its surroundings, that process is said to be adiabatic.

47. (c)

$$Q_{\text{poly}} = W_{poly} \cdot \frac{\gamma - n}{\gamma - 1}$$

$$\frac{Q_{poly}}{W_{poly}} = 5.5 = \frac{\gamma - n}{\gamma - 1}$$

$$\Rightarrow \quad 5.5 \times 0.5 = 1.5 - n$$

$$\Rightarrow \quad n = 1.5 - 2.75 = -1.25$$

$$\Rightarrow \quad \text{Required ratio, } \frac{n}{\gamma} = -\frac{5}{6}$$

48. (b)

According to the Kelvin–Planck statement, a system undergoing a cycle while communicating thermally with a single reservoir cannot deliver a net amount of work to its surroundings: The net work of the cycle cannot be positive. However, the Kelvin–Planck statement does not rule out the possibility that there is a net work transfer of energy to the system during the cycle or that the net work is zero. Thus, the analytical form of the Kelvin–Planck statement is

$$W_{\text{cycle}} \le 0 \text{ ; Single Thermal Energy reservoir}$$

$$W_{\text{cycle}} \le 0 \begin{cases} < 0; \text{ Internal irreversibilities present} \\ = 0; \text{No internal irreversibilities} \end{cases}$$

49. (b)

Both are expansion processes

$\Rightarrow$ W_1 and W_2 are positive.

Process (1),

$$PV^{-1} = C$$

$$P = CV$$

and from ideal gas equation,

$$pV = mRT$$

$$V^2 \propto T$$

$$V\uparrow = T\uparrow$$

Process (2),

$$PV^{1.2} = C$$

$$P = \frac{C}{V^{1.2}}$$

and from ideal gas equation,

$$pV = mRT$$

$$\frac{1}{V^{0.2}} \propto T$$

$$V\uparrow = T\downarrow$$

Process (1),

Also

$$Q_{poly} = \left(\frac{\gamma - n}{\gamma - 1}\right) W_{poly}$$

$$= \frac{1.4-(-1)}{1.4-1} W_{poly} = 6 \times W_{poly}$$

$$Q_{poly} = \text{Positive}$$

$\Rightarrow$ Heat added

$\Rightarrow$ $\Delta S_{(1)}$ is positive

Process (2),

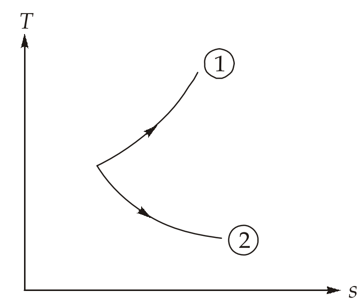
$$Q_{poly} = \left(\frac{\gamma - n}{\gamma - 1}\right) W_{poly}$$

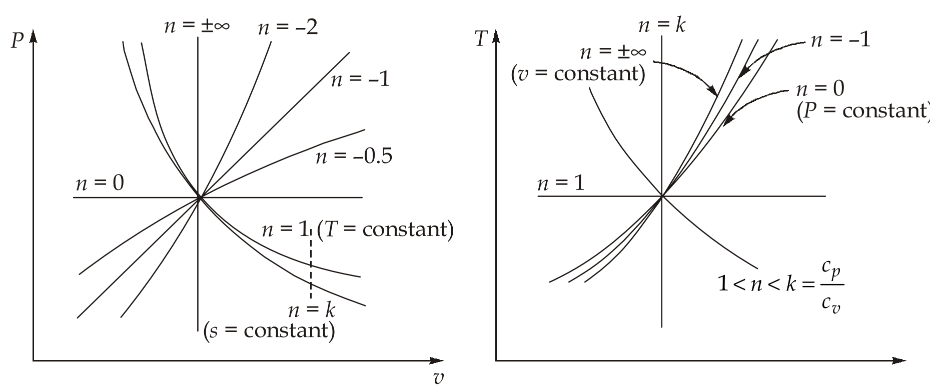
$$= \frac{1.4-1.2}{1.4-1} W_{poly} = 0.5\, W_{poly}$$

$$Q_{poly} = \text{Positive}$$

$\Rightarrow$ Heat added

$\Rightarrow$ $\Delta S_{(2)}$ is positive





Polytropic process on P-v and T-s diagrams

50. (a)

Irreversible processes normally include one or more of the following irreversibilities:

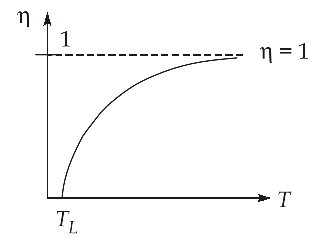
1. Heat transfer through a finite temperature difference
2. Unrestrained expansion of a gas or liquid to a lower pressure
3. Spontaneous chemical reaction
4. Spontaneous mixing of matter at different compositions or states
5. Friction—sliding friction as well as friction in the flow of fluids
6. Electric current flow through a resistance
7. Magnetization or polarization with hysteresis
8. Inelastic deformation

51. (d)

$$\eta = 1 - \frac{T_L}{T_H} \qquad \text{For carnot cycle}$$

A. With sink temperature keeping source at some temperature.

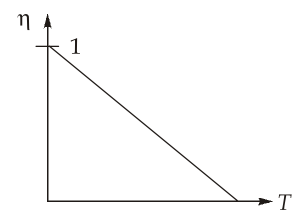
$$\eta = 1 - \frac{T_L}{T};$$



(A - 4)

B. With sink temperature keeping source at same temperature.

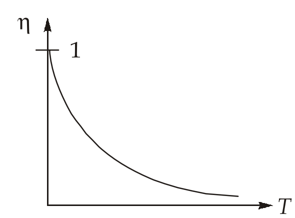
$$\eta = 1 - \frac{T}{T_H};$$



(B - 2)

C. With source temperature keeping same temperature difference between source and sink.

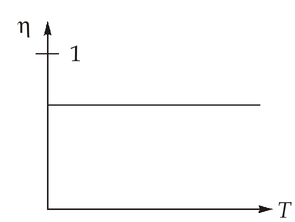
$$\eta = \frac{T_H - T_L}{T};$$



(C - 1)

D. With sink temperature keeping same temperature ratio between source and sink

$$\eta = 1 - \frac{T_L}{T_H};$$



(D - 3)

52. (c)

$$COP_{HP} = COP_R + 1 \qquad \text{...(i)}$$

$$COP_{HP} = (COP_R)^2 \qquad \text{...(ii)}$$

$$(COP_R)^2 = COP_R + 1$$

$$COP_R^2 - COP_R - 1 = 0$$

$$COP_R = \frac{1 \pm \sqrt{1+4}}{2}$$

$$COP_R = \frac{1 \pm \sqrt{5}}{2}$$

Since $$COP_R \geq 0$$

$$COP_R = \frac{1 + \sqrt{5}}{2}$$

$$COP_{HP} = 1 + COP_R$$

$$= 1 + \frac{1+\sqrt{5}}{2} = \frac{3+\sqrt{5}}{2} = 2.618$$

53. (c)

Given : m = 5 kg; c = 0.5 kJ/kgK; T_2 = 542.48°C = 815.48 K; T_1 = 27°C = 300 K

Entropy change of incompressible substance,

$$\Delta s = mc \ln\left(\frac{T_2}{T_1}\right) = 5(0.5)\ln\left(\frac{815.48}{300}\right)$$

$$\simeq 2.5 \ln(e) = 2.5 \text{ kJ/K}$$

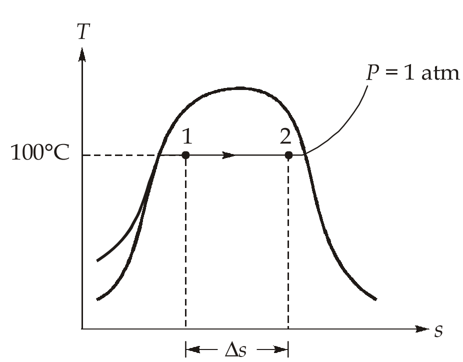
54. (a)

In the entropy relation $\frac{S}{K} = N \ln(W)$

where; 'S' is entropy; 'N' is number of molecules in a system; 'W' is thermodynamic probability

Boltzmann's constant, $K = 1.38 \times 10^{-23}$ J/K

55. (a)



Given : m = 2 kg

At 1 atm and 100°C,

$$s_f = 1.31 \text{ kJ/kgK}$$

$$s_g = 6.05 \text{ kJ/kgK}$$

$$x_1 = 0.2,\ x_2 = 0.8$$

$$s_2 - s_1 = m\left[\left(s_f + x_2 s_{fg}\right) - \left(s_f + x_1 s_{fg}\right)\right]$$

$$= m(x_2 - x_1)s_{fg} = 2(0.8 - 0.2)(6.05 - 1.31)$$

$$= 5.688 \text{ kJ/K} = 5688 \text{ J/K}$$

56. (d)

Entropy statement of the second law:

Unlike mass and energy, which are conserved, entropy is produced (or generated) within systems whenever non-idealities (called irreversibilities) such as friction are present.

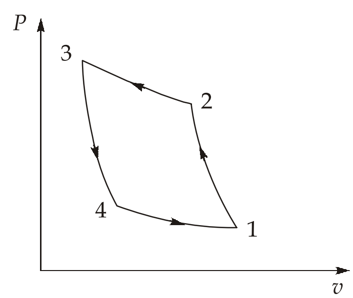
The entropy statement of the second law states:

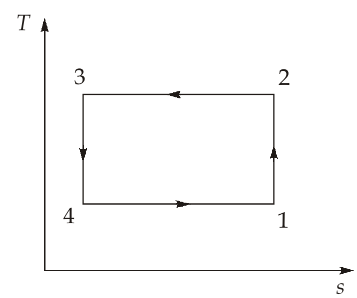
It is impossible for any system to operate in a way that entropy is destroyed.

Section C : Refrigeration and Air-Conditioning-1

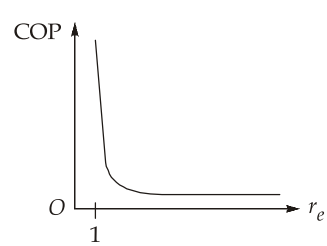
57. (c)

Reversed Carnot Cycle





$$\text{COP} = \frac{T_1}{T_2 - T_1} = \frac{1}{r_e^{\gamma-1} - 1}$$



58. (b)

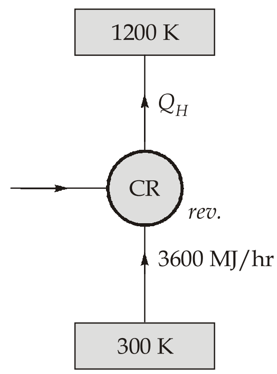
The main differences between Reversed Carnot cycle operating on perfect gas and wet vapour are:

(i) Work of isentropic compression is equal to work of isentropic expansion in case of perfect gas, and thus algebraic work for these two processes is zero. But for wet vapour region the work of isentropic compression is more than work of isentropic expansion. In fact, the net work of the cycle is the difference between the two.

(ii) Work during isothermal. And work during is isothermal = 0, for wet vapour region. But the difference of heat transfer during condensation and evaporation is the net work of the cycle. For perfect gas there is both heat transfer and work transfer during isothermal compression and isothermal expansion. Algebraic sum of heat transfer is equal to algebraic sum of work transfer during isothermal processes for perfect gas.

59. (d)

For reversible cyclic device



$$\oint \frac{dQ}{T} = 0$$

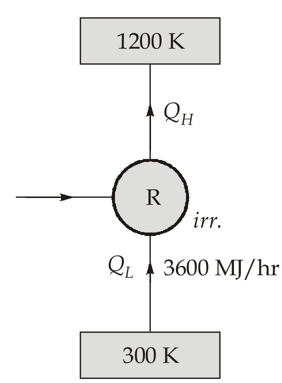
$$\Rightarrow \quad \frac{Q_H}{T_H} = \frac{Q_L}{T_L}$$

$$\Rightarrow \quad Q_H = \frac{T_H}{T_L} Q_L = \frac{1200}{300}\left(\frac{3600\times1000}{60\times60}\right)$$

$$= 4 \times 1000 \text{ kW}$$

$$= 4000 \text{ kW}$$

60. (b)



Let $$\frac{Q_L}{Q_H} = x$$

$$\text{COP}_{\text{act}} = 0.8\ \text{COP}_{\text{ideal}}$$

$$= 0.8\left(\frac{300}{1200-300}\right) = 0.8\left(\frac{300}{900}\right)$$

$$= \frac{0.8}{3} = \frac{4}{15}$$

$$\text{COP}_{\text{act}} = \frac{Q_L}{Q_H - Q_L} = \frac{1}{\left(\frac{Q_H}{Q_L}\right)-1}$$

$$\frac{4}{15} = \frac{1}{x^{-1}-1}$$

$$x^{-1} - 1 = \frac{15}{4} = 3.75$$

$$x^{-1} = 4.75$$

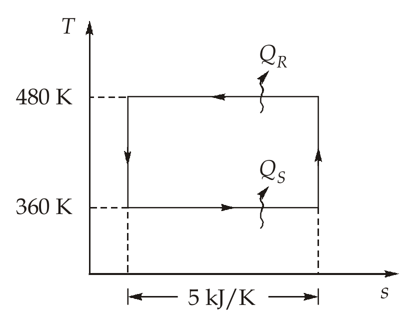
$$x = \frac{Q_L}{Q_H} = \frac{1}{4.75} = \frac{4}{19}$$

61. (c)

Effect of Temperature :

C.O.P. is improved either by lowering the higher temperature or by raising the lower temperature. This is applicable to all refrigerating machines, both theoretical and practical. But a little thought will reveal that both these temperatures have certain functional limitations and cannot be varied at will. The normal methods of heat rejection are by circulating cooling water or blowing ambient air. Thus, in order that there may be transfer of heat in the right direction, the higher temperature should be more than the water or air to which heat is rejected. The lower temperature is fixed by refrigeration application, i.e. it must be lower than the temperature of substance in space to be cooled.

62. (d)



$$\text{Heat supply temperature} = \frac{Q_s}{\Delta s} = \frac{1800}{5} = 360 \text{ K}$$

$$\text{Heat rejection temperature} = 207 + 273 = 480 \text{ K}$$

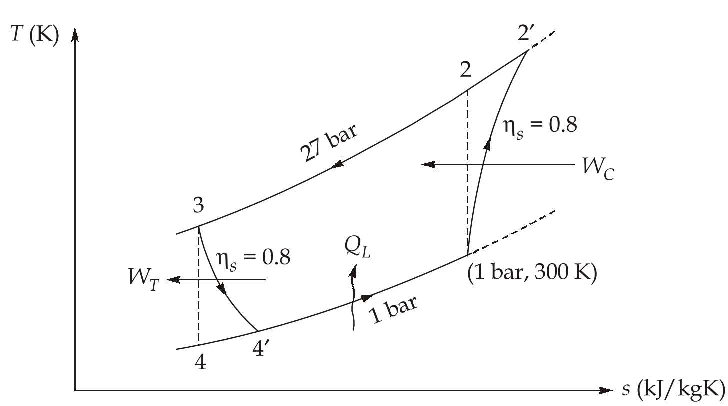
$$\text{Heat supplied, } Q_S = 1800 \text{ kJ}$$

$$\text{Heat rejected, } Q_R = T_H \cdot \Delta S = 480(5) = 2400 \text{ kJ}$$

$$W = Q_R - Q_S \quad \text{(to the refrigerant)}$$

$$= 2400 - 1800 = 600 \text{ kJ}$$

63. (b)



$$\eta_c = \frac{W_{ideal}}{W_{act}}$$

$$(W_{\text{act}})_c = \frac{W_{ideal}}{\eta_c}$$

$$\eta_T = \frac{W_{act}}{W_{ideal}}$$

$$(W_{\text{act}})_c = \eta_T \cdot W_{\text{ideal}}$$

$$\frac{(W_{act})_c}{(W_{act})_T} = \frac{1}{\eta_c \cdot \eta_T}\left(\frac{W_{ideal,c}}{W_{ideal,T}}\right) = \frac{1}{0.8\times 0.8}\left(\frac{h_2-h_1}{h_4-h_3}\right)$$

$$= \frac{1}{0.8^2}\left(\frac{T_2-T_1}{T_3-T_4}\right)$$

$$T_1 = 27°\text{C} = 300 \text{ K (Given)}$$

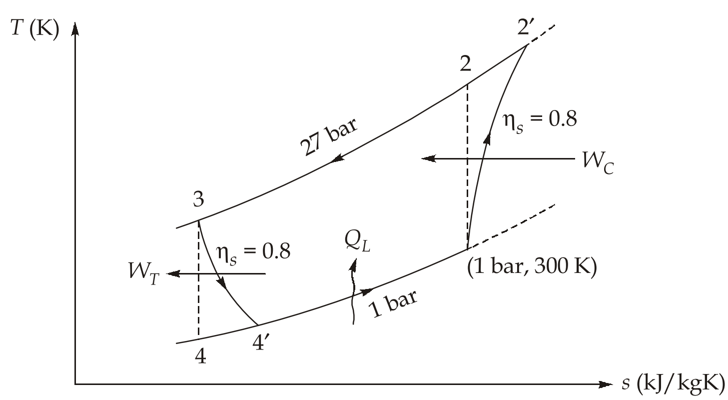
$$T_2 = T_1(r_p)^{\frac{\gamma-1}{\gamma}} = 300(27)^{\frac{1.5-1}{1.5}} = 900 \text{ K}$$

Similarly;
$$T_3 = 57°\text{C} = 330 \text{ K}$$

$$T_4 = T_3\left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}} = 330\left(\frac{1}{3}\right) = 110 \text{ K}$$

$$\frac{(W_{act})_c}{(W_{act})_T} = (1.25)^2\left(\frac{900-300}{330-110}\right) \simeq 4.26$$

64. (b)



$$c_p = 1.2 \text{ kJ/kgK}; R = 0.4 \text{ kJ/kgK}$$

$$c_v = 1.2 - 0.4 = 0.8 \text{ kJ/kgK}$$

$$\gamma = \frac{c_p}{c_v} = \frac{1.2}{0.8} = 1.5$$

$$T_1 = 300 \text{ K}; T_2 = 900 \text{ K}$$

Now,
$$\eta_c = \frac{(h_3 - h_{4'})}{(h_{2'} - h_1)}$$

$$\Rightarrow \qquad 0.8 = \frac{T_3 - T_{4'}}{T_3 - T_4}$$

$$\Rightarrow \qquad T_{4'} = 154 \text{ K}$$

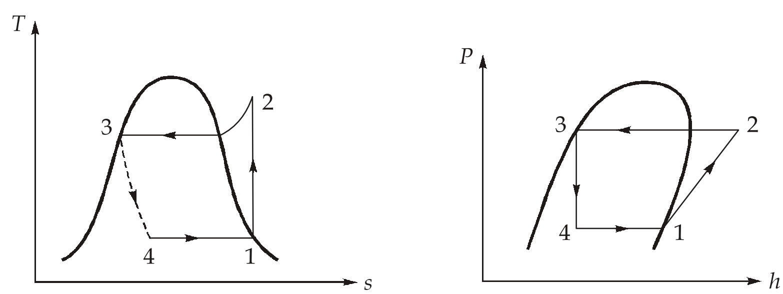
$$\text{COP} = \frac{Q_L}{W_C - W_T} = \frac{(h_1 - h_{4'})}{(h_{2'} - h_1) - (h_3 - h_{4'})}$$

$$= \frac{T_1 - T_{4'}}{(T_{2'} - T_1) - (T_3 - T_{4'})} = \frac{300 - 154}{(1050 - 300) - (330 - 154)}$$

$$= \frac{146}{574} \simeq 0.254$$

65. (d)

Simple VCRS Cycle,



Processes:

$1 \rightarrow 2$: Isentropic Compression
$2 \rightarrow 3$: Isobaric heat rejection
$3 \rightarrow 4$: Isenthalpic expansion
$4 \rightarrow 1$: Isobaric heat addition

66. (b)

$$T_E = 273 - 23 = 250 \text{ K}$$

$$T_H = 273 + 87 = 360 \text{ K}$$

$$T_o = 273 + 37 = 310 \text{ K}$$

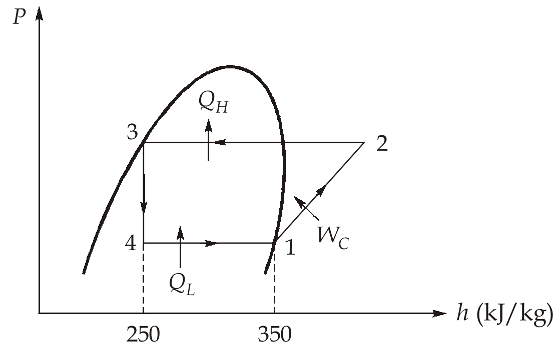
$$\text{COP} = \frac{T_E}{T_H} \times \frac{(T_H - T_o)}{(T_o - T_E)} = \frac{250\,(360 - 310)}{360\,(310 - 250)}$$

$$= \frac{25}{36} \times \frac{50}{60} = 0.579 \approx 0.58$$

67. (b)

In electrolux refrigerator, there is no circulation pump and the third fluid remains mainly in the evaporator.

68. (d)



$$\text{COP} = \frac{Q_L}{W_C}$$

$$\Rightarrow \quad 1.5 = \frac{350-250}{h_2-350}$$

$$\Rightarrow \quad h_2 = 350+\frac{200}{3}$$

Now, $$Q_H = h_2 - h_3 = \left(350+\frac{200}{3}\right)-250 = 100+\frac{200}{3}$$

$$= \frac{500}{3}\text{ kJ/kg}$$

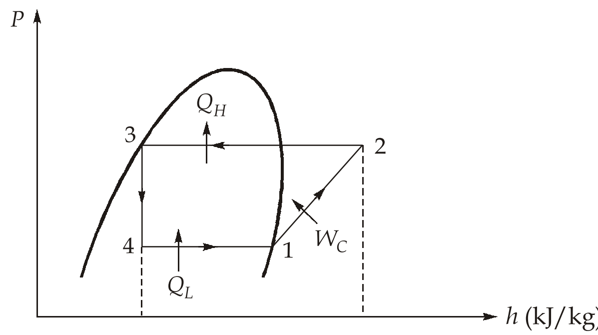
69. (c)

Relative Ozone Depletion or Destruction Potential. If the theory holds, the effectiveness of the various common refrigerants for destroying ozone is characterized by a factor called "Relative Ozone Destruction Efficiency," summarized in Table.

Refrigerant	Relative Efficiency
R-11	1.00
R-12	0.86
R-113	0.80
R-22	0.05

70. (b)

71. (a)



$$\text{COP} = \frac{Q_L}{W_C}$$

$$\eta_{isen} = 0.8$$

$$\Rightarrow \quad W'_C = \frac{W}{0.8}$$

$$W'_C = 1.25\, W_C$$

$$\text{COP}' = \frac{Q_L}{W'_C} = \frac{Q_L}{1.25 W_C} = \frac{5}{1.25} = 4$$

72. (a)

Refrigerant No.	Name and Chemical Formula	Formula
R-11	Trichloromonofluoromethane	CCl_3F
R-12	Dichlorodifluoromethane	$CC1_2F_2$
R-22	Monochlorodifluoromethane	$CHClF_2$
R-500	Azcotropic mixture of 73.8% (R-12) and 26.2% (R-152a)	

73. (c)

"R-134a" is CH_2FCF_3 i.e. Tetrafluoroethane

74. (c)

Automatic expansion valve works on the principle of maintaining a set pressure in the evaporator Thermostatic expansion valve maintains constant degree of superheat at evaporator exit.

75. (d)

In simple VCRS superheating always increases the compression work . But the refrigeration effect may or may not increase depending on whether superheating is done with useful cooling or without useful cooling. In the evaporator if there is superheating, it will require large size evaporator to handle gas/our phase.

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