MADE EASY

RPSC AEn-2024 Main Test Series

MECHANICAL ENGINEERING | **Test 4**

Test Mode : • Offline • Online

Subject : Heat Transfer, Refrigeration and Air-conditioning

DETAILED EXPLANATIONS

1. Solution:

Black Body : A black body is an ideal body that absorbs all incident radiation at all wavelengths and directions and emits the maximum possible thermal radiation at a given temperature.

Gray Body : A gray body is a body that absorbs and emits a constant fraction of radiation (emissivity less than 1) independent of wavelength, at a given temperature.

2. Solution:

Effective Room Sensible Heat Factor:

1. It is defined as the ratio of the effective room sensible heat to the effective room total heat.
2. Mathematically it is given as, effective room sensible heat factor,

$$\text{ERSHF} = \frac{ERSH}{ERTH} = \frac{ERSH}{ERSH + ERLH}$$

where, ERSH = Effective room sensible heat
ERLH = Effective room latent heat, and
ERTH = Effective room total heat

3. Solution:

The critical thickness of insulation is the thickness at which the rated heat loss from an insulated body is maximum. Beyond this thickness, any further increase in insulation reduces rate of heat loss due to increased thermal resistance.

4. Solution:

Irradiation (or Incident Radiation): The total radiant energy incident per unit area on a surface from all directions, usually denoted by G.

Radiosity : The total radiant energy leaving a surface per unit area, including emitted and reflected radiation, usually denoted by J.

5. Solution:

The physical significance of thermal diffusivity is that it tells us how fast heat is propagated or it diffuses through a material during changes of temperature with time.

6. Solution:

Lambert's cosine law states that the intensity of radiation emitted or reflected by a perfectly diffusing surface is directly proportional to the cosine of the angle between the surface normal and the direction of observation.

7. Solution:

The thermal boundary layer thickness is the distance from the surface into the fluid at which the temperature difference between the fluid and the surface becomes negligible (typically 99% of the temperature difference is dissipated).It indicates the region where heat transfer by conduction is significant.

8. Solution:

The Buckingham-π theorem states that any physically meaningful equation involving n variables can be reduced to a relationship among (n - m) dimensionless parameters (π-terms), where m is the number of fundamental dimensions involved.

It is used for dimensional analysis and similarity studies.

9. Solution:

Fin Effectiveness : It is defined as the ratio of heat transfer rate with fin to the heat transfer rate without fin.

Efficiency of Fin (fin) : It is defined as the ratio of actual heat transferred by fin to maximum heat transferable by fin, if entire fin area were at base temperature.

10. Solution:

Given: T_O = 1100 °C = 1373 K, T_E = –15 °C = 258 K, T_A = 40 °C = 313 K.

To find: COP

We know that,

$$\text{COP} = \left(\frac{T_E}{T_A - T_E}\right)\left(\frac{T_G - T_A}{T_G}\right)$$

$$= \left(\frac{258}{313-258}\right)\left(\frac{1373-313}{1373}\right) = \frac{258 \times 1060}{55 \times 1373}$$

$$= 3.62$$

11. Solution:

Film wise Condensation

1. Liquid condensate wets the surface.
2. Liquid condensate spreads out and collects in droplets.
3. It forms continuous films over the entire surface.
4. Continuous film offers resistance and restrict further transfer of heat between vapour and surface.

Dropwise Condensation

1. It does not wet the surface.
2. The liquid condensate in droplets.
3. It does not form any film over the surface.
4. There is no film barrier to heat flow, therefore high heat transfer rate are experienced between vapour and surface.

12. Solution:

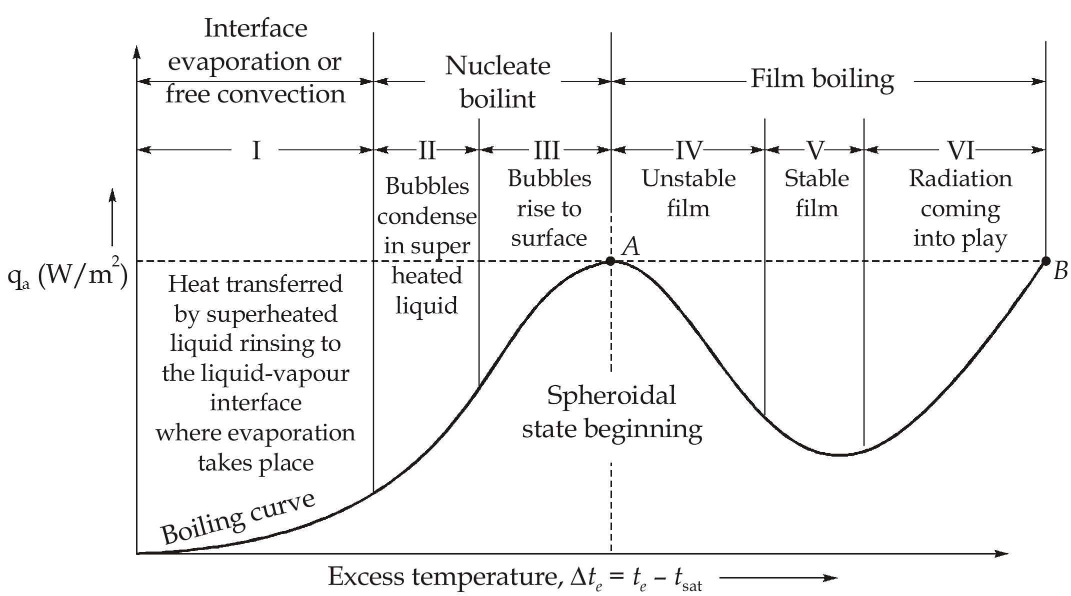


Figure: The boiling curve for water

13. Solution:

The desirable properties of an ideal refrigerant are

1. Low boiling point,
2. Low specific heat of liquid,
3. Low specific volume of vapour,
4. Low cost,
5. High critical temperature,
6. High latent heat of vapourisation,

7. Non-corrosive to metal,
8. Non-toxic,
9. High thermal conductivity,
10. Non-flammable, and
11. Easily available.

14. Solution:

Thermal analysis of human body:

1. The human body works best at a certain temperature but it cannot tolerate wide range of variations in their environmental temperature.
2. The human body maintains its thermal equilibrium with the environment by means of three modes of heat transfer i.e., evaporation, radiation and convection.
3. A human body feels comfortable when the heat produced by metabolism of human body is equal to the sum of the heat dissipated to the surroundings and the heat stored in human body by raising the temperature of body tissues.

Effective Temperature and Comfort:

1. Effective temperature is defined as that index which correlates the combined effects of air temperature, relative humidity and air velocity on the human body.
2. The effective temperature corresponds to the dry bulb temperature of the saturated air at which a given percentage of people feel comfortable.
3. For example: At 21°C (RH = 100% and air movement 8 m/min) most people feel comfortable.

15. Solution:

(i) **Dew point temperature:** It is the temperature of air recorded by a thermometer, when the moisture (water vapour) present in it begins to condense.

(ii) **Specific humidity:** It is the mass of water vapour present in 1 kg of dry air and is generally expressed in terms of grams of water per kg of dry air.

(iii) **Relative humidity:** It is the ratio of actual mass of water vapour in a given volume of moist air to the mass of water vapour in the same volume of saturated air at the same temperature.

(iv) **Degree of saturation:** It is the ratio of actual mass of water vapour in a unit mass of dry air to the mass of water vapour in the same mass of dry air when it it saturated at the same temperature.

(v) **Wet bulb temperature:** It is the temperature of air recorded by a thermometer, when its bulb is surrounded by a wet cloth exposed to the air. It is generally denoted by T_w or T_{wb}.

16. Solution:

Advantages of Hermetically Sealed Compressor:

1. The leakage of refrigerant is completely prevented.
2. It is more compact.
3. It is less noisy.
4. The lubrication is simple.
5. The motor is cooled more effectively because housed in a low pressure area.

Disadvantages of Hermetically Sealed Compressor:

1. The wiring of motor may get damaged/harmed in the presence of moisture.
2. Maintenance is difficult.
3. For evacuation and charging the refrigerant, a separate pump is needed.

17. Solution:

Refrigerating Effect: It is defined as the amount of cooling produced by a system. This cooling is obtained at an expense of some energy.

The practical unit of refrigeration is expressed in terms of 'tonne of refrigeration' or TR.

Coefficient of Performance of a Refrigerator: The ratio of heat extracted in the refrigerator to the work done on the refrigerant is known as coefficient of performance or theoretical coefficient of performance of a refrigerator (COP).

Mathematically, $(\text{COP})_{\text{th}} = W/Q$

18. Solution:

The logarithmic mean temperature difference (LMTD) is the average effective temperature difference between the hot and cold fluids in a heat exchanger.It accounts for the exponential variation of temperature difference along the length of the heat exchanger and is used to calculate the rate of heat transfer.

A counterflow heat exchanger is most preferred because it provides a higher logarithmic mean temperature difference (LMTD), resulting in more effective heat transfer and allowing the cold fluid to reach a temperature close to the hot fluid inlet temperature.

19. Solution:

Given: t_{c1} = 25°C; t_{c2} = 65°C, $(c_p)_h$ = 1.45 kJ/kgK; $\dot{m}_h = 0.9$ kg/s; t_{h1} = 230°C; t_{h2} = 160°C, U = 420 W/m^2°C.

(i) The rate of heat transfer, Q:

$$Q = \dot{m}_h \times (c_p)_h \times (t_{h1} - t_{h2})$$

or $$Q = 0.9 \times (1.45) \times (230 - 160)$$

$$= 91.35 \text{ kJ/s.}$$ **Ans.**

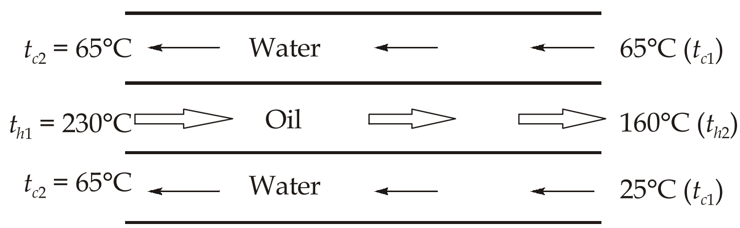
(ii) The mass flow rate of water, $\dot{m}_c$:

Heat lost by oil (hot fluid) = Heat gained by water (cold fluid)

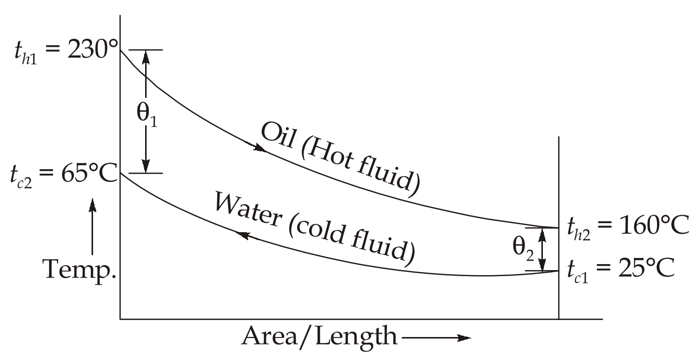
$$\dot{m}_h \times (c_p)_h \times (t_{h1} - t_{h2}) = \dot{m}_c \times (c_p)_c \times (t_{c2} - t_{c1})$$

$$91.35 = \dot{m}_c \times 4.187 \times (65 - 25)$$

$$\dot{m}_c = \frac{91.35}{4.187 \times (65 - 25)} = 0.545 \text{ kg/s}$$



(a) Flow measurement



(b) Temperature distribution

Counter-flow heat exchanger

(iii) The surface area of heat exchanger, A; Logarithmic mean temperature difference (LMTD) is given by:

$$\theta_m = \frac{\theta_1 - \theta_2}{\ln\left(\frac{\theta_1}{\theta_2}\right)} = \frac{(t_{h1} - t_{c2}) - (t_{h2} - t_{c1})}{\ln\left[\frac{(t_{h1} - t_{c2})}{(t_{h2} - t_{c1})}\right]}$$

$$= \frac{(230 - 65) - (160 - 25)}{\ln\left[\frac{(230 - 65)}{(160 - 25)}\right]}$$

or, $$\theta_m = \frac{165 - 135}{\ln\left[\frac{165}{135}\right]} = 149.5°\text{C}$$

Also, $$Q = UA\theta_m$$

or, $$A = \frac{Q}{U\theta_m} = \frac{91.35 \times 10^3}{420 \times 149.5} = 1.45 \text{ m}^2$$ **Ans.**

20. Solution:

Given: $m = 6$ kg/min, $\eta_{relative} = 50\%$, $x_2 = 0.6$, $c_{pw} = 4.187$ kJ/kgK, Latent heat of ice = 335 kJ/kg.

Refer to figure.

$h_{f2} = 31.4$ kJ/kg $\qquad h_{fg2} = 154.0$ kJ/kg;

$h_{f3} = 59.7$ kJ/kg; $\qquad h_{fg3} = 138$ kJ/kg;

$h_{f4} = 59.7$ kJ/kg; $\qquad$ ... From the table given above

$$h_2 = h_{f2} + xh_{fg2} = 31.4 + 0.6 \times 154 = 123.8 \text{ kJ/kg}$$

For isentropic compression 2-3, we have

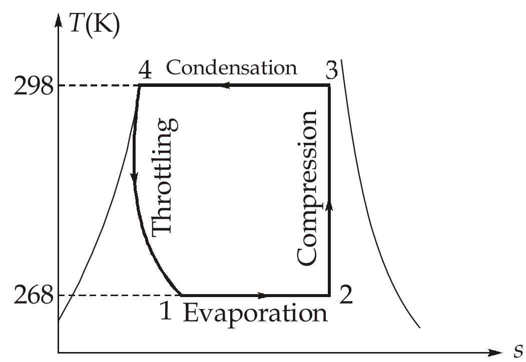
$$s_3 = s_2$$

$$s_{f3} + x_3 \frac{h_{fg3}}{T_3} = s_{f2} + x_2 \frac{h_{fg2}}{T_2}$$

$$0.2232 + x_3 \times \frac{138}{298} = 0.1251 + 0.6 \times \frac{154}{268}$$

$$= 0.4698$$

$\therefore$
$$x_3 = (0.4698 - 0.2232) \times \frac{298}{138} = 0.5325$$



Now,
$$h_3 = h_{f3} + xh_{fg3} = 59.7 + 0.5325 \times 138$$
$$= 133.2 \text{ kJ/kg}$$

Also,
$$h_1 = h_{f4} = 59.7 \text{ kJ/kg}$$

$$\text{Theoretical COP} = \frac{R_w}{W} = \frac{h_2 - h_1}{h_3 - h_2} = \frac{123.8 - 59.7}{133.2 - 123.8} = 6.82$$

Actual,
$$\text{COP} = \eta_{relative} \times (\text{COP})_{theoretical}$$
$$= 0.5 \times 6.82 = 3.41$$

Heat extracted from 1 kg of water at 20°C for the formation of 1 kg of ice at 0°C

$$= 1 \times 4.187 \times (20 - 0) + 335$$
$$= 418.74 \text{ kJ/kg}$$

Let,
m_{ice} = Mass of ice formed in kg/min.

$$(\text{COP})_{actual} = 3.41 = \frac{R_n(\text{Actual})}{W}$$

$$= \frac{m_{ice} \times 418.74}{m(h_3 - h_2)} = \frac{m_{ice} \times 418.74(\text{kJ/min})}{6 \times (133.2 - 123.8)(\text{kJ/min})}$$

$\therefore$
$$m_{\text{ice}} = \frac{6 \times (133.2 - 123.8) \times 3.41}{418.74} = 0.459 \text{ kg/min}$$

$$= \frac{0.459 \times 60 \times 24}{1000} \text{ tonnes (in 24 hours)}$$

$$= 0.661 \text{ tonnes}$$ **Ans.**

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