2019

RANK IMPROVEMENT WORKBOOK

Mechanical Engineering

Refrigeration & Air-Conditioning

Answer Key of Objective & Conventional Questions

MADE EASY Publications

1 Basic Concepts, Heat Engine, Refrigerator & Reversed Carnot Cycle

LEVEL 1 Objective Questions

1.	(c)
2.	(a)
3.	(b)
4.	(b)
5.	(d)
6.	(d)
7.	(d)
8.	(c)
9.	(b)
10.	(a)
11.	(c)
12.	(d)

LEVEL 2 Objective Questions

13.	(c)
14.	(d)
15.	(c)
16.	(a)
17.	(a)
18.	(c)
19.	(b)
20.	(c)

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LEVEL 3 Conventional Questions

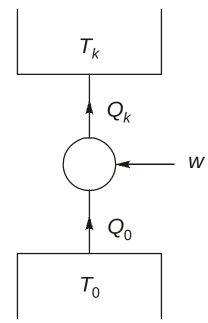
Solution : 21

$$\dot{m} = 0.2272 \text{ kg/min}$$
$$W_C = 749.6 \text{ W}$$
$$\text{Condenser heat rejection} = 4.165 \text{ kW}$$
$$\text{COP} = 5.2895$$

Solution : 22

For summer : COP = 5.05

For winter : $t_k = 55°C$ COP = 7.3



Solution : 23

$$\text{COP} = 5.56$$
$$\dot{W} = 0.63 \text{ kW}$$
$$\dot{m}_a = 0.413 \text{ kg/s}$$
$$A = 2.975 \text{ m}^2$$

■■■■

2 Vapour Compression Refrigeration Cycle

LEVEL 1 Objective Questions

1.	(c)
2.	(c)
3.	(c)
4.	(b)
5.	(a)
6.	(a)
7.	(c)
8.	(a)
9.	(a)
10.	(a)
11.	(b)

LEVEL 2 Objective Questions

12.	(b)
13.	(a)
14.	(b)
15.	(c)
16.	(c)
17.	(c)
18.	(a)
19.	(d)
20.	(c)
21.	(b)
22.	(b)
23.	(c)
24.	(b)
25.	(a)
26.	(c)
27.	(d)
28.	(d)

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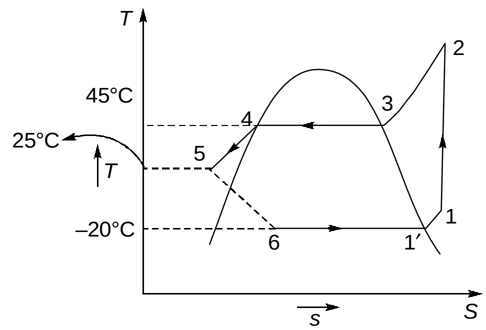
LEVEL 3 Conventional Questions

Solution : 29



mas flow ratem, $\dot{m}$ = 0.2931 kg/s

W_C = 12.021 kW

Condensor heat rejection, Q_{CR} = 47.017 kW

COP = 2.911

Solution : 30

T_2 = 348.427 K

η_v = 83.96%

$\dot{m}$ = 0.3979 kg/s

R.C. = 17.613 TR

W_C = 19.4 kW

COP = 3.177

Solution : 31

COP = 4.9

Power input = 11.3 kW

Solution : 32

Refrigerating effect per kg = 131.14 kJ/kg

Mass of refrigerant = 18.3 kg/min

Theoretical piston displacement per minute = 1.441 m^3/min

Theoretical power required = 6.79 kW

= 2807.4 kJ/min

d = 90 min

and l = 112.5 mm

■■■■

3 VARS, Gas Cycle Refrigeration & other Refrigeration System

LEVEL 1 Objective Questions

1.	(b)
2.	(c)
3.	(d)
4.	(d)
5.	(c)
6.	(b)
7.	(a)
8.	(d)
9.	(a)
10.	(d)
11.	(d)
12.	(a)
13.	(a)

LEVEL 2 Objective Questions

14.	(c)
15.	(a)
16.	(b)
17.	(a)
18.	(b)
19.	(d)
20.	(a)
21.	(b)

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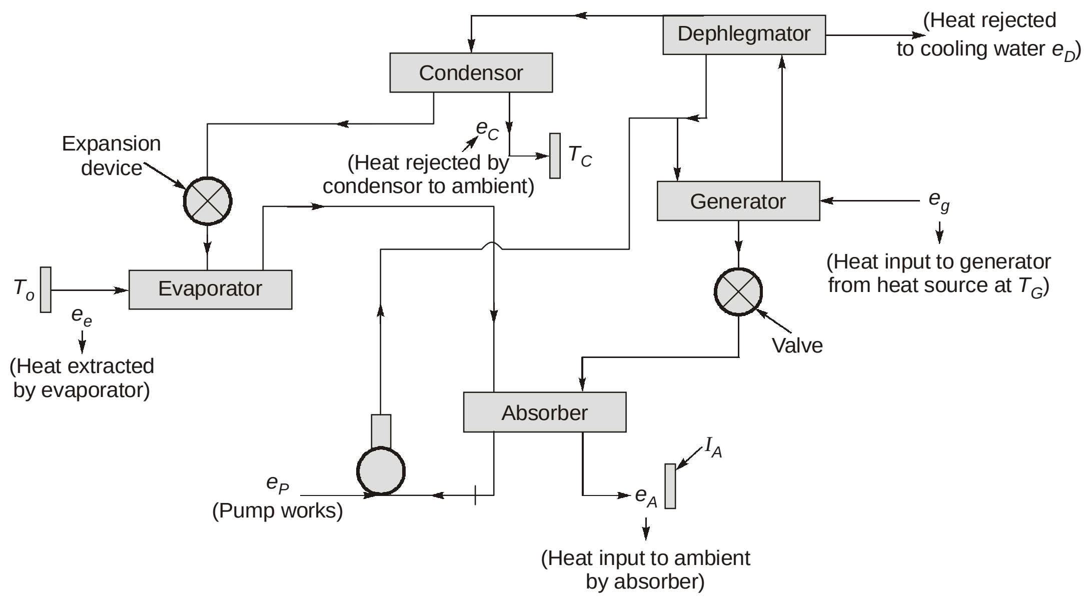
LEVEL 3 Conventional Questions

Solution : 22

Vapour absorption system with aqua-ammonia as refrigerant is used to utilize available heat energy as an alternative to compressor work. General schematic is as shown below:



As compared to a vapour compression system differences are:

- **Absorber:** Refrigerant vapours of ammonia are absorbed in a weak solution with water.
- **Pump:** Used to pump aqua-ammonia solution to condensor pressure.
- **Generator:** Distillation of ammonia vapour from the rich solution leaving weak solution for recirculation.
- **Dephlegmator:** Further concentration of vapour to separate water from ammonia vapour.

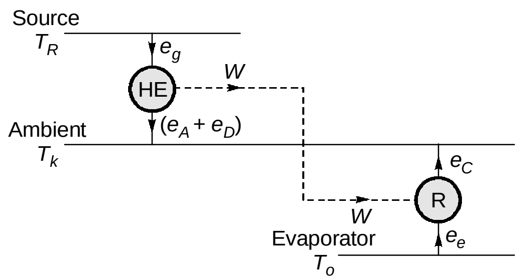
Nature of heat/work interactions as required are mentioned in the figure.

Refrigerant vapour of NH_3 formed as a result of heat extraction in evaporator goes to absorber where it is dissolved in a weak aqua-ammonia solution. Ammonia vapour loses heat e_A which is rejected by the absorber and forms a concentrated solution which is pumped to condenser pressure by pump. Pump work = (–*vdp*), is usually negligible since specific volume-v of liquid is very less. In generator distillation of vapour of NH_3 takes place by supplying heat from source- e_g at T_h. Weak solution is recirculated through a valve to absorber. Further condensation of ammonia vapours takes place in dephlegmator along with rejection of heat e_D to cooling water.

Maximum COP of cycle

Aqua-ammonia cycle is a heat operated refrigeration machine. It can be approximated as a combination of a heat engine operated on aqua solution circuit and a refrigerator operated on ammonia cycle.

For heat source temperature T_R, ambient temperature ($T_A = T_C = T_K$) and evaporator temperature T_0, above system can be shown as:



Work output of heat engine is used to power the refrigerator.

Energy balance of above system can be shown as below

$$e_e + e_P + e_g = e_C + e_D + e_A = e_K \quad \text{(net heat rejected)}$$

$$\text{COP of cycle} = \frac{e_e}{e_g} = \frac{e_e}{W} \times \frac{W}{e_g}$$

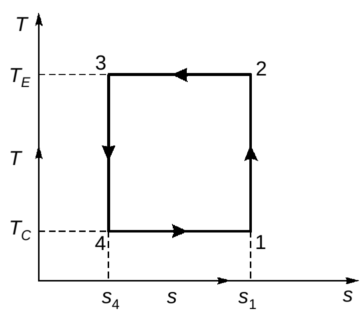
$$= \text{COP}_R \times \eta_{HE}$$

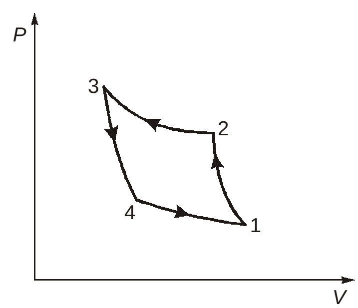
$$\text{COP}_R = \text{COP of refrigerator}$$

$$\eta_{HE} = \text{efficiency of heat engine}$$

$$\text{COP}_{max} = 1.625$$

Solution : 23





1 – 2 ⟶ Isentropic compression

2 – 3 ⟶ Isothermal Heat Rejection

3 – 4 ⟶ Isentropic expansion

4 – 1 ⟶ Isothermal Heat addition

As we can see that in p-v diagram, both in process 1-2, and 2-3 the pressure is increasing so two compressors are required.

Similarly in process 3-4 and 4-1 the pressure is decreasing and volume is increasing so two expanders are required.

Work done by compressors (per kg) = $w_{12} + w_{23}$

$$= \frac{\gamma}{\gamma - 1} R(T_1 - T_2) + RT_E \log_e \frac{V_3}{V_2} = c_p (T_C - T_E) + RT_E \log_e \frac{V_3}{V_2}$$

$$\text{Work done by expanders} = c_p(T_3 - T_4) + RT_C \log_e\left(\frac{V_1}{V_4}\right) = c_p(T_E - T_C) + RT_C \log_e\left(\frac{V_1}{V_4}\right)$$

Alternatively Net work required = Heat rejected – Heat absorbed

$$= T_E(s_1 - s_4) - T_C(s_1 - s_4) = (T_E - T_C)(s_1 - s_4)$$

$$(COP)_R = \frac{\text{Heat absorbed}}{\text{Work done}} = \frac{T_C(s_1 - s_4)}{(T_E - T_C)(s_1 - s_4)} = \frac{T_C}{T_E - T_C}$$

Solution : 24

T_2 = 405.676 K

T_4 = 203.9 K

m_a = 0.050402 kg/s

Volume flow rate at inlet to compressor

V_1 = 2.37 m^3/min

Volume flow rate at exit to turbine

V_4 = 1.76 m^3/min

Solution : 25

$\dot{m}$ = 2.233 kg/min

(ii) At compressor inlet $\dot{V}_1$ = 0.09863 m^3/s

At turbine exit: $V_4 = 6.602 \times 10^{-3}$ m^3/s

W_C = 6.178 kW

W_T = 4.135 kW

COP = 1.713

Solution : 26

Theoretical COP = 1.75

Mass of air circulated per minute = 53.8 kg/min

D = 530 mm

L = 795 mm

Solution : 27

T_2 = 412.08 K

T_4 = 203.91 K

V_1 = 0.0499 m^3/s

V_4 = 0.03667 m^3/s

Solution : 28

$$Q_E = 33.433 \text{ kW}$$

Solution : 29

Q_G = Heat added to absorption fluid
W_P = Pump work added to absorption fluid system by pump
Q_E = Heat added to absorption fluid system in the evaporator
Q_0 = Heat reflected from absorption fluid system at condenser, absorber and heat exchangers to environments at temperature to assumed constant

Applying the energy balance equation,

$$Q_0 = Q_E + Q_G + W_P$$

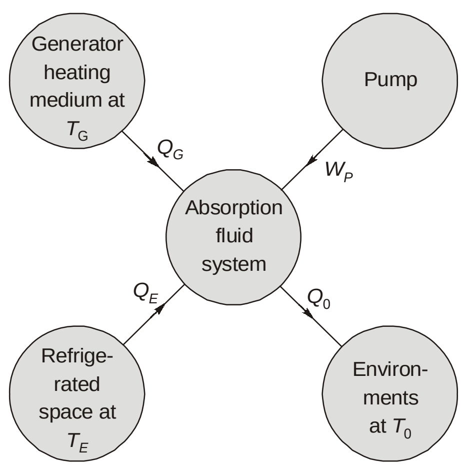
Where pump work is very small and neglected

$$\therefore \quad Q_0 = Q_E + Q_G \quad \text{... (i)}$$

Clausius's inequality for reversible cycle,

$$\oint \frac{\delta Q}{T} = 0$$

$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{Q_0}{T_0} = 0$$



$$\frac{Q_G}{T_G} + \frac{Q_E}{T_E} - \frac{(Q_E + Q_G)}{T_0} = 0$$

$$\frac{Q_G}{T_G} - \frac{Q_G}{T_0} + \frac{Q_E}{T_E} - \frac{Q_E}{T_0} = 0$$

$$Q_G\left[\frac{1}{T_G} - \frac{1}{T_0}\right] = Q_E\left[\frac{1}{T_0} - \frac{1}{T_E}\right] = Q_E\left[\frac{T_E - T_0}{T_0 T_E}\right]$$

or

$$Q_G\left[\frac{T_G - T_0}{T_G}\right] = Q_E\left[\frac{T_0 - T_E}{T_E}\right]$$

$$\frac{Q_E}{Q_G} = \left(\frac{T_E}{T_0 - T_E}\right)\left(\frac{T_G - T_0}{T_G}\right)$$

$$\therefore \qquad COP = \frac{Q_E}{Q_G} = \left(\frac{T_E}{T_0 - T_E}\right)\left(\frac{T_G - T_0}{T_G}\right)$$

Now it is given that $T_G = 383$ K, $T_E = 268$ K, $T_0 = 308$ K

$$\Rightarrow \qquad COP = \left(\frac{268}{308-268}\right)\left(\frac{383-308}{383}\right)$$

$$COP = 1.31$$

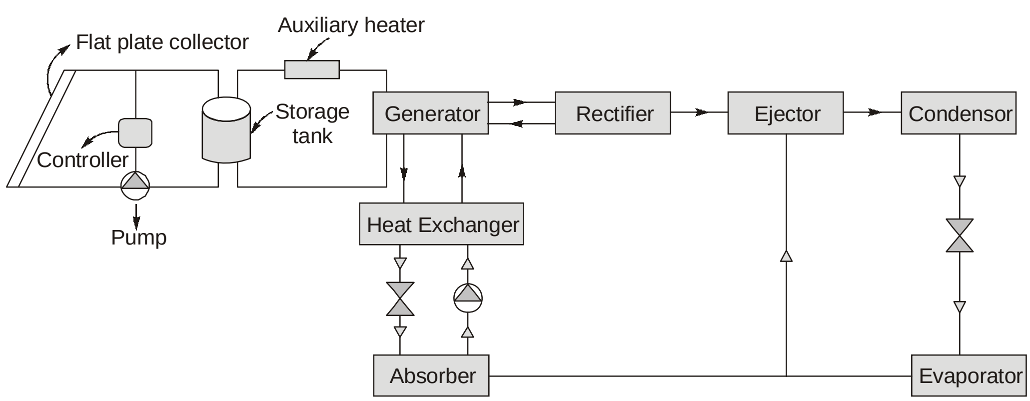
Solution : 30

Vapour Absorption Refrigeration System

Vapour absorption refrigeration system is based on heat energy. It is mostly preferred in those areas where the cost of electricity is very high or large amount of heat energy is available.

In the vapour-absorption system, the function of compressor is accomplished in a three-step process by the use of the absorber, heat exchanger and generator.

VARS system based on solar heating supplies heat to the generator of VARS system. Solar heating system consists solar flat collector, controllers, storage tank, pump and an auxiliary heater which supplies heat to the generator. Schematic diagram of the whole system is as given below:



As shown in above diagram, solar heating system supplies heat to the generator. Normally NH_3–H_2O combination is used as refrigerant and absorber in VAR system.

⇒ The heat from the surrounding is absorbed in evaporator by which low pressure ammonia vapour from the evaporator comes in contact in the absorber with the weak solution (the concentration of NH_3 is low in H_2O) coming from the generator, it is readily absorbed, releasing the latent heat of condensation.

⇒ Strong solution rich in ammonia, is pumped to the generator where the heat (Q_a) is supplied from auxiliary heater.

⇒ In condensor, the ammonia vapour gets condensed, and throttled by the expansion valve, then sent to the evaporator where it absorbs latent heat of vapourisation from the surrounding.

⇒ Water vapour going to the condensor along with the ammonia vapour after condensation may get frozen to ice and block the expansion valve. So an analyzer-rectifier combination is used to eliminate water vapour going into the condensor.

⇒ The analyzer is a direct contact type heat exchanger consisting of a series of trays mounted above the generator. The strong solution from the absorber flows downward over the trays to cool the outgoing vapours. since the saturation temperature of water is higher than that of ammonia at a given pressure, it is the water vapour that condenses first. As the vapour passes upward through the analyzer, it is cooled and enriched by ammonia, and the liquid is heated. Thus the vapour going to the condenser is lower in temperature and richer in ammonia, and the heat input to the generator is decreased.

⇒ The final reduction in the percentage of water vapours in the ammonia going to the condenser occurs in the rectifier which is a water-cooled heat exchanger which condense water vapour and returns it to the generator through the drip line.

COP of VARS system:

COP of a VARS system is given by following expression:

$$\text{COP} = \frac{T_E}{T_G}\left[\frac{T_G - T_O}{T_O - T_E}\right]$$

Given: T_E = 5°C = 278 K, T_G = 90°c = 363 K and T_O = 40°C = 313 K

$$\Rightarrow \quad \text{COP} = \frac{278}{363}\left[\frac{363-313}{313-278}\right] \Rightarrow \text{COP} = 1.094$$

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4 Refrigerants & Refrigeration Equipments

LEVEL 1 Objective Questions

1.	(a)
2.	(a)
3.	(d)
4.	(a)
5.	(c)
6.	(d)
7.	(c)
8.	(a)
9.	(b)

LEVEL 2 Objective Questions

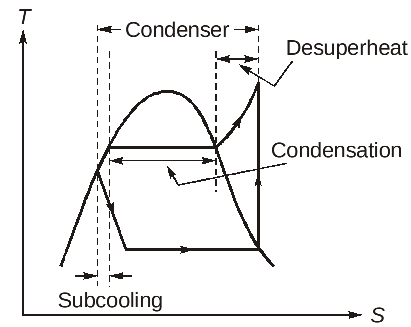
10.	(c)
11.	(b)
12.	(a)
13.	(c)
14.	(a)

■■■■

LEVEL 3 Conventional Questions

Solution : 15

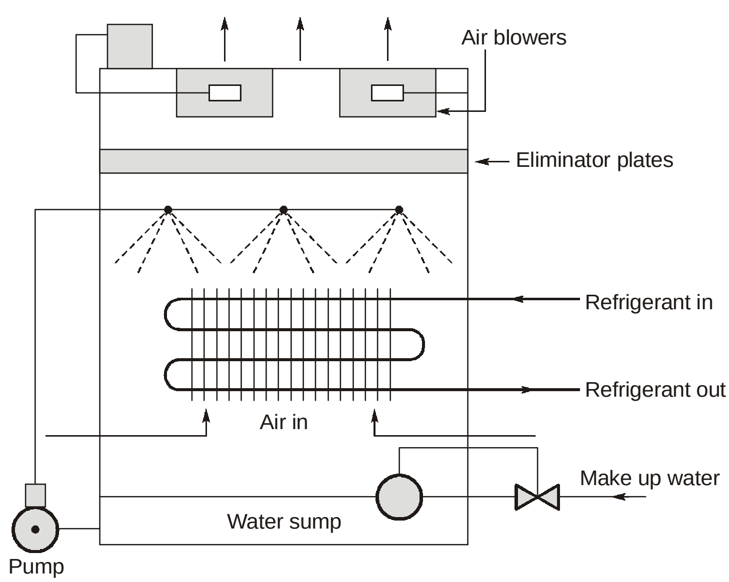
Functions of condensor in a refrigerating machine are as follows:



- To enable rejection of heat from the refrigerant in a refrigeration cycle.
- Enables desuperheat, condensation and subcooling of refrigerant to get vapour to condense to subcooled liquid stage which can then be fed to expansion device.

Different types of condensers are :

- Air-cooled condensers-for small cooling load operation like domestic refrigerators and air conditioners. This can be further classified as:
  - Natural convection type
  - Forced convection type
- **Water-cooled condensor:** Water is used to extract heat from the refrigerant. Further classified as:
  - Double tube type
  - Shell and tube type
  - Shell and coil type
- **Evaporative condensers:** Combines the features of both a cooling tower and a water-cooled condenser in a single unit.



Consider and evaporative condenser as shown above. Water is pumped from the sump and sprayed on tubes carrying refrigerant. Water droplets on tube get evaporated by extracting latent heat of vaporization from refrigerant. Water is continuously recirculated and make up water is added as required.

Air is continuously recirculated using blowers and used to cool the refrigerant tubes which are connected to a plate to enhance area of heat exchange as shown above. The role or air primarily to enhance evaporation of water.

Evaporative condensers are used in medium to large capacity systems. These are normally cheaper than water cooled condensers which require a separate cooling tower.

Solution : 16

Types of compressors used in VCR plants:

Compressor is used to compress the refrigerant to a pressure that is higher than in the evaporator (upto 8–10 times) so that condensation process can take place at a temperature that is compatible with readily available cold source, typically outside air.

Different types of compressors which are used in refrigeration are as given below:

(a) Reciprocating compressors: These are divided into hermatic, semi-hermatic and open type and are used above all for applications with very high cooling capacity requirements. In general these are noisy compressors which creates vibrations that can be felt around the entire circuit.

Reciprocating compressors are called hermatic compressors when the casing is welded and sealed and the cylinder heads can not be accessed for inspection or maintenance.

Semi-hermatic means the compressor itself and the motor are housed in the same casing, which is designed to be opened for insepection and servicing. These are made in such a way as to avoid air or dust from entering the mechanism.

Reciprocating compressors are defined as open when one end of the crankshaft protrudes outside of casing that houses the pistons and mechanisms inside compressor and can be opened.

(b) Rotary compressors: It includes rotary vane, scroll, screw and centrifugal compressors. These are hermatic compressors used in many applications and different operating ranges.

Rotary vane compressors consist of a cylindrical casing, two openings - one suction and one discharge and a rotor positioned eccentrically with respect to the casing. In this compression occurs by refrigerant flowing into the chamber where, due to eccentric rotation, there is a reduction in the desired volume.

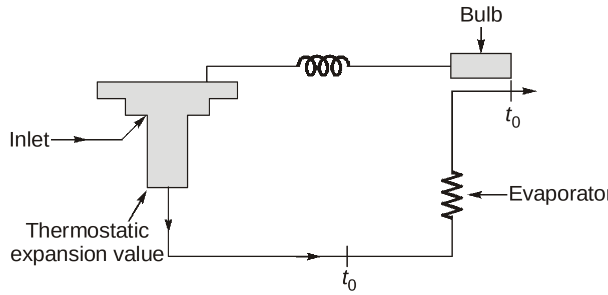
Scroll compressors use two scrolls, one fixed and other moving and coupled to the motor. The scrolls are interleaved so as to be in contact with one another in various places and thus form a series of gradually thinner pockets air towards the centre. The fluid is compressed by rotation of the orbiting scroll around the fixed scroll until being discharged in the centre. These are widely used in home and commercial air conditioning systems.

Screw compressors are based on a mechanism made up of two intermeshing screws, called rotors. As the rotors revolve, the fluid is drawn in through the inlet port, filling the volume between two lobes. When the space between the lobes are full of fluid, suction ceases, the fluid between the lobes then forced due to rotation into an increasingly small space, causing compression.

Centrifugal compressor feature a cast iron casing, a steel shaft and a cast aluminium alloy impeller. The fluid is drawn in by the impeller near its axis and due to centrifugal force is pushed to the edge of the compressor casing. The fluid leaves the impeller with significant kinetic energy, which is then converted into pressure energy in the diffuser. Its use is limited to high cooling capacity and low compression ratios (usually large chillers running on R134a). Cooling capacity can be varied by using fins that change the angle at which fluid enters the impeller.

Solution : 17

Consider the thermostatic expansion valve as shown in figure:



$$\text{Evaporator inlet temperature} = t_0$$

$$\text{Evaporator outlet temperature} = t_0'$$

$$\text{Degree of superheat} = t_0' - t_0$$

This degree of superheat result into a pressure difference ($P_0' - P_0$) which actuates the valve, where P_0' and P_0 are respective saturation pressure.

Given: **Case I:** $t_0 = 0°\text{C}, t_0' = 10°\text{C}$

$$P_0 = 2.928 \text{ bar } P_0' = 4.146 \text{ bar}$$

We have, $P_0' - P_0 = 1.218 \text{ bar}$

Case II: $t_0 = -30°\text{C}, P_0 = 0.8438 \text{ bar}$

Since valve follow up spring setting remains the same, ($P_0' - P_0$) will remain the same.

$$P_0' - P_0 = 1.218 \text{ bar}$$

$$\Rightarrow \quad P_0' = 0.8438 + 1.218 = 2.0618 \text{ bar}$$

Hence approximate refrigerant outlet temperature corresponding to this saturation pressure will be –10°C as per the given table.

Hence, degree of superheat required to maintain evaporator temperature of

$$-30°\text{C} = -10°\text{C} - (-30°\text{C}) = 20°\text{C}$$

Solution : 18

When the refrigerant enters the space to be cooled, if absorbs heat from the surroundings. This process is usually accompanied by a phase change process which maximizes the cooling effect.

Good qualities of refrigerant:

(i) It should be non-poisonous
(ii) It should be non-explosive
(iii) It should be non-corrosive
(iv) It must be non-inflammable
(v) Leakage should be non-inflammable
(vi) It should have a well balanced enthalpy of evaporation per unit mass.
(vii) A minimum difference between the vaporising pressure and condensing pressure is desirable.

The refrigerant which does not destroy ozone layer is R-134a Tetra fluoro ethane ($C_2H_2F_4$).

Refrigerant which do not contain chlorine does not harm the ozone layer.

Solution : 19

1. **The common items of control involved in air-conditioning are given below:**
   (i) Expansion devices
      (a) Automatic expansion valve
      (b) Thermostatic expansion valve
   (ii) Cut outs for refrigeration units
      (a) High pressure cut-out
      (b) Low pressure cut-out
   (iii) Back pressure valves
   (iv) Liquid level regulating devices
      (a) High-side float valve
      (b) Low-side float valve
   (v) Flow-regulating devices
      (a) Solenoid valves
      (b) Check valves
      (c) Water and Brine valves
   (vi) Thermostats
      (a) Evaporator thermostat
      (b) Room thermostat

2. **Adiabatic saturation temperature** is the temperature at which the air becomes adiabatically saturated by the evaporation of water into air.

   If the bulb of wet bulb thermometer is covered by a wick thoroughly wetted by water, the temperature which is measured by the thermometer is the **wet bulb temperature.**

   Both these temperature are equivalent when the air is fully saturated.

3. **Metabolism:** When food is digested and converted to energy, heat is released. This process is known as metabolism.
   For an average healthy person the metabolic rate is of the order of 50W – 75W. This value may be increased during hard work.
   We are interested in the metabolic rate of the occupants of a building because human comfort condition cannot be achieved until the heat generated by metabolism is accounted and taken away.

Solution : 20

A refrigerant is said to be ideal if it has all of following properties:

- Low boiling point
- High critical temperature
- high latent heat of vaporization
- Low specific heat of liquid
- Low specific volume of vapour
- Non-corrosive to metal
- Non-flammable and non-explosive
- Non-toxic
- Low cost
- Mixes well with oil

- Low viscosity
- Freezing temeprature should be low
- Low pressure ratios
- Easy to liquefy at moderate pressure and temperature
- Ease of locating leaks by odour or suitable indicator.

Solution : 21

Refrigerant number	Chemical name	Chemical formula
R - 11	Trichloromonofluoro methane	CCl_3F
R - 12	Dichlorodifluoro methane	CCl_2F_2
R - 13	Monochlorotrifluoro methane	$CClF_3$
R - 22	Monochlorodifluro methane	$CHClF_2$
R - 717	Ammonia	NH_3

■■■■

5 Psychrometry

LEVEL 1 Objective Questions

1.	(b)
2.	(c)
3.	(d)
4.	(d)
5.	(a)
6.	(c)
7.	(c)
8.	(d)
9.	(b)
10.	(d)

LEVEL 2 Objective Questions

11.	(a)
12.	(a)
13.	(a)
14.	(c)
15.	(c)
16.	(c)
17.	(d)
18.	(d)
19.	(a)
20.	(b)
21.	(c)
22.	(b)

■■■■

LEVEL 3 Conventional Questions

Solution : 23

At state (3) t_{d3} = 31°C

$t_{\omega 3}$ = 18.3°C

Solution : 24

Relative humidity = 82.7%

t_{ADP} = 21.7°C

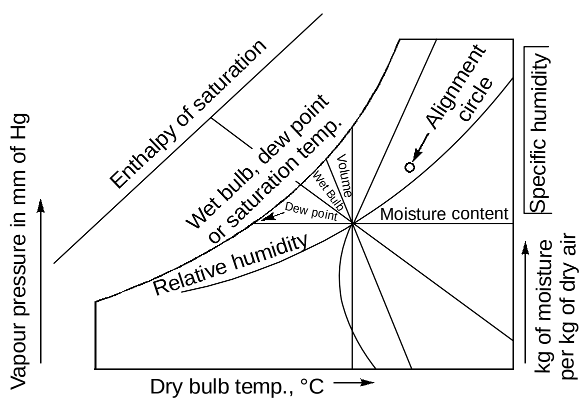
Solution : 25

Heat added in sensible heating = 857.556 kJ/min

Solution : 26

1. Specific humidity: ω = 0.0066638 kg vapour/kg of dry air
2. Relative humidity (ϕ) ϕ = 33.48%
3. Degree of saturation (μ) μ = 32.77%
4. Enthalpy of moist air (h) = 42.098 kJ/kg of dry air

Solution : 27



Solution : 28

m_a = 9.27 kg

ω = 0.0262 kg H_2O/kg dry air

The enthalpy of air $h = h_a + wh_v \approx C_pT + wh_{g@30°C}$

= 97.1 kJ/kg of dry air

Solution : 29

(i) RH of heated air = 41 % (read from chart)

(ii) WBT of heated air = 16.1°C (read from chart)

(iii) Heat added to air/min = 2370.6 kJ

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6 Air Conditioning Systems & Comfort Conditions

LEVEL 1 Objective Questions

1.	(b)
2.	(d)
3.	(a)
4.	(a)
5.	(d)
6.	(d)
7.	(a)
8.	(c)
9.	(a)
10.	(c)

LEVEL 2 Objective Questions

11.	(b)
12.	(a)
13.	(d)
14.	(d)
15.	(c)
16.	(d)
17.	(a)
18.	(c)
19.	(c)
20.	(d)
21.	(b)
22.	(d)
23.	(c)
24.	(b)

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LEVEL 3 Conventional Questions

Solution : 25

$$\omega_i = 9.88 \times 10^{-3} \text{ kg/kg d.a.}$$
$$\omega_0 = 6.35 \times 10^{-3} \text{ kg/kg d.a.}$$
$$\text{(OASH)} = 11.03 \text{ kW}$$
$$\text{(OALH)} = 9.705 \text{ kW}$$
$$\text{(ERSH)} = 101.66 \text{ kW}$$
$$\text{Effective room latent heat} = 16.46 \text{ kW}$$
$$\text{Volume flow rate of supply air} = 377 \text{ m}^3\text{/min}$$

Temperature at the inlet of cooling coil,

$$t_2 = 13.995 \simeq 14°\text{C}$$

Solution : 26

$$V = 114.2187 \text{ m}^3\text{/min}$$
$$\text{Outside air sensible heat} = 6.537 \text{ kW}$$
$$\text{Grand total heat} = 30.537 \text{ kW}$$
$$ERSHF = 0.753$$

Solution : 27

$$\text{BPF} = 0.15 = \omega_3 = 9.02106 \times 10^{-3} \text{kg/kg dry air}$$

At point 3,

$$\text{BPF} = t_3 = 14.25°\text{C}$$
$$h_3 = 37.115 \text{ kJ/kg}$$
$$\text{RSH} = 549.332 \text{ kW}$$
$$\text{RLH} = 108.35 \text{ kW}$$
$$\text{Condensate rate} = 0.084 \text{ kg of vapour/sec}$$

Solution : 28

$$Q_s = 3.63 \text{ kW}$$
$$Q_L = 0.166$$
$$Q_{\text{Total}} = 3.80 \text{ kW}$$

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