Chapter 3.4: HVAC & Refrigeration System

Part–I: Objective type questions and answers

1.	One ton of refrigeration (TR) is equal to ____. a) 3024 Kcal/h b) 3.51 kW c) 120oo BTU/h d) all
2.	The driving force for refrigeration in vapour absorption refrigeration plants is____ a) Mechanical energy b) Thermal energy c) Electrical energy d) All
3.	The main disadvantage of use of HFCs and HCFCs compared to use of CFCs is_____ a) Low Efficiency b) High heat output c) High emissions d) All
4.	COP of absorption refrigeration systems a) Between 4-5 b) less than 1.1 c) above 1.1 d) always 2.5
5.	Match the following in respect of typical specific energy consumption (kW per TR) of refrigeration compressors. **Refrigeration Compressor** — **kW/TR** a) Reciprocating — i) 0.63 kW/TR b) Centrifugal — ii) 0.65 kW/TR c) Screw — iii) 0.7 – 0.9 kW/TR Ans. a-iii; b-i; c-ii
6.	The essential parameters to estimate cooling load from air side across air handling unit (AHU) / Fan Coil Unit (FCU) are_______. a) Flow rate b) dry bulb temperature c) RH% or wet bulb temperature d) all
7.	In water cooled refrigeration systems, condenser cooling water temperature should be close to: a) dry bulb temperature b) wet bulb temperature c) dew-point temperature d) any of the above
8.	Centrifugal compressors are most efficient when they are operating at_____. a) 50% load b) Full load c) 75% Load d) All load conditions
9.	In general, designed chilled water temperature drop across the chillers is____ °C. a) 5 °C b) 1 °C c) 10 °C d) 15 °C
10.	Higher COP can be achieved with_____. a) Lower evaporator temperature and higher condenser temperature b) Higher evaporator temperature and Lower condenser temperature c) Higher evaporator temperature and higher condenser temperature d) Lower evaporator temperature and Lower condenser temperature
11.	The required A/C size for comfort conditions for general living room (12 ft x 12 ft) at residence is_____. a) < 0.5 TR b) 1 to 1.5 TR c) > 2.5 TR d) any of the above

12.	Typical range of COP value for a compression refrigeration cycle is: a) 1 to 10 b) 1 to 20 c) 2 to 5 d) 2 to 20
13.	The specific energy for a centrifugal chiller producing chilled water at 5.5 °C and condenser water temperature around 30 °C is the order of: a) 0.65 – 0.8 kW / TR b) 1.0 kW / TR c) 1.15 – 1.25 kW/ TR d) 0.45 – 0.55 kW/ TR
14.	Approximate percentage reduction in power consumption with 1 °C rise in evaporator temperature in refrigerating systems is _______. a) 2% b) 3% c) 1% d) 4%
15.	The refrigerant side heat transfer area in evaporators is of the order of ____. a) 0.1 sqm/TR b) 0.3 sqm/TR c) 0.4 sqm/TR d) 0.5 sqm/TR and above
16.	The percentage refrigeration compressor power reduction with 0.55 deg. C temperature reduction in water returning from cooling tower is ________. a) 2% b) 3% c) 1% d) 4%
17.	Cascade systems for refrigeration are preferable in the temperature range of _______. a) 5°C to 10°C b) -5°C to -10°C c) -46°C to -101°C d) 0°C to 10°C
18.	The efficiency of screw compressor at part load compared to centrifugal compressor is __. a) higher b) lower c) Same d) None
19.	Which of the following compressor has recently become practical in the market? a) reciprocating b) screw c) scroll d) all the above
20.	The device used to cool the refrigerant in vapour absorption chiller is: a) vacuum pump b) condenser c) vacuum condenser d) none of the above
21.	The refrigerant temperature after the expansion device compared to after condenser in the vapour compression refrigeration cycle is____ a) higher b) lower c) Same d) None

Part – II: Short type questions and answers

1.	Define one 'Ton of Refrigeration (TR)'. A ton of refrigeration is defined as the quantity of heat to be removed in order to form one ton of ice in 24 hours when the initial temperature of water is 0 °C. This is equivalent to 50.4 Kcal/min or 3024 Kcal/h in metric system.
2.	What are the commonly used refrigerants for vapour compression chillers? Commonly used refrigerants for vapour compression chillers are chlorinated fluorocarbons (CFCs, also called Freons): R-11, R-12, R-21, R-22, R-134 and R-502.
3.	In which range of temperature the application of 'brine plants' are made use of?

	'Brine plants' are used for typically sub zero temperature applications.
4.	List the main parameters on which the choice of HVAC components depends on. The choice of refrigerant and the required cooling temperature and load determine the choice of compressor, as well as the design of the condenser, evaporator, and other auxiliaries. Additional factors such as ease of maintenance, physical space requirements and availability of utilities for auxiliaries (water, power, etc.) also influence component selection.
5.	Write down basic formula for estimating the tonnage of a chiller? (Or refrigeration TR). The refrigeration TR is assessed as TR = $Q \cdot C_p \cdot (T_i - T_o) / 3024$ Where Q is mass flow rate of coolant in kg/hr C_p is coolant specific heat in kCal /kg °C T_i is inlet, temperature of coolant to evaporator (chiller) in ^{0}C T_o is outlet temperature of coolant from evaporator (chiller) in ^{0}C.
6.	What do you mean by kW / TR pertaining to refrigeration? "KW/TR" is the specific power consumption which is a useful indicator of the performance of refrigeration system. By measuring refrigeration duty performed in TR and the Kilo Watt inputs measured, kW/TR is used as a reference energy performance indicator.
7.	Define COP? COP is nothing but Coefficient of performance which is a standard measure of refrigeration efficiency of an ideal refrigeration system depends on two key system temperatures, namely, evaporator temperature T_e and condenser temperature T_c with COP being given as ; COP = $T_e / T_c - T_e$
8.	Ice is formed at 0°C from water at 30 °C. In the refrigeration system, same temperature water is used for condenser cooling and the temperature of the brine is- 15°C at evaporator. Consider the system as ideal refrigeration; find the CoP of the refrigeration system. Evaporator temperature (T1) = -15 °C Condenser temperature (T2) = 30 °C CoP of ideal cycle = T1/(T2-T1) $= \frac{(-15+273)}{(30+273)-(-15+273)} = 5.7$
9.	What are the parameters required to be measured while estimating the chiller performance in KW/TR? Q : mass flow rate of coolant in kg/hr T_i : inlet, temperature of coolant to evaporator (chiller) in ^{0}C T_o : outlet temperature of coolant from evaporator (chiller) in ^{0}C. Actual power drawn by compressor, chilled water pump, condenser water pump and cooling tower fan
10.	Name the parameters that a psychometric chart provide for an air conditioning engineer? Air parameters in psychometric chart • Dry bulb temperature (°C) ; • Relative humidity (%) • Wet bulb temperature (°C) ; • Specific volume (m^3/kg of dry air) • Enthalpy (Kcal/kg of dry air) ; • Specific humidity (gm/kg of dry air)

11. List the types of refrigeration compressors used in industries. Select the lowest specific power consumption (kW/TR) refrigeration system for Air-conditioning and compare with other options (w.r.t power consumption) for 350 TR cooling load.

Major refrigeration compressor types for industrial application are:

a) Reciprocating

b) Centrifugal

c) Screw

Lowest specific power consumption (kW/TR) can be achieved from centrifugal compressors for 350 TR air conditioning load comparison among the compressors for specific power (kW/TR)

	Reciprocating	Centrifugal	Screw
Sp. Power (kW/TR)	0.7-0.9	0.63	0.65

12. List out any two types of vapour absorption chillers based on the refrigerant- absorbent combination.

- Lithium bromide- water (LiBr- H2O) cycle
- Ammonia- Water (NH3-H2O) cycle

13. Which refrigerants based on their absorption system are used for sub-zero temperature applications?

Ammonia refrigerant based absorption systems operate at above atmospheric pressures and are capable of low temperature operation (below 0 °C)

14. How do you calculate TR across the Air Handling Units?

Refrigeration load in TR is assessed as ;

$$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$

Where Q is the air flow in CMH

ρ is density of air kg/m^3

h_{in} is enthalpy of inlet air kCal/kg

h_{out} is enthalpy of outlet air kCal/kg

15. A reciprocating refrigeration compressor of 100 TR is working at full load with 4.5 °C temperature difference across the evaporator.

i) Estimate the water flow rate if water is secondary coolant,

ii) Assess the connected motor size (kW) to this refrigeration compressor

Capacity of reciprocating compressor = 100 TR

Working fluid = Water (sp. Heat of water 1.0 Kcal/kg °C)

Chilled temperature across evaporator = 4.5 °C

i) Chilled water flow rate Q (kg/h) $= \frac{100x3024}{4.5x1}$ = 67200 kg/hr

ii) Specific power consumption of reciprocating compressor = 0.7-0.9 kW/TR

For connected motor assessment consider higher specific power consumption

Required motor power = 100 x 0.9 = 90 kW

So, connected motor may be 90 kW (or) next higher size – 110 kW

16.	What is the function of a condenser in a refrigeration cycle? The function of a condenser is to receive superheated refrigerant vapour from the compressor, remove the superheat and then liquefy the refrigerant with the rejection of latent heat.
17.	Why CFC's are phased out? Which are the alternatives to CFC's? CFC's are phased out due to their damaging impact on the protective troposphere ozone layer around the earth. Two alternative refrigerants developed which are: a) Hydro chloro Fluro carbon (HCFC) b) Hydro fluro carbon (HFC)
18.	Under what conditions 'Screw chiller performance from efficiency point of view compared to other type of 'chillers'? The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situation, where part-load operation is common.
19.	List three important characteristics of 'evaporative cooling systems'. Three important points of 'evaporative cooling system' are: a) Less expensive and less energy intensive b) Most suitable for tropical weather conditions c) The temperature can be controlled by controlling the air flow and the water circulation rate
20.	Write short note on 'chilled water storage'. Cold storage: By providing a chilled water storage facility with very good cold insulation, chilled water requirements can be met without operating the chillers continuously. These systems are economical if small variations in temperature are acceptable. It allows chillers to operate at periods of low electricity demand to reduce peak demand charges.

Part–III: <u>Long type questions and answers</u>

1. Estimate tonne of refrigeration from the data given below for two AHUs?

Parameter	AHU-A	AHU-B
Evaporator area (m^2)	8.75	0.39
Inlet velocity (m/s)	1.81	11.50
Inlet air DBT (°C)	21.5	24.5
RH (%)	75.0	73.5
Enthalpy (kJ/kg)	53.0	59.3
Out let air DBT (°C)	17.4	19.5
RH (%)	90.0	83.0
Enthalpy (kJ/kg)	46.4	53.0
Density of air (kg/m^3)	1.14	1.05

AHU refrigeration load =

$$\frac{Air\ \ flow\,rate\,(m^3 h)\ x\,Density\,of\ \ air\ (kg\ /\ m^3\,)\ x\,Difference\,in\,enthalpy}{3024\ \ x\,4.18}$$

	AHU-A $= \frac{(8.75\,x\,1.81\,x\,3600)\,x\,(1.1.4)\,(53-46.4)}{3024\,x\,4.18}$ = 33.9 TR AHU-B $= \frac{(0.39\,x\,11.5\,x\,3600)\,x\,(1.05)\,x\,(59.3-53)}{3024}$ = 8.4 TR
2.	Compare the performance of centrifugal chiller with vapour absorption chiller using the data given below

Parameter	Centrifugal chiller	VAM
Chilled water flow (m^3/h)	189	180
Condenser water flow (m^3/h)	238	340
Chiller inlet temp (°C)	13.0	14.6
Condenser water inlet temp (°C)	27.1	33.5
Chiller outlet temp (°C)	7.7	9.0
Condense water outlet temp (°C)	35.7	39.1
Comp. power consumption (kW)	190	-
Steam consumption (kg/h)	-	1570
Chilled water pump (kW)	28	28
Condenser water pump (kW)	22	33
Cooling tower fan (kW)	6.0	15

i) Evaluate the tonnes of refrigeration (TR) of both the system?

ii) Compare both the chillers auxiliary power consumption, give the reason?

Refrigeration load (TR) $= \frac{Chilled water flow\,(m^3 h)\ x\ Sp.heat\ x\ Differ.temp\,(°C)}{3024}$

Density of water = 1000 kg/m^3

i) Centrifugal chiller TR $= \frac{189\,x\,1000\,x\,1\,x\,(13-7.7)}{3024}$ = 331 TR

VAM TR $= \frac{180\,x\,1000\,x\,1(14.6-9.0)}{3024}$ = 333 TR

ii) Auxiliary power consumption : Chilled water pump + condenser water pump + cooling tower fan

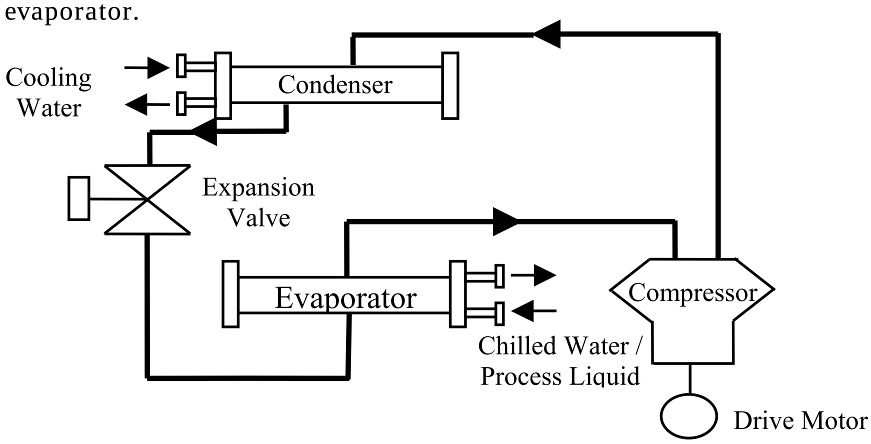
Auxiliary power (kW) : 28 + 22 + 6.0 = 56 kW

VAM auxiliary power (kW) : 28 + 33 + 15 = 76 kW

Reason: For the same refrigeration load around 330 TR centrifugal chiller auxiliary power consumption is lower compared to VAM. It is mainly due to higher condenser heat load, where condenser pump and cooling tower fan power consumption is high.

3.	Briefly explain the methodology of refrigeration plant energy audit? The cooling effect produced is quantified as tons of refrigeration. 1 ton of refrigeration = 3024 kCal/hr heat rejected. The specific power consumption kW/TR is a useful indicator of the performance of refrigeration system. By measuring refrigeration duty performed in TR and the Kilo Watt inputs measured,

	kW/TR is used as a reference energy performance indicator. The refrigeration TR is assessed as TR = $Q \cdot C_p \cdot (T_i - T_o) / 3024$ Where Q is mass flow rate of coolant in kg/hr C_p is coolant specific heat in kCal /kg deg C T_i is inlet, temperature of coolant to evaporator (chiller) in ^{0}C T_o is outlet temperature of coolant from evaporator (chiller) in ^{0}C. The above TR is also called as chiller tonnage. In a centralized chilled water system, apart from the compressor unit, power is also consumed by the chilled water (secondary) coolant pump as well condenser water (for heat rejection to cooling tower) pump and cooling tower fan in the cooling tower fan. Effectively, the overall energy consumption would be towards ; ▪ Compressor kW ▪ Chilled water pump kW ▪ Condenser water pump kW ▪ Cooling tower fan kW, for induced / forced draft towers The specific power consumption for certain TR output would therefore have to include : ▪ Compressor kW/TR ▪ Chilled water pump kW/TR ▪ Condenser water pump kW/TR ▪ Cooling tower fan kW/TR and overall kW/TR as a sum of the above. In case of air conditioning units, the air flow at the Fan Coil Units (FCU) or the Air Handling Units (AHU) can be measured with an anemometer. Dry bulb and wet bulb temperatures are measured at the inlet and outlet of AHU or the FCU and the refrigeration load in TR is assessed as: $$TR = \frac{Q \times \rho \times (h_{in} - h_{out})}{3024}$$ Where Q is the air flow in CMH ρ is density of air kg/m^3 h_{in} is enthalpy of inlet air kCal/kg h_{out} is enthalpy of outlet air kCal/kg Use of handy psychometric charts can help to calculate h_{in} and h_{out} from dry bulb, wet bulb temperature values which are, in-turn measured, during trials, by a whirling psychrometer.
4.	Explain how capacity is controlled in refrigeration machines. The capacity of compressors is controlled in a number of ways. Capacity control of reciprocating compressors through cylinder unloaders results in incremental capacity modulation as opposed to continuous capacity modulation of centrifugal and screw compressors through vane control or sliding valves, respectively. Therefore, temperature control requires careful system design. Usually, when using reciprocating compressors in applications with widely varying loads, it is desirable to control the compressor by monitoring the return water (or other secondary coolant) temperature rather than the temperature of the water leaving the chiller. This prevents excessive on-off cycling or unnecessary loading / unloading of the compressor. However, if load fluctuations are not high, the temperature of the water leaving the chiller should be monitored. This has the advantage of preventing operation at very low water temperatures, especially when flow reduces at low loads. The leaving water temperature should be monitored for centrifugal

	and screw chillers. Capacity regulation through speed control is the most efficient option. However, when employing speed control for reciprocating compressors, it should be ensured that the lubrication system is not affected. In the case of centrifugal compressors, it is usually desirable to restrict speed control to about 50 % of the capacity to prevent surging. Below 50 %, vane control or hot gas bypass can be used for capacity modulation. The efficiency of screw compressors operating at part load is generally higher than either centrifugal compressors or reciprocating compressors, which may make them attractive in situations where part-load operation is common. Screw compressor performance can be optimized by changing the volume ratio. In some cases, this may result in higher full-load efficiencies as compared to reciprocating and centrifugal compressors. Also, the ability of screw compressors to tolerate oil and liquid refrigerant slugs makes them preferred in some situations.
5.	Explain the principle of 'vapour compression' system with a neat sketch? A 'vapour compression' refrigeration system has four basic components : (1)an evaporator where cooled low pressure liquid refrigerant evaporates as it absorbs heat (2) a compressor, where the refrigerant in vapour form is compressed (3) a condenser, where heat in the high temperature, high pressure vapour is extracted by heat exchange with a cooler medium and (4) an expansion device, where the liquid refrigerant pressure is reduced to the evaporator pressure, further cooling the refrigerant in the process. The refrigerant leaves the expansion valve as a low temperature, low pressure liquid and is returned to the evaporator process is the heat load for evaporator and cooling tower is the sink for condenser in industrial refrigeration systems. The refrigerant absorbs heat from the coolant in the evaporator and evaporates. The low pressure refrigerant is then compressed to high pressure in the compressor. The hot discharge is cooled in the condenser before entering the expansion valve where it expands and cools before entering the evaporator.  *Fig : Schematic of a Basic Vapour Compression Refrigeration System*