B.E.

Seventh Semester Examination, December-2008

Refrigeration & Air Conditioning (ME-403-E)

Note : Attempt any *five* questions. All questions carry equal marks

Q. 1. (a) A refrigerator working on Bell-Colman Cycle operates between pressure limits of 1.05 bar and 8.5 bar. Air is drawn from the cold chamber at 10°C. Air coming out of compressor is cooled to 30°C before entering the exp. cylinder. Exp. And compressor follow the law $pv^{1.35}$ = constant. Determine the theoretical COP of the system.

Ans. $\gamma = 1.4$

$C_p = 1$ kJ/kg-K for air

$$T_2 = T_1\left[\frac{P_2}{P_1}\right]^{(n-1)/n}$$

$$= (10+273)\left(\frac{8.5}{1.05}\right)^{0.35/1.35}$$

$$= 283 \times 1.714$$

$$= 485\text{ K}$$

Similarly, $$T_4 = \frac{T_3}{1.714} = \frac{(30+273)}{1.714}$$

$$= 177\text{ K}$$

Heat extracted from cold chamber per kg of air

$$= C_P(T_1 - T_4)$$

$$= 1(283-177)$$

$$= 106\text{ kJ/kg}$$

Heat Rejected

$$= C_p(T_2 - T_3)$$

$$= 1(485-303)$$

$$= 182\text{ kJ/kg}$$

Work done $$= \frac{n}{n-1}(p_2v_2 - p_1v_1) - \frac{n}{n-1}(p_3v_3 - p_4v_4)$$

$$= \frac{n}{n-1}R[(T_2 - T_1) - (T_3 - T_4)]\text{ kJ/kg}$$

$$\frac{C_p}{c_v} = \gamma$$

$$C_v = \frac{C_p}{\gamma} = \frac{1}{1.4} = 0.70 \text{ kJ/kg-K}$$

$$R = C_p - C_v$$

$$= 1 - 0.7 = 0.3 \text{ kJ/kg °C.}$$

Work done $= \frac{1.35}{0.35} \times 0.3[(485 - 283) - (303 - 177)]$

$$= \frac{1.35}{0.35} \times 0.3 \times 76$$

$$= 88 \text{ kJ/kg}$$

$$\text{COP} = \frac{104}{88}$$

$$\boxed{= 1.18}$$ **Ans.**

Q. 1. (b) What is the necessity of cooling the aeroplane?

Ans. It is a common assumption that the aeroplane does not require any cooling or air-conditioning because the temperature is low at higher altitude compared on the ground.

But there are many external & internal heat sources which add the heat in the passenger cabin & increase the temperature of air in the cabin.

If the conversion of the KE into enthalpy is isentropic, then the temperature rise can be calculated as follows :

$V_1 = V_a$ = Speed of Aeroplane

h_1 = Enthalpy of air before compression

h_2 = Enthalpy of air after compression

V_2 = Velocity of stagnant air

Hence, $\frac{V_1{}^2}{2} + h_1 = \frac{V_2^2}{2} + h_2$

As, $V_2 = 0$

So, $(h_2 - h_1) = C_p(T_2 - T_1) = \frac{V_1^2}{2}$

$$\Delta T = (T_2 - T_1) = \text{Rise in temperature} = \frac{V_1^2}{2C_p}$$

Internal Source : Human body continuously generates heat at a rate of 400 KJ per hour at rest & this heat is dissipated to the surrounding or to the cabin air.

Q. 2. A refrigerating machine using NH_3 operates between the temperature limits of 15° and 30°C. Find the COP of the system. Also find corresponding value for a reversed Carnot cycle operating between the same temperatures. The properties of NH_3 are given below :

n/

Pressure	Temp.	Liquid		Vapour	
(bar)	°C	hf (kJ/kg)	Sf (kJ/kg-K)	hg (kJ/kg)	(kJkg-K)
2.41	– 5	351	3.95	1667.5	9.05
11.895	30	562	4.69	1711	8.48

Ans.

$$COP = \frac{T_1}{T_3}\left[\frac{T_3 - T_2}{T_2 - T_1}\right]$$

$$T_3 = 150 + 273$$
$$= 423 \text{ K}$$
$$T_2 = 30 + 273$$
$$= 303 \text{ K}$$
$$T_1 = -20 + 273$$
$$= 253 \text{ K}$$

$$COP = \frac{253}{423}\left[\frac{423 - 303}{303 - 253}\right]$$
$$= 1.435$$

$$COP = \frac{T_1}{T_3}\left[\frac{T_3 - T_2}{T_2 - T_1}\right]$$

$$T_3 = 200 + 273$$
$$= 473 \text{ K}$$
$$T_2 = 30 + 273$$
$$= 303 \text{ K}$$
$$T_1 = -40 + 273$$
$$= 233 \text{ K}$$

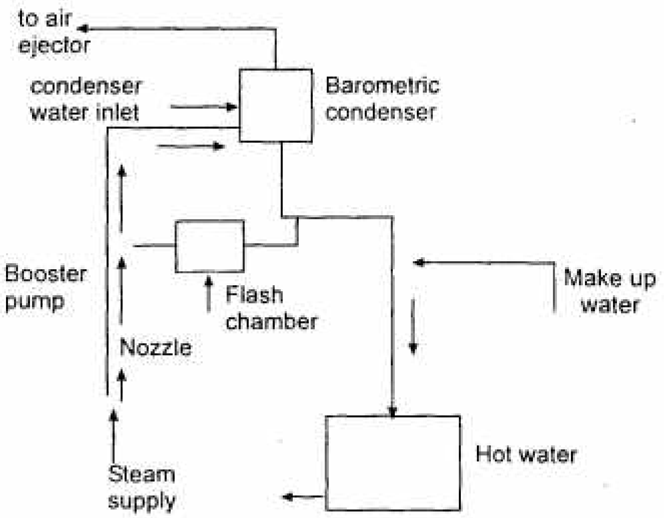
$$COP = \frac{233}{473}\left[\frac{473 - 303}{303 - 233}\right] = 1.2$$

% decrease in COP

$$= \frac{1.435 - 1.2}{1.435} \times 100$$
$$= 16.4\ \%$$

Q. 3. (a) Draw a neat compact diagram of Electro-Lux refrigerator and explain its working principle. What is the important role of hydrogen in this refrigeration system? What are its advantages over absorption type refrigeration system?

Ans. This type of refrigeration is generally used for domestic purposes only as it is more complicated in construction & working.



Steam jet refrigeration system with Barometric condenser

The basic components are :

(i) Generator
(ii) Separator
(iii) Analyser
(iv) Rectifier
(v) Main condenser
(vi) Helping condenser
(vii) Liquid heat exchanger
(viii) Weak Liquid pre-cooler
(ix) Absorber
(x) Gas Heat exchanger
(xi) High temperature evaporator
(xii) Low temp. evaporator
(xiii) Hydrogen Reserviour

Q. 3. (b) What are the advantages and disadvantages of steam jet refrigeration system over other types of refrigeration system?

Ans. Advantages :

(i) Flexible in operation

(ii) Cooling capacity can be easily & quickly changed.

(iii) No moving parts

(iv) Vibration free

(v) Simple construction

(vi) Relatively less plant weight

(vii) Can be installed out of doors.

(viii) Particularly useful to air-conditioning installations.

Disadvantages :

(i) Use of direct evaporation to produce distled water is usually limited as tremendous volumes vapour is to be handled.

(ii) About twice as much heat must be removed in the condenser of steam jet unit per ton of refrigeration compared with the vapour compression system.

(iii) The system is useful for comfort air-conditioning but is not particularly feasible for water temperature below 4° C.

Q. 4. (a) Differentiate between the refrigeration and air conditioning.

Ans. The history behind the air-conditioning is more than hundred years old. The human life is becoming more uncomfortable in rapidly developing like New York & Tokyo drop due to ↑ in population &

industrial growth. Full air-conditioning signifies the automatic control of an atmospheric environment either for comfort of human beings or animals or for proper performance of some industrial or scientific process.

The general air-conditioning systems air broadly classified into two groups :

(a) Comfort air-conditioning and (b) Industrial air-conditioning

The comfort air-conditioning systems are subdivided as

(i) Summer ac (ii) Winter ac (iii) Year around ac

Refrigeration : In air cycle refrigeration, air is used as working fluid. Absorbing the heat from low temperature system & discharging the same to high temperature system is done by air. As air is not changing its phase throughout the cycle, the heat carrying capacity per kg of air is very small compared with vapour compression machine. The air refrigeration machine was used universally in olden days because of its availability in abundance compared with other refrigerants.

Q. 4. (b) Describe the various methods of refrigeration.

Ans. (i) Ice refrigeration

(ii) Evaporative Refrigeration

(iii) Refrigeration by expansion of air

(iv) Refrigeration by throttling of gas

(v) Vapour refrigeration system

(vi) Steam jet refrigeration system

(vii) Refrigeration by using liquid gases.

(viii) Dry ice refrigeration.

Q. 5. Atmospheric air at 12°C and 75% R.H. is to be conditioned to a temperature of 22°C and 60% R.H. The amount of air supplied is 200 cu. M./min. The required condition is achieved first by heating and then by adiabatic humidifying. Find the following :

(a) Amount of steam required in kg per hour through the heating coil at pressure 2 bar and 0.96 dry. Assume only latent heat of steam is used for heating.

(b) The quantity of water required per hour in humidifier.

Ans.

$$COP = \frac{T_1}{T_3}\left(\frac{T_3 - T_2}{T_2 - T_1}\right) \text{ where } T_3 > T_2 > T_1$$

$$T_3 = 100 + 273 = 373 \text{ K}$$

$$T_2 = 20 + 273 = 293 \text{ K}$$

$$T_1 = -10^\circ C + 273$$

$$= 263 \text{ K}$$

$$COP = \frac{263}{373}\left[\frac{373-293}{293-263}\right]$$

$$= 1.915 \text{ Ans.}$$

Q. 6. The air in a room is to be maintained at 21°C and 50% R.H. by air supplied at a temperature of 16°C. The design outdoor conditions are :

Sensible heat gain = 20000 kJ/ hr. Latent heat gain = 4000 kJ/hr

Outdoor conditions = 32°C DBT and 40%R.H.

The ratio of re-circulated air to fresh air is fixed at 3 : 1 by mass. The plant consists of a direct expansion cooling coil and after-heater and a constant speed fan. Calculate :

(a) The quantity of air supplied per minute in cubic meters.

(b) The load on refrigerating plant in tons of refrigeration assuming the bypass factor of the cooling coil 0.1.

(c) The load on after-heater in kW.

Ans. Psessure of H_2 in evaporation $= 15 - 2.5 = 12.5$ Bas

$$= 12.5 \text{ bar}$$

$$V_{sh} = \frac{R_h T_h}{p_4}$$

$$R_h = \frac{R}{MH_2} = \frac{8314}{2}$$

$$= 4157$$

$$V_{sh} = \frac{4175\,(20+273)}{12.5 \times 10^5}$$

$$= 0.974 \text{ m}^3/\text{kg}$$

Mass of H_2 / kg of NH_3

$$= \frac{0.5}{0.974} = 0.51 \text{ kg}$$

Refrigerating effect of kg on NH_3 & H_2 leaving the evaporation—Heat of NH_3 & H_2 centering the evaporator

$$= [1670 + 0.51 \times 12.8\,(-15 - 0) - (336 + 0.51 \times 12.8\,(20 - 0)]$$

$$= 1572 - 466.5 = 1105.5 \text{ kJ/kg}$$

Heat supplied in generator per kg of NH_3 generated $\Rightarrow$

$$= 418 + 1320$$

$$= 1738 \text{ kJ/kg}$$

$$\text{COP} = \frac{\text{Refrigerating effect}}{\text{Heat supplied}}$$

$$= \frac{1105.5}{1738}$$

$$= 0.636 \textbf{ Ans.}$$

Q. 7. (a) What are the different types of compressors? Mention the fields for the use of each in refrigeration systems giving reasons.

Ans. (a) Vapour pressure compression (b) Wet & Dry compression

(i) As working cycle is near the Carnot cycle, the COP is quite high. The COP of the vapour cycle lies between 3 & 4 whereas the COP of air cycle is always less than 1.

(ii) Running cost of vapour refrigeration system is only 20% of air refrigeration system used on ground level.

(iii) As heat is carried away by latent heat of vapour, the amount at liquid circulated is less per ton of refrigeration, so that the size of evaporator is smaller for some refrigeratring effect.

(iv) Just by adjusting the throttle valve of the same unit, the required temperature of the evaporation can be achieved.

Disadvantages :

(i) First investment cost is high.

(ii) Major problem is to prevent leakage of the refrigerant.

Q. 7. (b) Explain the working with neat sketch of following types of condensers :

(i) Shell and coil condenser

(ii) Double pipe water cooled condenser.

Ans. A cooling tower is a special case of a water spray-chamber & the principles used to a water spray can also be used to the cooling tower overall heat **transfer coefficient.**

The heat transferred from hot to cold fluid through a solid barrier.

$$Q = \frac{T_i - T_o}{\left[\frac{1}{h_i A} + \frac{x}{KA} + \frac{1}{h_o A}\right]}$$

$$Q = VA\,(T_i - T_o) = \frac{T_i - T_o}{\frac{1}{UA}}$$

$$\frac{1}{U} = \frac{1}{h_i} + \frac{x}{k} + \frac{1}{h_o}$$

$$Q = \frac{T_i - T_o}{\left[\frac{1}{2\pi L R_1 h_i} + \frac{\log_e (R_2 / R_1)}{2\pi L K_1} + \frac{1}{2\pi L R_2 h_o}\right]}$$

$$Q = V_o (A_0)(T_i - T_o)$$

$$Q = \frac{T_i - T_o}{\frac{1}{2\pi R_2 L V_o}}$$

$$\frac{1}{V_0 R_2} = \frac{1}{R_1 h_i} + \frac{\log_e (R_2 / R_1)}{K_1} + \frac{1}{R_2 h_o}$$

$$\frac{1}{V_0} = \frac{R_2}{R_1} \times \frac{1}{h_i} + \frac{1}{h_o} \frac{R_2 \log_e (R_2 / R_1)}{K_1}$$

$$A_m = \frac{A_o + A_i}{2}$$

$$\frac{1}{V_0} = \frac{A_o}{A_i} \times \frac{1}{h_i} + \frac{\delta}{K} \cdot \frac{A_o}{A_m} + \frac{1}{h_0}$$

$$\frac{1}{V} = \frac{d_o}{d_i} \cdot \frac{1}{h_i} + \left(\frac{d_o - d_i}{d_o + d_i}\right) \frac{d_o}{k} + \frac{1}{h_o}$$

Q. 8. Write short notes on :

(a) Necessity of air craft refrigeration

(b) Effects of operating conditions on COP of VCRS

(c) Necessity of compound compression

(d) Psychometric Processes.

Ans. (a) Necessity of Air Craft Refrigeration :

Ans. It is a common assumption that the aeroplane does not require any cooling or air-conditioning because the temperature is low at higher altitude compared on the ground.

But there are many external & internal heat sources which add the heat in the passenger cabin & increase the temperature of air in the cabin.

If the conversion of the KE into enthalpy is isentropic, then the temperature rise can be calculated as follows :

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Hence, $$\frac{V_1^2}{2} + h_1 = \frac{V_2^2}{2} + h_2$$

As, $$V_2 = 0$$

So, $$(h_2 - h_1) = C_p (T_2 - T_1) = \frac{V_1^2}{2}$$

$$\Delta T = (T_2 - T_1) = \text{Rise in temperature} = \frac{V_1^2}{2C_p}$$

Internal Source : Human body continuously generates heat at a rate of 400 KJ per hour at rest & this heat is dissipated to the surrounding or to the cabin air.

(b) Effects of Operating Conditions on COP of VCRS :

The specific heat of liquid refrigerant is C_{pl}

$$\text{Area of } cefc = h_{f_1} - h_{f_2}$$

$$= C_{pl} [T_1 - T_2]$$

$$ef = C_{pl} \log_e \left(\frac{T_1}{T_2}\right)$$

Total heat at 'c' = Total heat at 'd'

area '*cef*' = area '*dfgu*'

$$C_{pl} (T_1 - T_2) - T_2 C_{pl} \log_e \frac{T_1}{T_2} = T_2 f_d$$

$$f_d = \frac{1}{T_2}\left[C_{pl} (T_1 - T_2) - T_2 C_{pl} \log_e \frac{T_1}{T_2}\right]$$

$$W \text{ (Work done)} = C_{pl}\ (T_1 - T_2) - T_2\ C_{pl}\ \log_e\left(\frac{T_1}{T_2}\right) + \frac{x_1 hgfi}{T_1}[T_1 - T_2]$$

$$R = \text{area } adui$$

$$= T_2\left[\frac{x_1 hfgi}{T_1} - f_d\right]$$

$$R = T_2\left[\frac{x_1 hfgi}{T_1} - \frac{1}{T_2}\left[C_{pl}(T_1 - T_2) - T_2 C_{pl}\log_e\left(\frac{T_1}{T_3}\right)\right]\right]$$

$$= \left[\frac{x_1 hfgi}{1}\cdot\frac{T_2}{T_1} - C_{pl}\ (T_1 - T_2) + T_2 C_{pl}\log_e\frac{T_1}{T_2}\right]$$

$$\boxed{COP = \frac{R}{W}}$$

(c) Necessity of Compound Compression : The dual compressor is used to replace 2 compressors which are required for multi-expansion valve system. The object of this system is to combine 2 separate systems into one without affecting the performance of the system. The simplest form of the dual compressor.

Their are 2 valves, one low pressure suction, other high pressure delivery valve & medium pressure suction ports as dual compressor shows considerable variation in design, particularly with regard to the location of valves & ports & method of operating the valves.

Considering energy balance of low pressure mixture & high pressure mixture:

$$u_m(1+R) = u_l + Rh_h$$

$$(1+R)\left[h_m - \frac{p_n\ v_n}{J}\right] = \left[h_l - \frac{p_1 v_1}{J}\right] + Rh_n$$

(d) Psychometric Processes : The thermodynamic physical, as well as safe working properties should be taken into account because selecting a refrigerant for a particular purpose. There is not a single best refrigerant which can be used for the refrigeration purposes. Different applications require different characteristics.

Enough attention has been given to describe the different required properties of a refrigerant & this all give sufficient insight to the students for selection of a refrigerant for a particular application. They are adviced to give attention to following properties before selection a refrigerant & compressor.

(i) Working pressure range & pressure ratio

(ii) Corrosiveness & flammability

(iii) Space limitations

(iv) Temperature required in the evaporator

(v) Air miscibility

(vi) etc.