UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2022

Module Number: ME5305 **Module Name: Refrigeration and Air-Conditioning**

[Three Hours]

[Answer **all questions**, each question carries **10** marks]

Note: Provide neat sketches and state any reasonable assumptions made; Symbols have their usual meaning; Psychometric chart is provided.

Q1 a) Draw the pressure-volume (p-v) diagram and temperature-entropy (T-s) diagram for the Bell-Coleman cycle and briefly explain its four processes.

[5.0 Marks]

b) Briefly explain the behaviour of the entropy of a working substance with its temperature with the aid of sketches.

[2.0 Marks]

c) What are the differences between open cycle and dense cycle of air refrigeration system?

[3.0 Marks]

Q2 In an open cycle air refrigeration machine, air is drawn from a cold chamber at the temperature of -2 °C and the pressure of 1 bar and compressed to 11 bar. Then it is cooled at this pressure to the cooler temperature of 20 °C and then expanded in expansion cylinder and returned to the cold room. The compression and expansion processes are isentropic, and follow the law of $pv^{1.4} = constant$.
Take specific heat of air at constant pressure and gas constant as 1 kJ/kg K and 287 J/kg K, respectively.

a) Sketch the p-v and T-s diagram of the refrigeration cycle.

[1.0 Mark]

b) Calculate the theoretical Coefficient of Performance (C.O.P.) of the system if the refrigeration capacity is 15 tonnes.

[3.0 Marks]

c) Calculate the air circulation rate in kg/min.

[2.0 Marks]

d) Find the piston displacement per minute in the compressor and expander.

[2.0 Marks]

e) Calculate the theoretical power requirement of the cycle per tonne of refrigeration.

[2.0 Marks]

Q3 a) The actual vapour compression cycle differs from the theoretical vapour compression cycle in many ways, some of which are unavoidable and cause losses.

i) Sketch the T-s diagram of actual vapour compression cycle.

[2.0 Marks]

ii) Briefly explain four main deviations between the theoretical cycle and actual cycle.

[2.0 Marks]

b) Saturated ammonia at a pressure of 2.5 bar enters a 160 mm × 150 mm (bore × stroke) twin cylinder, single acting compressor. The compressor is operating at 250 r.p.m. and has volumetric efficiency of 79 %. The compressor head pressure is 12 bar. The subcooled liquid ammonia at 22 °C enters the expansion valve. Sketch the T-s diagram and p-h diagram for the vapour compression refrigeration cycle and find the followings.

i) The ammonia circulation rate in the system in kg/min.

[3.0 Marks]

ii) The refrigeration capacity in tonnes of refrigeration.

[3.0 Marks]

Refer the following table for the properties of ammonia.

Pressure (bar)	Sat. temp. (°C)	Specific volume of the vapour (m^3/kg)	Specific enthalpy (kJ/kg)		Specific entropy (kJ/kg K)	
			Liquid	Vapour	Liquid	Vapour
2.5	-15	0.5098	112.4	1426.58	0.4572	5.5497
12	30	0.1107	323.08	1468.87	1.2037	4.9842

Take the specific heat at constant pressure for liquid ammonia and for superheated ammonia vapour as 4.606 kJ/kg K and 2.763 kJ/kg K, respectively.

Q4 a) In compound compression vapour refrigeration systems, the superheated vapour refrigerant leaving the first stage of compression is cooled by suitable method before being fed to the second stage of compression. Such type of cooling of the refrigerant is called "intercooling". Two stage compression with liquid intercooler is one of the compound compression vapour refrigeration systems.

i) Draw a schematic diagram of two stage compression with liquid intercooler.

[1.0 Mark]

ii) Draw the p-h diagram of the system.

[1.0 Mark]

iii) Starting from the mass balance of the liquid intercooler, show that the C.O.P. of the system is given by,

$$C.O.P. = \frac{210\,Q}{60\,P}$$

where,

Q = load on the evaporator in tonnes of refrigeration

P = power required to drive the system.

[4.0 Marks]

b) The R-12 refrigerant at saturation vapour pressure of 1.4 bar is condensed at a pressure of 10 bar by two stage compression with intercooling by liquid refrigerant at a pressure of 4 bar. Calculate the power needed to compress R-12 refrigerant, if the mass flow rate of the refrigerant is 20 kg/min. Assume that liquid refrigerant leaves the condenser is saturated and the refrigerant vapour leaves the evaporator is dry saturated. Following information are given for R-12 refrigerant.

Enthalpy of saturated vapour entering the low pressure compressor = 178 kJ/kg

Entropy of saturated vapour entering the low pressure compressor = 0.71 kJ/kg K

Enthalpy of superheated vapour leaving the low pressure compressor = 195 kJ/kg

Enthalpy of saturated vapour leaving the intercooler = 191 kJ/kg

Entropy of saturated vapour entering the high pressure compressor = 0.695 kJ/kg K

Enthalpy of superheated vapour leaving the high pressure compressor = 210 kJ/kg

Enthalpy of saturated liquid leaving the condenser = 77 kJ/kg

[4.0 Marks]

Q5 a) Briefly explain two methods of obtaining humidification?

[1.0 Mark]

b) Define the term "Sensible Heat Factor".

[1.0 Mark]

c) Consider two air stream which have different enthalpies and different specific humidities are mixed. The final condition of the air mixture depends on the masses involved, and on the enthalpy and specific humidity of each of the constituent masses which enter the mixture. Starting from the mass balance of the system, show that,

$$\frac{m_1}{m_2} = \frac{h_3 - h_2}{h_1 - h_3}$$

where,
m_1 = mass of first air stream
m_2 = mass of second air stream
h_1 = enthalpy of first air stream
h_2 = enthalpy of second air stream
h_3 = enthalpy of air mixture.

[2.0 Marks]

d) The saturated air stream leaving the cooling section of an air conditioning system at a temperature of 14 °C at the rate of 50 m^3/min is mixed adiabatically with the outside air at a temperature of 32 °C and 60% relative humidity at a rate of 20 m^3/min. Assuming that the mixing process occurs at a pressure of 1 atmosphere, determine the followings of the air stream mixture.

i) Specific humidity

[2.0 Marks]

ii) Relative humidity

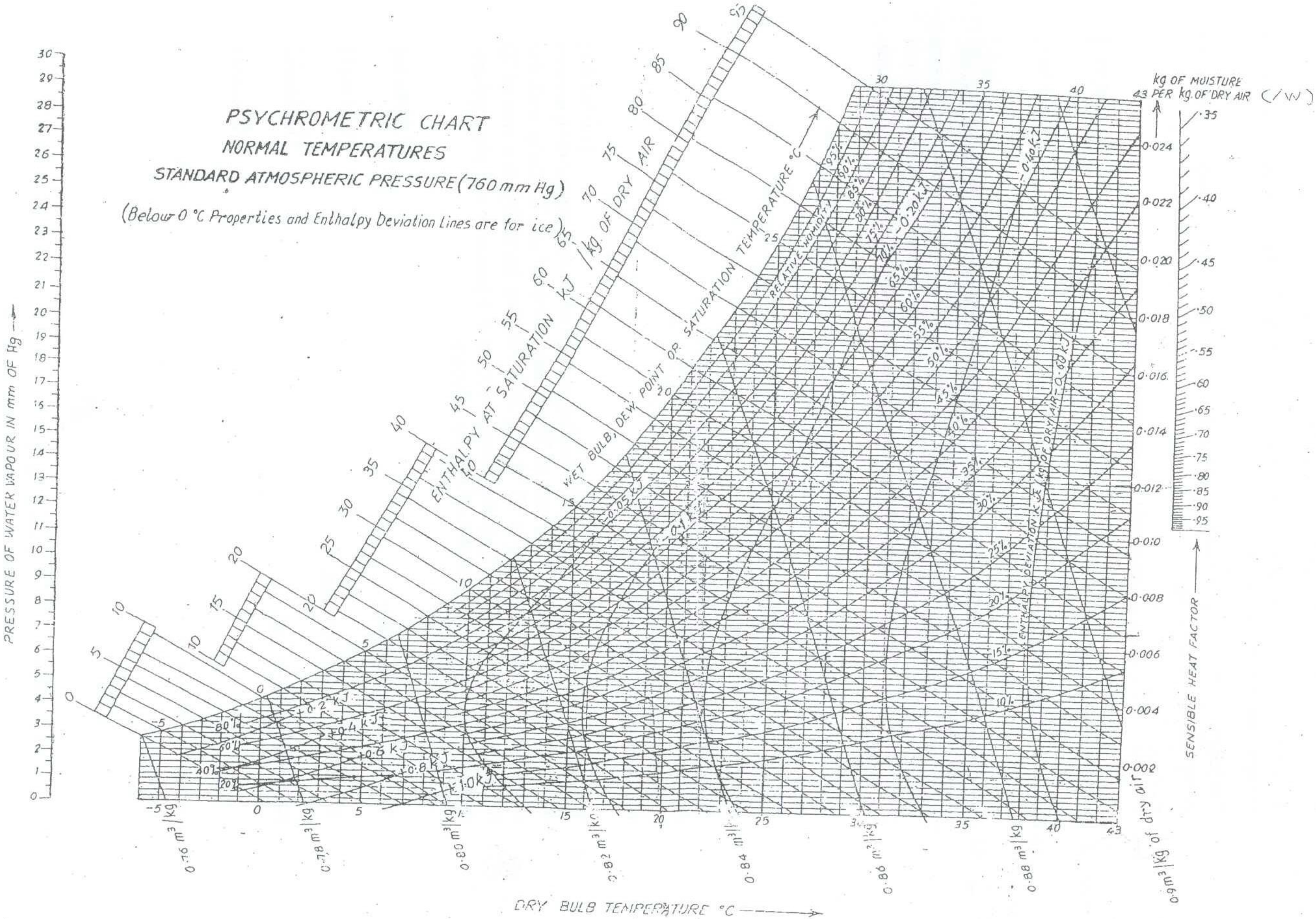
[1.0 Mark]

iii) Dry bulb temperature

[1.0 Mark]

iv) Volume flow rate

[2.0 Marks]



PSYCHROMETRIC CHART
NORMAL TEMPERATURES
STANDARD ATMOSPHERIC PRESSURE (760 mm Hg)
(Below 0 °C Properties and Enthalpy Deviation Lines are for ice)
PRESSURE OF WATER VAPOUR IN mm OF Hg
ENTHALPY AT SATURATION kJ / kg OF DRY AIR
WET BULB, DEW POINT OR SATURATION TEMPERATURE °C
RELATIVE HUMIDITY
ENTHALPY DEVIATION kJ / kg OF DRY AIR
DRY BULB TEMPERATURE °C
kg OF MOISTURE PER kg OF DRY AIR
SENSIBLE HEAT FACTOR
0.76 m³/kg
0.78 m³/kg
0.80 m³/kg
0.82 m³/kg
0.84 m³/kg
0.86 m³/kg
0.88 m³/kg
0.9 m³/kg of dry air