UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: August 2018

Module Number: ME5304 **Module Name: Refrigeration and Air-Conditioning**

[Three Hours]

[Answer **all questions**; Each question carries **ten marks**; Provide neat sketches and state any reasonable assumptions made; Symbols have their usual meaning; Psychometric chart and enthalpy concentration diagrams for R717, R22, R12 are provided]

Q1 a) State and briefly explain **five** key characteristics of a refrigerant.

[2.0 Marks]

b) What are the reasons for superheating the refrigerants in a refrigerator, before entering the compressor? How does it affect the coefficient of performance (COP) of the system?

[2.0 Marks]

c) A refrigeration system of a food storage chamber is having a capacity of 10 TR, running on a single-stage ammonia (R-717) refrigeration system. The ammonia liquid evaporates in the evaporator at -20 °C and the vapour is condensed in the condenser at 30 °C. The vapour is dry and saturated before entering the compressor. Sketch P-h and T-s diagrams for the refrigeration cycle and determine the following.

i) Mass flow rate of the refrigerant.

ii) Work input to the compressor.

iii) COP of the system.

v) COP of the system, if the ammonia liquid is subcooled to 10 °C before the expansion at the throttling valve.

[6.0 Marks]

Q2 a) Provide a neat sketch of the "Cascade Refrigeration System" and explain the advantage of it over the "Single-stage Refrigeration System".

[1.0 Mark]

b) What are the advantages of the compound vapour compression cycle with an intercooler?

[1.0 Mark]

c) A cascade refrigeration system running on R-22 and R-12 cycles delivers a 20 TR refrigeration output. Here, the low-temperature cycle operates with R-22 where the evaporator temperature is -40 °C and the condenser temperature is - 20 °C, which rejects heat to the high-temperature cycle. The high-temperature cycle operates with R-12 where the evaporator temperature is -30 °C and the condenser temperature is 20 °C. The refrigerant leaving the evaporator of the high-temperature cycle is subcooled by 10 °C before entering the expansion valve. However, there is no sub cooling in the low-temperature cycle. For both cycles, refrigerants leave the respective evaporators in dry and saturated conditions.

Neglecting any heat losses and assuming that the compressions are isentropic, determine the following.

i) Compression ratio for each refrigeration cycle.
ii) Refrigerant mass flow rate for each refrigeration cycle.
iii) Overall COP of the cascade refrigeration system.
iv) Power required to run the system.

[8.0 Marks]

Q3 a) State the key assumptions made in order to simplify the analysis of a "Air Cycle Refrigeration System".

[1.0 Mark]

b) Briefly describe the cooling process of an aircraft using a block diagram representing the "Simple Air Cooling System" and the corresponding T-s diagram of the Brayton cycle.

[3.0 Marks]

c) A simple air-cooled system is used in a flying aircraft to fulfil a cooling load of 12 TR. The outside atmospheric pressure is 0.9 bar and temperature is 10 °C. The pressure of the cooling air intake of the heat exchanger is 1.013 bar due to ramming. The hot air provided by the main compressor of the air craft engine to the heat exchanger, which is at 4 bar is cooled by 50 °C using this cooling air stream. The cabin of the aircraft is maintained at 1.01 bar and 25 °C. Determine the following.

i) Power of the main compressor used to deliver the pressurised air to the heat exchanger.
ii) COP of the cooling system.
iii) If the above system is replaced by a "Simple Air Evaporative Cooling System", state the key changes that can happen to the above system configuration and the performance parameters.

Given:

$$C_p = 1.0 \text{ kJ/kg/K}; \gamma = 1.4; m_a = \frac{210*Q}{C_p*(\Delta T)} \text{ kg/min}; P = \frac{m_a*C_p*(\Delta T)}{60} kW$$

[6.0 Marks]

Q4 a) Briefly explain **three** differences between the simple vapour absorption refrigeration cycle and the simple vapour compression refrigeration cycle.

[1.0 Mark]

b) In an aqua-ammonia based simple vapour absorption refrigeration cycle, the temperatures of the evaporator, absorber, condenser, and generator are -38 °C, 29 °C, 39 °C, and 100 °C, respectively. The concentration and the enthalpy of the aqua-ammonia solution are as follows.

Particulars	Concentration (mass of NH_3/mass of solution)	Enthalpy (kJ/kg)
Strong solution leaving the absorber	0.421	42
Weak solution leaving the generator	0.375	353
Vapour leaving the generator	0.945	1900
Liquid leaving the condenser	0.945	500
Vapour leaving the evaporator	0.945	1418

i) Draw a schematic diagram of the system.
ii) Determine the mass flow rate of the solution in the evaporator for a 1 TR capacity.
iii) Determine the mass flow rates of the strong and weak solutions considering overall mass balance and material balance or partial mass balance of NH_3 in the absorber.

[6.0 Marks]

c) Domestic Electrolux refrigerator uses ammonia, hydrogen, and water for its operations. This type of a refrigerator is also called as a three-fluid absorption refrigeration system.
i) What is the main purpose of domestic Electrolux refrigerator compared with other types of refrigerators?
ii) Draw a schematic diagram of a domestic Electrolux refrigeration system.
iii) Briefly explain the principle of operation of a domestic Electrolux refrigerator.

[3.0 Marks]

Q5 a) Air conditioning systems are used to supply and maintain desirable internal atmospheric conditions for human comfort, irrespective of thermal conditions.
i) What are the factors affecting the comfort delivered by an air conditioning system?
ii) Briefly explain the working principle of a winter air conditioning system with the aid of neat sketches.

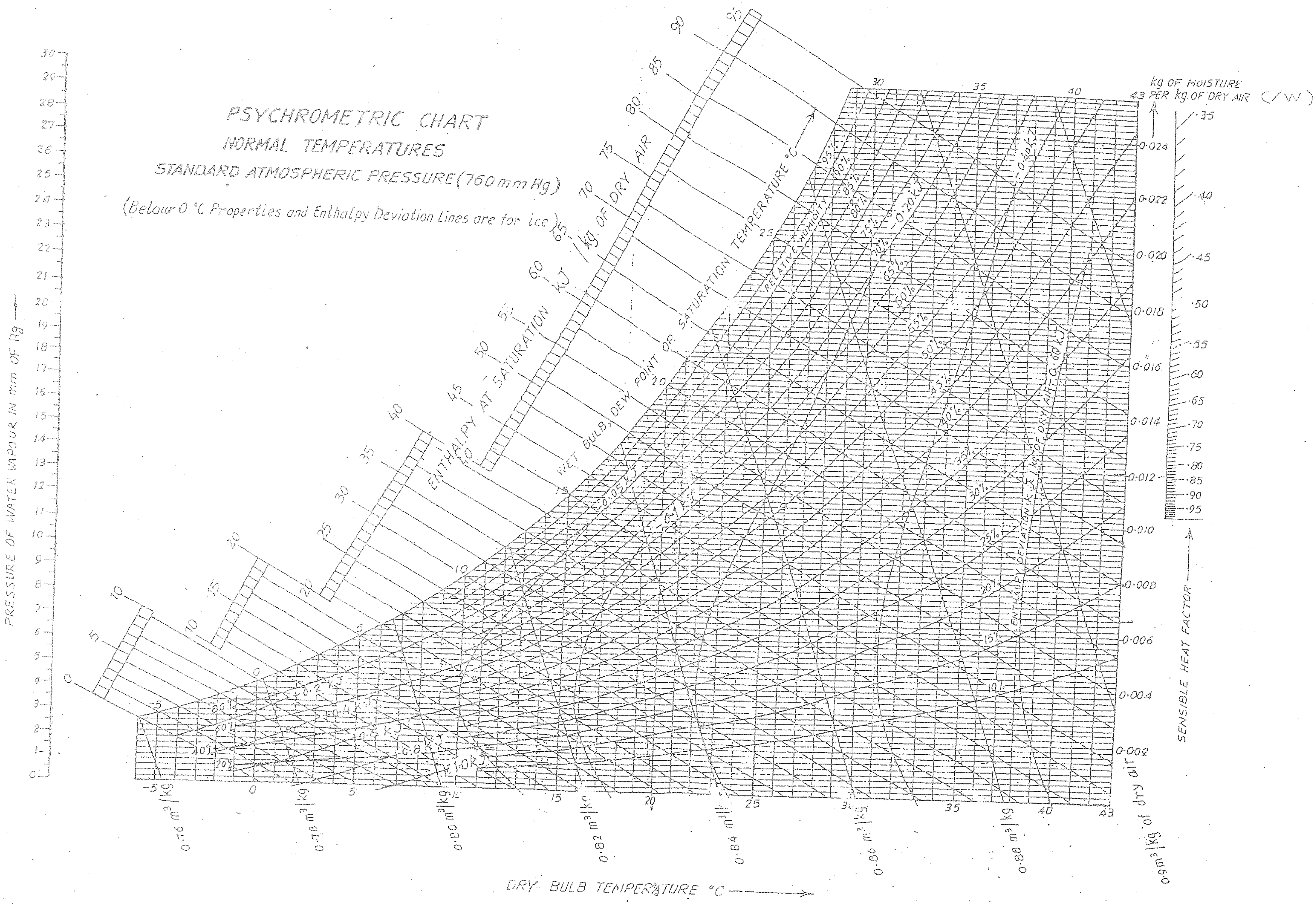
[2.0 Marks]

b) A mixture of re-circulated room air and outdoor fresh air enters a cooling coil at 32 °C dry bulb temperature and 19 °C wet bulb temperature. The air mixture is supplied to the room at a rate of 45 m^3/min and the effective surface temperature of the cooling coil is 4 °C. The cooling coil has capacity of 12.5 kW of refrigeration with the above given entering air state. Determine the dry and wet bulb temperatures of the air leaving the room and the by-pass factor of the coil.

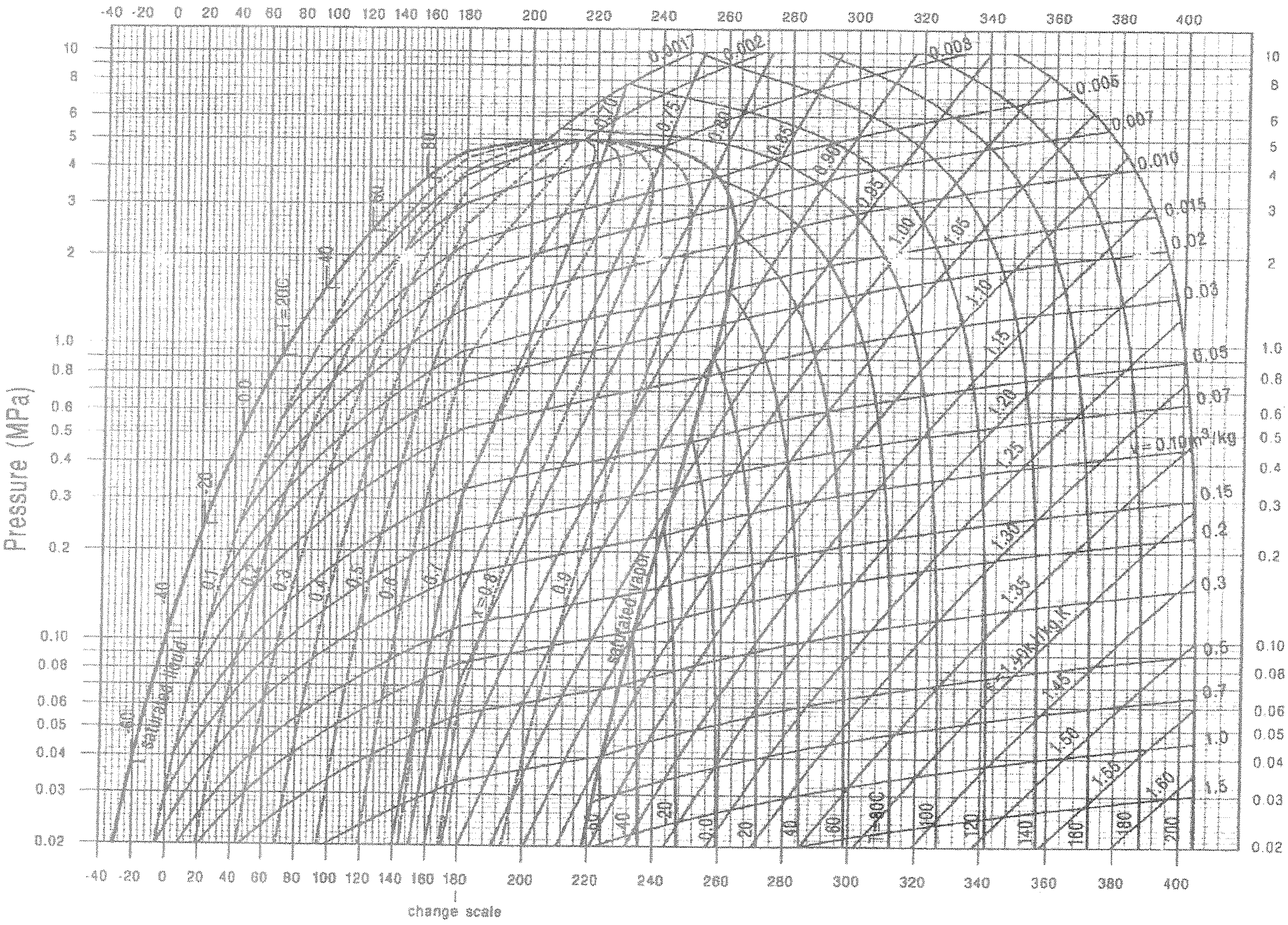
[5.0 Marks]

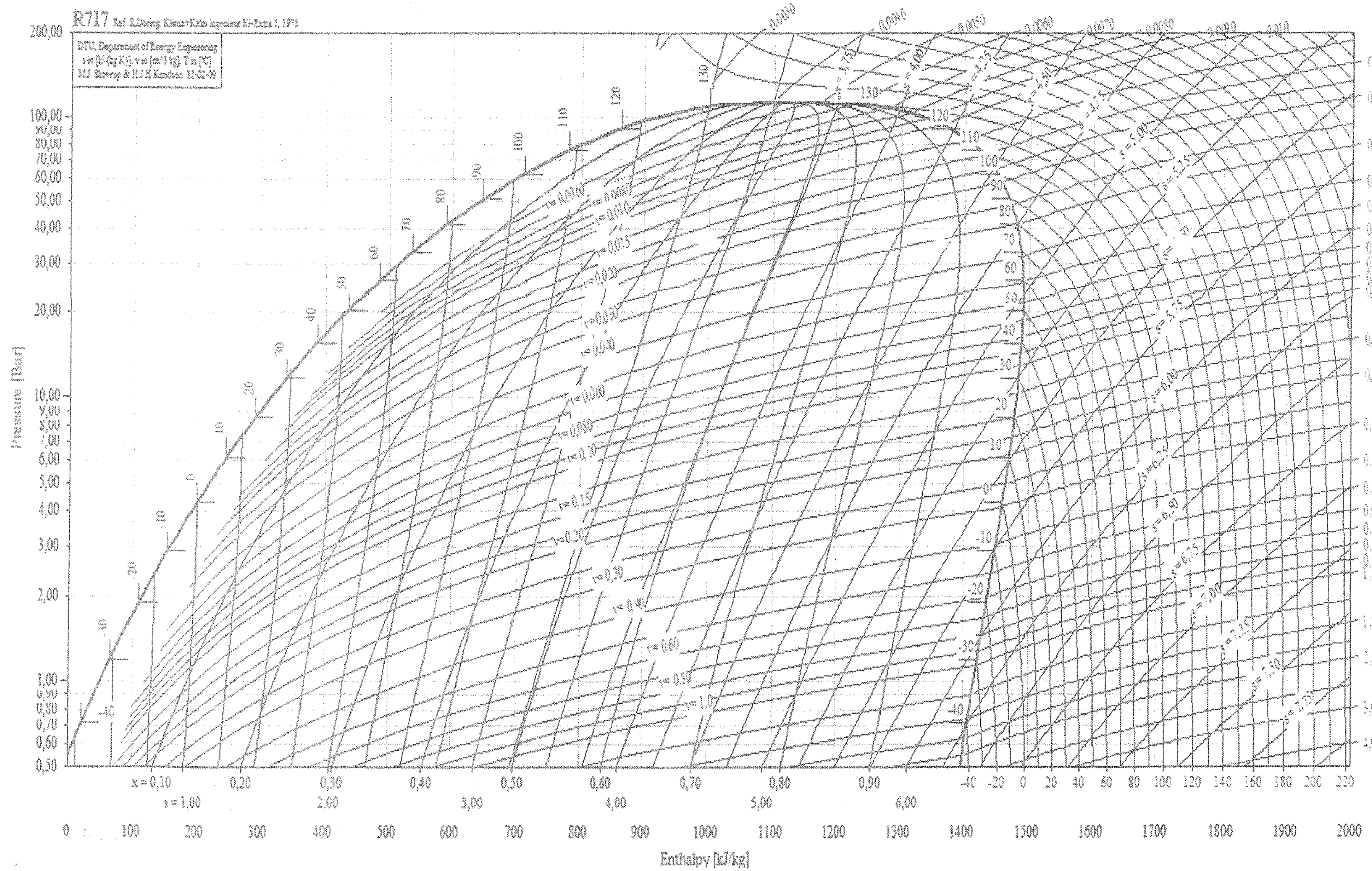
c) Atmospheric air at a pressure of 760 mmHg, a dry bulb temperature of 17 °C and a wet bulb temperature of 10 °C enters a heating coil whose temperature is at 42°C. If the by-pass factor of the heating coil is 0.5, determine the followings.
i) Dry bulb temperature of the air leaving the coil.
ii) Wet bulb temperature of the air leaving the coil.
iii) Relative humidity of the air leaving the coil.
iv) The sensible heat added to the air flow per unit mass of dry air.

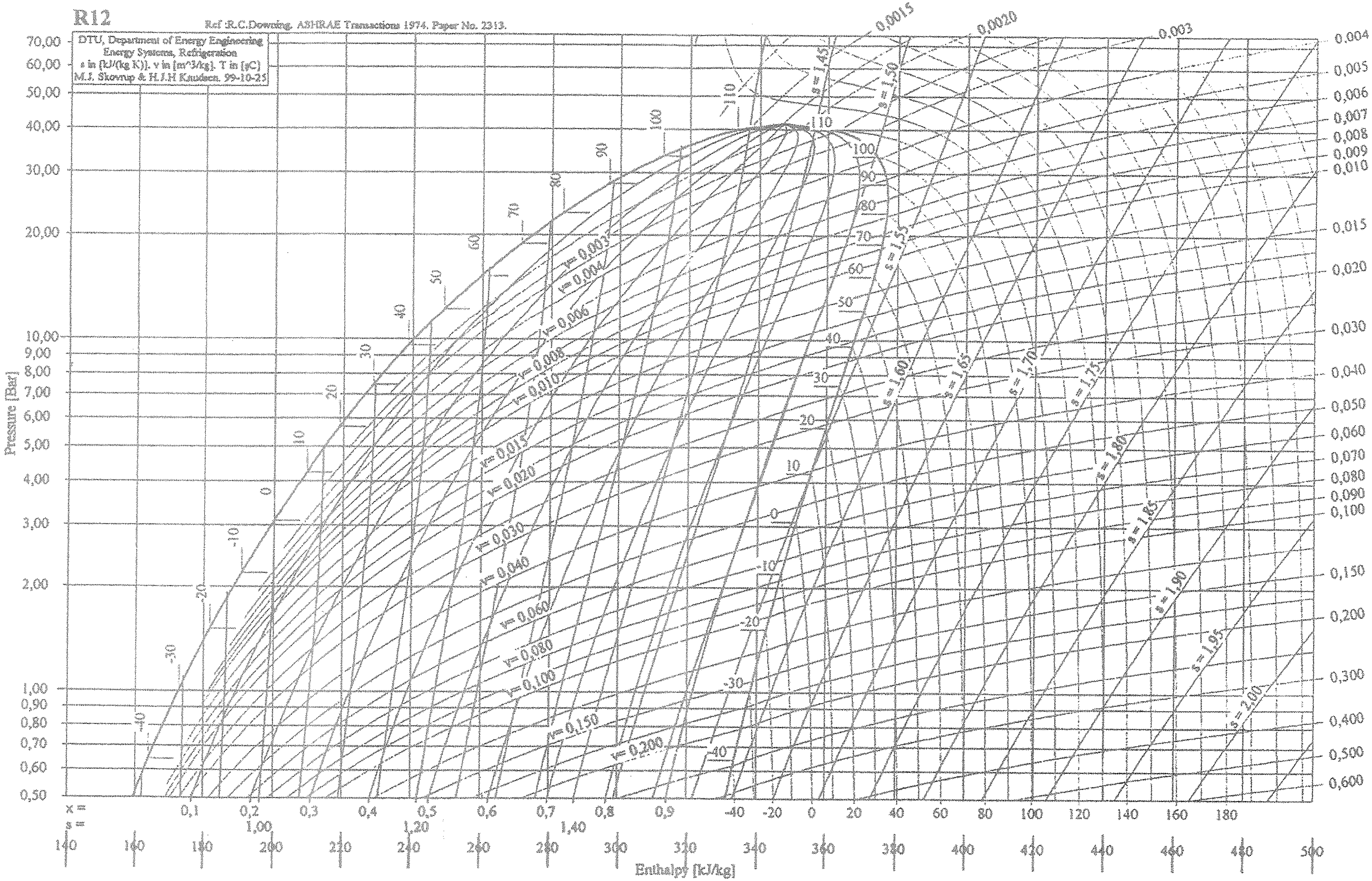
[3.0 Marks]


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
SENSIBLE HEAT FACTOR
kg OF MOISTURE PER kg OF DRY AIR (W)
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

Pressure-Enthalpy Diagram for R22




R717 Ref. R.Döring. Klima+Kälte ingenieur Ki-Extra 5, 1978
DTU, Department of Energy Engineering
s in [kJ/(kg K)], v in [m^3/kg], T in [ºC]
M.J. Skovrup & H.J.H Knudsen. 12-02-09
Pressure [Bar]
Enthalpy [kJ/kg]


R12
Ref :R.C.Downing. ASHRAE Transactions 1974. Paper No. 2313.
DTU, Department of Energy Engineering
Energy Systems, Refrigeration
s in [kJ/(kg K)], v in [m^3/kg], T in [ºC]
M.J. Skovrup & H.J.H Knudsen. 99-10-25
Pressure [Bar]
Enthalpy [kJ/kg]
x =
s =