



UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 5 Examination in Engineering: March 2026

Module Number: ME5305

Module Name: Refrigeration and Air-Conditioning
(C-23)

[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; Psychrometric chart and p-h chart for Ammonia are provided.

Q1 a) Briefly explain **two** practical difficulties encountered when using air refrigeration systems.

[2.0 Marks]

b) Draw the $p-v$ diagram and $T-s$ diagram for the reversed Brayton cycle. Hence, prove that the Coefficient of Performance (C.O.P.) of the system can be expressed as follows.

$$C.O.P. = \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}} - 1}$$

where r_p - compression or expansion ratio
 γ - isentropic index

[4.0 Marks]

c) A Carnot refrigeration cycle absorbs heat at 270 K and rejects it at 300 K.

i) Calculate the C.O.P. of the refrigeration cycle.

[1.0 Mark]

ii) If the cycle is absorbing 1130 kJ/min at 270 K, how much work is required per second in kJ?

[1.0 Mark]

iii) If the Carnot heat pump operates between the same temperatures as the above refrigeration cycle, determine the C.O.P. of the heat pump.

[1.0 Mark]

iv) Determine the heat delivery (kJ/min) by the heat pump at 300 K if it absorbs 1130 kJ/min at 270 K.

[1.0 Mark]

Q2 a) Briefly explain **three** different industrial applications of vapour compression refrigeration cycles.

[3.0 Marks]

b) A vapour compression refrigerator uses methyl chloride (R-40) and operates between pressure limits of 177.4 kPa and 967.5 kPa. At entry to the compressor, the methyl chloride is dry saturated and after compression has a temperature of 102 °C. The compressor has a bore and stroke of 75 mm and runs at 8 revolutions

per second with a volumetric efficiency of 80%. The temperature of the liquid refrigerant as it leaves the condenser is 35 °C and its specific heat capacity is 1.624 kJ/kg K. The specific heat capacity of the superheated vapour may be assumed to be constant. Specific heat capacity of water is 4.187 kJ/kg K.

The relevant properties of methyl chloride are as follows:

Saturation temperature °C	Pressure kPa	Specific volume m ³ /kg		Specific enthalpy kJ/kg		Specific entropy kJ/kg K	
		Liquid	Vapour	Liquid	Vapour	Liquid	Vapour
-10	177.4	0.00102	0.233	45.38	460.76	0.183	1.762
45	967.5	0.00115	0.046	132.98	483.6	0.485	1.587

i) Calculate the C.O.P. of the system.

[2.0 Marks]

ii) Determine the mass flow rate of the refrigerant.

[2.0 Marks]

iii) Determine the cooling water required by the condenser if its temperature rise is limited to 12 °C.

[2.0 Marks]

c) Draw the $T-s$ diagram of the actual vapour compression refrigeration cycle.

[1.0 Mark]

Q3 a) What thermodynamic and operational requirements necessitate the use of a compound (multi-stage) vapor compression system in preference to a single-stage compression system?

[2.0 Marks]

b) A two-stage compression ammonia refrigeration system operates between overall pressure limits of 14 bar and 2 bar. The temperature of the desuperheated vapour and subcooled liquid refrigerant is limited to 30 °C. The flash tank separates dry vapour at 5 bar pressure, and the liquid refrigerant then expands to 2 bar. Calculate the C.O.P. of the machine and the power required to drive the compressor, if the mechanical efficiency of the drive is 80% and the load on the evaporator is 10 TR.

[6.0 Marks]

c) State the meanings of the terms: refrigerator, refrigerant, and refrigeration.

[2.0 Marks]

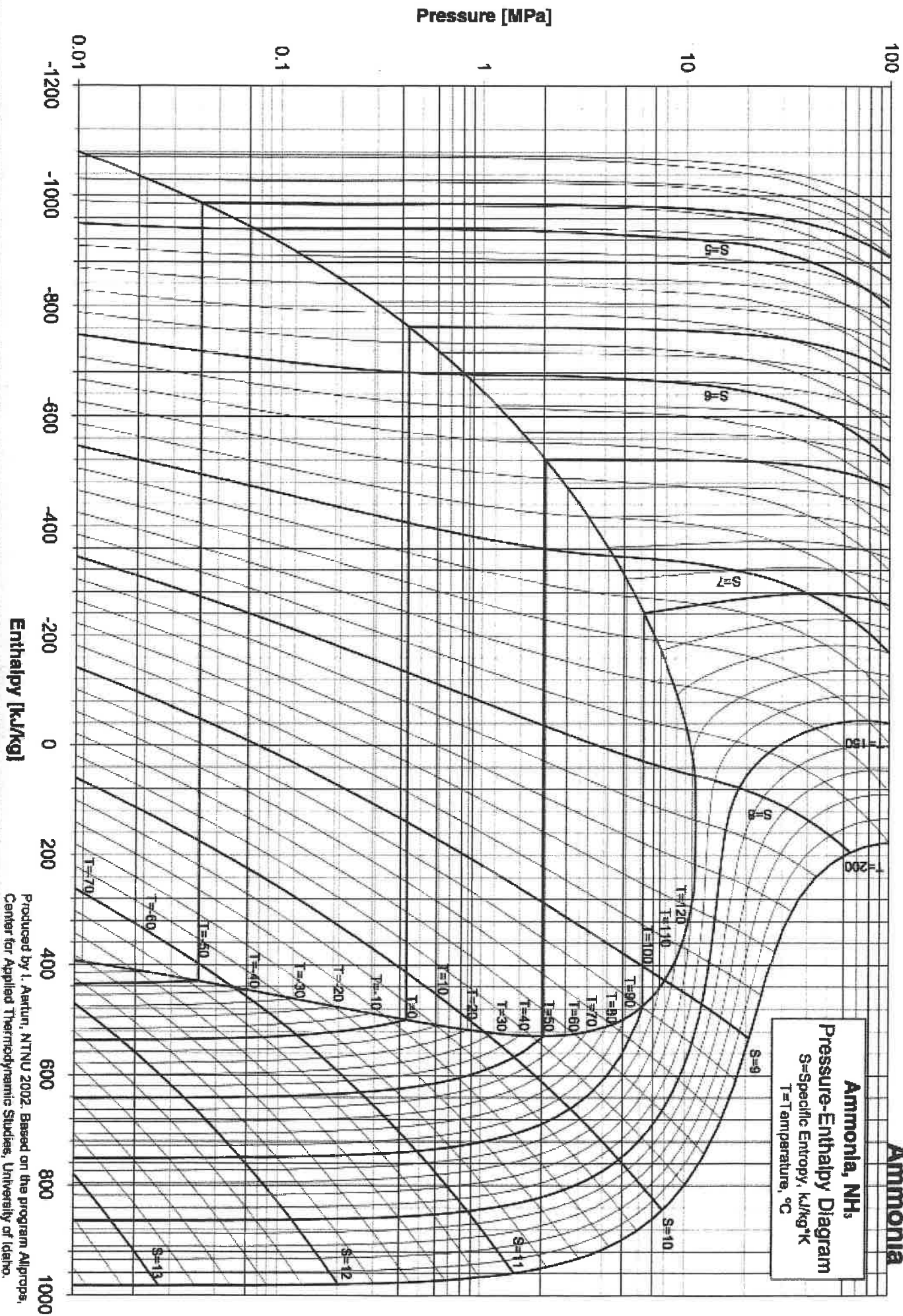
Q4 a) Draw the $p-h$ diagram and calculate the power needed to compress 20 kg/min of ammonia from saturated vapour at 1.4 bar to a condensing pressure of 10 bar by two-stage compression with intercooling by liquid refrigerant at 4 bar. Assume saturated liquid to leave the condenser and dry saturated vapour to leave the evaporator.

[4.0 Marks]

- b) Two cooling machines are connected one after the other such that the heat rejected by the first unit becomes the input to the second. The first unit extracts heat from a reservoir maintained at 127°C at a rate of 4 kJ/s and discharges it to an intermediate reservoir at an unknown temperature T . The second unit then absorbs this same heat from the intermediate reservoir and expels it to a high-temperature reservoir at 1227°C . Assuming both machines operate with identical coefficients of performance, determine:
- The temperature of the intermediate reservoir [1.5 Marks]
 - The C.O.P. of each machine [1.0 Mark]
 - The heat rejected to the 1227°C reservoir [1.5 Marks]
- c) Draw the p - v and T - s diagram for the reversed Carnot cycle. [2.0 Marks]
- Q5 a) An air-conditioning system draws a mixture of return air and fresh outdoor air at a volumetric flow rate of $39.6\text{ m}^3/\text{min}$ into a cooling coil. The air enters the coil at a dry-bulb temperature of 31°C and a wet-bulb temperature of 18.5°C . The coil has an effective surface temperature of 4.4°C and is sized to provide a cooling capacity of 12.5 kW under these inlet conditions. Determine the dry and wet bulb temperatures of the air leaving the coil and the bypass factor. [5.0 Marks]
- b) Two air streams are combined: one is recirculated air flowing at $800\text{ m}^3/\text{min}$ with a dry-bulb temperature of 22°C and a dew point of 10°C , while the other is fresh air at $300\text{ m}^3/\text{min}$ with a dry-bulb temperature of 30°C and 50% relative humidity. Determine the properties of the resulting mixture, including its enthalpy, specific volume, humidity ratio, and dew point temperature. [5.0 Marks]

Ammonia

Ammonia, NH₃
Pressure-Enthalpy Diagram
 S=Specific Entropy, kJ/kg·K
 T=Temperature, °C



Enthalpy [kJ/kg]

Produced by I. Aertun, NTNU 2002. Based on the program Allprogs, Center for Applied Thermodynamic Studies, University of Idaho.

PSYCHROMETRIC CHART NORMAL TEMPERATURES

STANDARD ATMOSPHERIC PRESSURE (760 mm Hg)
(Below 0 °C Properties and Enthalpy Deviation lines are for ice)

