Minerals Council South Africa

MEMORANDUM

SUBJECT: **CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN MINE ENVIRONMENTAL CONTROL**	EXAMINER**: JJ Pienaar**
PAPER 2 – THERMAL ENGINEERING	MODERATOR: **Marthinus v/d Bank**
SUBJECT CODE: **COMMEC2**	
EXAMINATION DATE: **05 October 2022**	TOTAL MARKS: **[100]**
TIME: **14:30 – 17:30 (3 HOURS)**	PASS MARK: **(60%)**

NUMBER OF PAGES: **14**

SPECIAL REQUIREMENTS:

THIS IS **NOT** AN **OPEN BOOK EXAMINATION**.
FORMULA HANDOUTS AVAILABLE INSTRUCTIONS TO CANDIDATES:

1. Answer all 4 questions **legibly** in English.
2. Write your **ID number** on the outside cover of each book used and on any graph paper or other loose sheets handed in.

NB: Your name **must not** appear on any answer book or loose sheets.

3. Show all calculations and **check calculations on which the answers are based**.
4. Hand-held electronic calculators may be used for calculations.
5. Write **legibly** in ink on the **right hand page** only – **left hand pages will not be marked**.
6. Illustrate your answers by means of sketches or diagrams wherever possible.
7. Answers must be given to an accuracy which is typical of practical conditions.

NB: Ensure that the correct unit of measure (SI unit) is recorded as marks will be deducted from answers if the incorrect unit is used. (Even if the calculated value is correct).

8. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
9. Cell phones and any other electronic devices are **NOT** allowed in the examination room. **Only Calculator**
10. **The following charts to be included: Psychrometric chart: 115 kPa and PH Diagram: Refrigerant R134 A**

QUESTION 1

1.1. Define the following:

1.1.1 Overall coefficient of heat transfer. (3)

In most practical situations the rate (½) of heat transfer (½) is governed by all three of the processes of conduction (½), radiation (½) and convection (½), depending on the particular configuration (½) of the equipment involved.

1.1.2 Hypothermia and give the temperature at which this condition can occur. (2)

Also known as Systemic Cold Stress (½). Hypothermia is the condition of having an abnormally low (½) deep body (½) or 'core' temperature (½). Below 35°C (½)

1.1.3. Enthalpy. (3)

This is the sum (½) of the sensible internal energy (½) and pressure energy (½) of the dry air and water vapour components (½) of an air / water vapour mixture (½). This energy is expressed as kilojoules per kilogram dry air (kJ/kg) (½).

1.1.4. Microbiological fouling (3)

An accumulation (½) of biological micro-organisms (½) in the tubes (½), including bacteria (½), algae (½) and fungi (½)

1.1.5. Sigma heat / energy (3)

This is the enthalpy of the air / water vapour mixture (½) minus the enthalpy of the water vapour (½) in the liquid phase at the wet bulb temperature (½). This heat content remains almost constant (½) at constant wet bulb temperature (½). This energy is expressed as kilojoules per kilogram dry air (kJ/kg) (½).

1.2. State the three factors affecting the rate of transfer of heat by radiation? (3)

The difference between the fourth powers of the absolute temperatures of the two surfaces exchanging radiation (1)
The area of the smaller of the two surfaces (1)
The emissivity and view factor (1)

1.3. Give three symptoms of condenser tube fouling: (3)

Reduced duty of the condenser (1)
Increase in condenser pressure (1)
Increase in load on the compressor. (1)

Total Marks: (20)

QUESTION 2 (General Calculations)

2.1 The length of a conveyor belt in a platinum mine is 3000m. The amount of ore that is conveyed on this conveyor is at a rate of 800 tons/hour. The vertical lift of the conveyor is a height of 250m. The conveyor motor consumes 1500kW and the combined motor and transmission efficiency is 95%. Assume gas 9,79m/s^2.

Calculate the following:

(a) The heat emitted at the gear head (4)

The work done against gravity = massflow of ore x g x height (1)
= (800 x 1000) / (60 x 60) x 9,79 x 250
= 545 kW (1)

The heat generated at the gear head = Motor power x (100 - % efficiency motor) (1)
= 1 500 x (100 - 95) %
= 75 kW (1)

(b) The heat emitted along the length of the conveyor belt. (2)

Heat along belt = Input power– work against gravity– heat from gear head (1)
= 1500 – 545 – 75
= 880 kW (1)

2.2. You are the ventilation engineer on a shaft and you have to make an estimate of the heat load potential of a new kind of explosive to be tested on your shaft. The following technical details of the explosive are available.

- ANFO based explosives heat release 3 700 kJ/kg of explosives
- The charge density of ANFO explosives 0,8 kg/ton of rock blasted

It is known that the heat generated by the explosives will be removed in two stages, namely with the blasting fumes and some will be retained in the rock as heat. With high fragmentation it is assumed that 45% of the heat will be removed with the fumes. It is also estimated that 20% of the heat will be removed within the first hour after blasting. The amount of rock to be blasted is 2000 tons and assume the Cp of rock as 950J/kg^{o}C.

Determine the following:

2.2.1. The total amount of heat produced by the explosives (kJ) (2)

Heat produced by explosives = mass of explosives used x heat release rate of explosives (1)
= (2000 x 0,8) x 3700
= 5 920 000kJ (1)

2.2.2. How much of the total heat produced remains in the rock and is not removed with the fumes (kJ) (2)

Heat remaining in the rock total = amount of heat released x percentage remaining (1)

= 5 920 000 x (100 - 45) %
= 3 256 MJ (1)

2.2.3. The amount of heat removed with the fumes within the first hour after blasting (2)

Amount of heat removed in the first hour = (total amount of heat released / (60 x 60)) x percentage removed (1)
= (5 920 000 / 3600) x 0.2
= 329kW (1)

2.2.4. The rise in temperature of the rock blasted within the first hour (3)

Heat in rock (kJ)	=	mass of rock x $C_{p\ rock}$ x Δt	(1)
Δt	=	heat in rock (kJ) / mass of rock x $C_{p\ rock}$	(1)
	=	(5 920 000 x (80/100)) / (2000 x 1000 x 0.950)	
	=	2,49 (2.5)°C	(1)

2.2.5. What would be the rise in temperature in the rock be (within the first hour) if the explosives used were a nitro glycerine based explosive with a heat release rate of 5800 kJ/kg explosive used assume same charge density. (3)

Heat in rock (kJ)	=	mass of rock x $C_{p\ rock}$ x Δt	(1)
Δt	=	heat in rock (kJ) / mass of rock x $C_{p\ rock}$	(1)
	=	((2000 x 0.8 x 5800) x 0.8% remaining) / 2000 x 1000 x 0.950	
	=	3.9°C	(1)

2.3. A diesel machine with a machine power rating of 187 kW is used in an underground working environment. The fuel consumption is 0,178 litres of fuel per kW per hour. The amount of water produced per each litre of diesel is 1 litre of water for each litre of diesel. The latent heat of water is 2 450 kJ/kg. Assume that the utilization is 80% and that the calorific value of the diesel fuel is 35 000 kJ/litre of diesel.

Determine the following:

2.3.1. The amount of fuel consumed in litres/second (2)

Amount of fuel consumed = Rated power x utilization % x rate of fuel consumption (1)
= 187 x 0,8 x (0,178/3600)
= 0,007397 litres/second or 26,6 litres/hour (1)

2.3.2. The amount of water produced in litres/second (1)

The amount of water produced is a 1 to 1 ratio; therefore the amount of water produced is also 0,007397 litres/second (1)

2.3.3. The total amount of heat produced (kW) (2)

The amount of heat produced = fuel consumption in litres/second x Calorific value of diesel (1)
= 0,007397 x 35 000
= 259 kW (1)

2.3.4. The heat factor for the machine (2)

Heat factor = heat produced / rated kW power (1)
= 259 / 187
= 1.39 (1.4) (1)

2.3.5. The split in latent and sensible heat produced by the machine (kW) (2)

Latent heat produced water = amount of water produced x latent heat of water (1)
= 0,007397 x 2 450
= 18,1 kW (1)

2.3.6. A mine produces 2 million litres of fissure water per day. The water temperature is 45ºC and the water temperature of the water in the settling dams are approximately 28ºC. What heat load is imposed on the mine? (3)

Heat load imposed = massflow of water x c x Δt (1)
= (2 000 000 / (24 x 60 x 60)) x 4.187 x (45 – 28)ºC (1)
= 1 648kW (1)

Total Marks: (30)

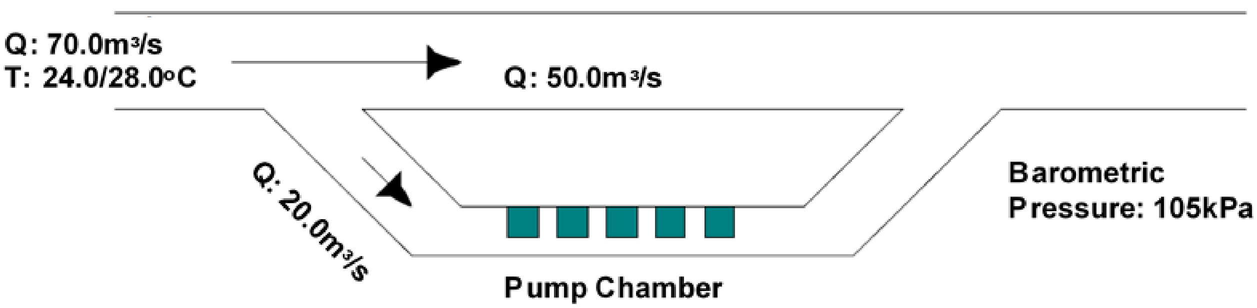
QUESTION 3 (Psychrometry)

3.1. An air quantity of 70m^3/s leaves the bottom station of a downcast shaft where the following conditions prevail:

Barometric pressure 105kPa
Temperature 24/28ºC

20m^3/s of this air passes through a pump chamber where 5 pumps each driven by an 800 kW air cooled motor with an efficiency of 94%, are installed.

After the pump chamber the air mixes with the rest of the air which remained at constant temperature.



3.1.1. What will be the wet-bulb temperature and dry-bulb temperature of the air after thorough mixing? (12)

Condition of the air leaving the shaft station at 105 kPa barometric pressure and 24/28ºC:

Sigma heat content, S	=	68,7 kJ/kg	(1)
Moisture content, r	=	16,5 g/kg	(1)
A.S.V. of the air (v)	=	0,846 m3/kg	(1)
Massflow of the air	=	Q / V	(1)
	=	70 / 0.846	
	=	82.9 kg/s	(1)

The rated power of each motor is = 800 kW (NB this is output power)
This 800 kW is 94% of the power supplied to the motor, the heat given off by each motor can now be calculated:

Heat given off by each motor	=	input power - output power	(1)
	=	(output power / Efficiency$_{motor}$) – 800	
	=	(800 / 0.94) – 800	
	=	51.1 kW	(1)
Five motors will therefore give off	=	51,1 x 5	
	=	255,5 kW of heat	(1)

The heat added to the air by the pump motors is therefore 255,5 kW say 256 kW
The heat added to the air per kg:

Increase in heat per kg	=	256 / 82.9	
	=	3.1 kJ/kg	(1)

The Sigma heat of the air after mixing	$= S_{in} + \Delta S$	(1)
	= 68,7 + 3,1	
	= 71,8 kJ/kg	(1)

Assuming that the moisture content remains constant at 16,5 g/kg as before:

Using the 105 kPa psychrometric chart read off the temperature of the air after mixing with the fresh air again:

Temperature of the mixed air is 24,8/31,0ºC (1)

3.1.2. If water cooled motors are installed in the pump chamber , the waste heat to be removed by the ventilating air would only be 20% of that in the case of air cooled motors. What would the condition of the mixed air be in this case? (5)

Heat given off water cooled motors	=	256 x 0,2	
	=	51,2 kW	(1)
Increase in heat per kg	=	51.2 / 82.9	
	=	0.6 kJ/kg	(1)
The Sigma heat of the air after mixing	=	$S_{in} + \Delta S$	(1)
	=	68,7 + 0,6	
	=	69,3 kJ/kg	(1)

Assuming that the moisture content remains constant at 16,5 g/kg as before:

Using the 105 kPa psychrometric chart read off the temperature of the air after mixing with the fresh air again:

Temperature of the mixed air is 24,2/29,2ºC (1)

3.1.3. The mixed air, as calculated in part (a) passes through a wet section of the haulage where it picks up a total of 120 g/s of water, the wet-bulb temperature remaining practically constant. Assuming no heat flow to or from the rock, what will be the drybulb temperature after the wet section? (3)

If the air picks up 120 g/s of water, then the moisture pick-up per unit mass as follows:

Increase in moisture per kg	=	120 / 82.9	
	=	1.5 g/kg	(1)
The moisture content will then be	=	16,5 + 1,5	
	=	18,0 g/kg	(1)

If the wet bulb temperature remains constant (24,8ºC) then the dry-bulb temperature under these conditions as read off the 105 kPa psychrometric chart will be 27,9ºC. (1)

Total Marks: (20)

QUESTION 4 (Selected Examination Questions and Answers Paper 2 Page 78 Question 2) (Refrigeration)

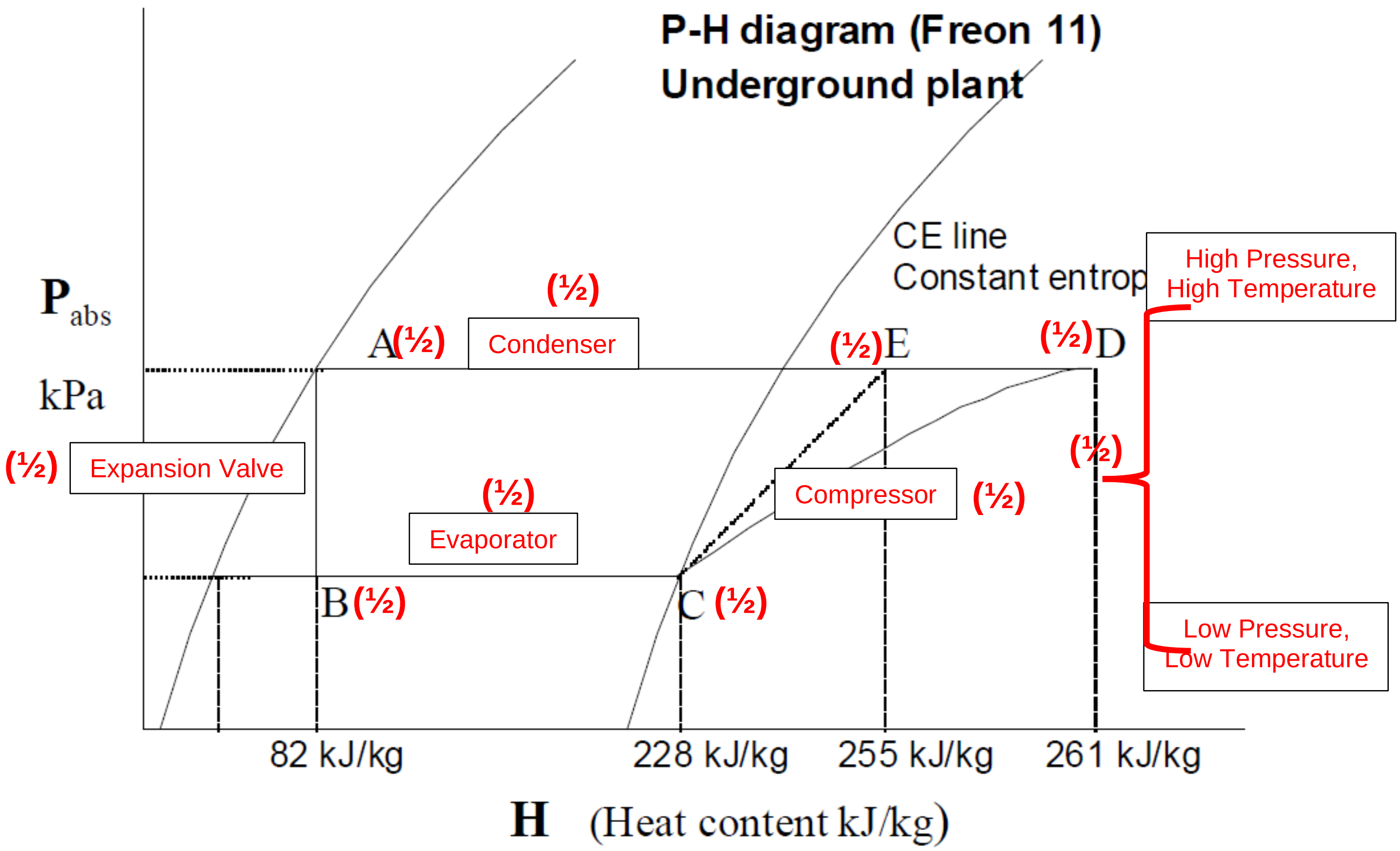
4.1 The following measurements were taken on an underground refrigeration plant using Freon 11

Plant room barometric pressure	105 kPa
Evaporating pressure	44,5 kPa vacuum
Condensing pressure	165 kPa gauge
Compressor inlet temperature	10ºC
Compressor outlet temperature	72.5ºC
Evaporator duty	3 190 kW

It is proposed to relocate this plant on surface where the new condensing temperature will be 40ºC and the evaporating temperature will be 3ºC. From the compressor curve the refrigerant mass flow through the evaporator is expected to increase by 36% and the compressor efficiency will decrease by 9,2%. The motor used for the underground plant has 16% spare capacity

NB: The attached pressure enthalpy charts (R-11) will be required to answer the following questions.
On these charts, clearly indicate all points plotted to obtain your answer; remember to submit these charts with your answer book(s).

4.1.1. Plot the refrigeration cycle **for the underground plant** on this ph chart, indicating the main components of the cycle, briefly describe what happens to the refrigerant at each component of the cycle. (5)



From this pressure enthalpy chart calculate the following:

4.1.2. Compressor efficiency of this refrigeration plant. (1)

Compressor efficiency = $(H_E - H_C) / (H_D - H_C) \times 100\%$

= (255 – 228) / (261 – 228) X 100%

= 81.8% (1)

4.1.3. The Carnot COP of this refrigeration plant. (3)

Evaporating temperature T_1 = (10 + 273) = 283K (1)

Condensing gttemperature T_2 = (55 + 273) = 328K (1)

Carnot COP = $T_1 / (T_2 - T_1) \times 100\%$

= 283 / (328 – 283) x 100%

= 6.29 (1)

4.1.4. The actual compressor COP of this refrigeration plant. (1)

Actual compressor COP = $(H_c - H_b) / (H_D - H_C)$

= (228 – 82) / (261 – 228)

= 4.42 (1)

4.1.5. The massflow of the refrigerant of this refrigeration plant. (1)

Evaporating duty = $m_{refrigerant}$ x heat $exchanged_{evaporator}$

Massflow refrigerant = Evaporator duty / heat $exchanged_{evaporator}$

= 3190 / 146

= 21.85 kg/s (1)

4.1.6. The compressor input power of this refrigeration plant. (1)

Compressor input power = $m_{refrigerant}$ x actual heat of compression

= $m_{refrigerant}$ x $(H_D - H_C)$

= 21.85 x (261 – 228)

= 721.1 kW (1)

4.1.7. The ideal work done by the compressor of this refrigeration plant. (1)

Ideal work done by the compressor = motor output power x $eff_{compressor}$

= 721.1 x 0.818

= 589.8 k kW (1)

4.1.8. The heat losses in the compressor of this refrigeration plant. (1)

Heat losses in the compressor = motor output power x $\%_{losses}$

= 721.21 x 0.182

= 131.3 kW (1)

4.1.9. The compressor motor power in of this refrigeration plant assuming a motor efficiency of 95%. (1)

Compressor motor power in = Compressor motor power out / $efficiency_{motor}$

= 721.1 / 0.95

= 759 kW (1)

4.1.10. The new mass flow of refrigerant of this refrigeration plant on Surface. (1)

Mass flow of refrigerant = 1.36 x 21.85

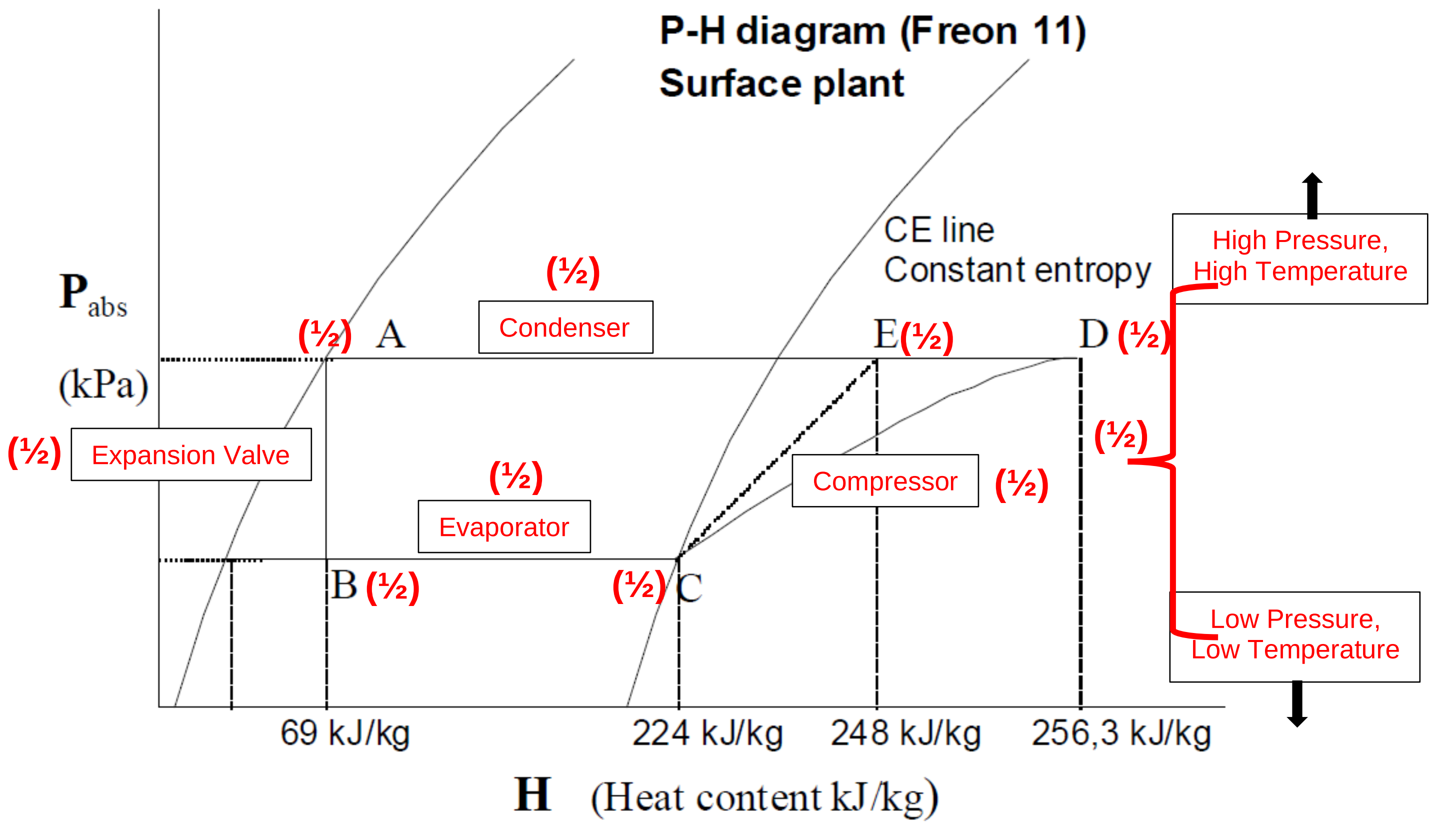
= 29.72 kg/s (1)

4.1.11. The new compressor efficiency of this refrigeration plant on Surface. (1)

New compressor efficiency = 0.908 x 81.8

= 74.3% (1)

4.1.12. Plot the refrigeration cycle for the **plant on surface** on thesecond ph chart, indicating the main components of the cycle, briefly describe what happens to the refrigerant at each component of the cycle. (5)



From the pressure enthalpy chart of the **plant on surface** calculate the following:

4.1.13. The Carnot COP of this refrigeration plant. (3)

Evaporating temperature T_1	=	(3 + 273)	=	276K	(1)
Condensing gttemperature T_2	=	(40 + 273)	=	313K	(1)
Carnot COP	=	$T_1 / (T_2 – T_1)$ x 100%			
	=	276 / (313 – 276) x 100%			
	=	7.26			(1)

4.1.14. The actual compressor COP of this refrigeration plant. (1)

Actual compressor COP	=	$(H_c – H_b) / (H_D – H_C)$	
	=	(224 – 69) / (256.3 – 224)	
	=	4.8	(1)

4.1.15. The new evaporator duty of this refrigeration plant. (1)

Evaporating duty = $m_{refrigerant}$ x heat $exchanged_{evaporator}$

= 29.72 x (H_c – H_b)

= 29.72 x x(224 – 69)

= 4607 kW (1)

4.1.16. The compressor motor potential of this refrigeration plant. (1)

Motor potential = 1.16 x 721.1

= 836.4 kW (1)

4.1.17. The surface compressor power required for this refrigeration plant. (1)

Surface compressor power = (H_d – H_c) x m

= (256.3 – 224) x 29.72

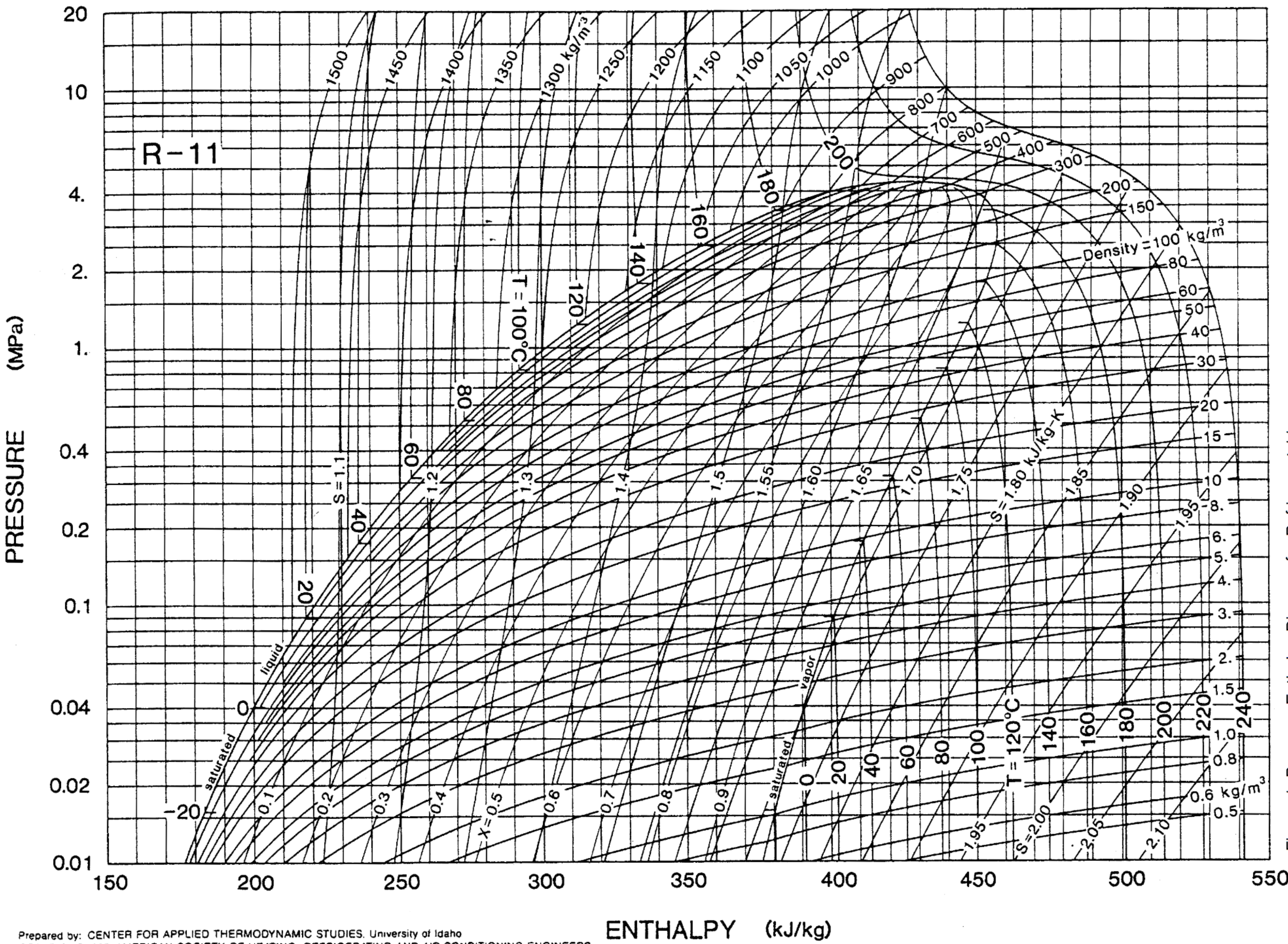
= 960 kW (1)

4.1.18. Will the motor be suitable for the surface plant. (1)

The output power of the compressor motor needed is 960 kW vs Motor potential available of 836.4 kW

The motor is therefore not suitable for the surface plant. (1)

Total Marks: (30



Prepared by: CENTER FOR APPLIED THERMODYNAMIC STUDIES, University of Idaho

Figure 1. Pressure-Enthalpy Diagram for Refrigerant 11

DATA BOOK

SECTION: REFRIGERATION EQUIPMENT
TOPIC: REFRIGERANT PROPERTIES

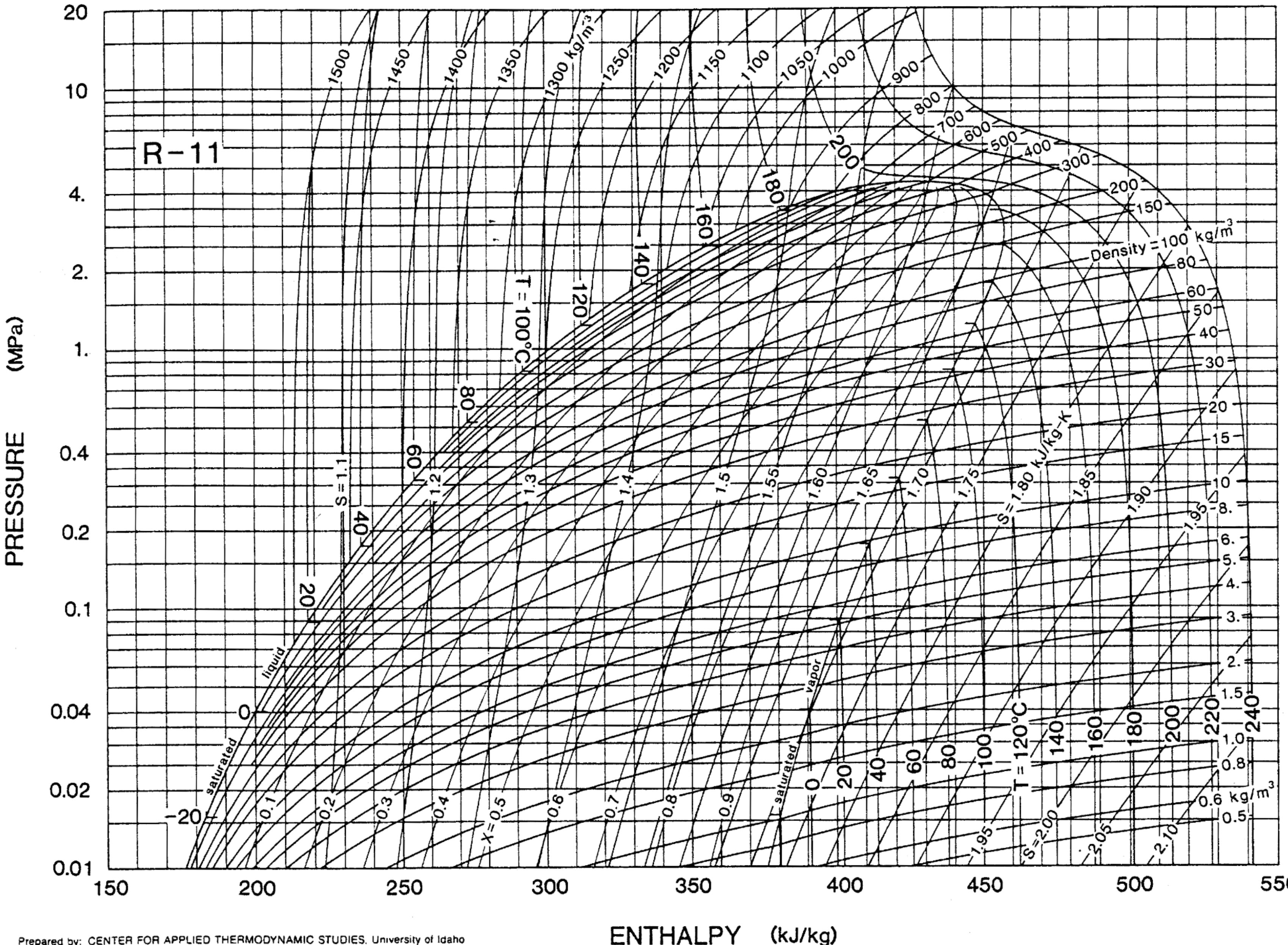


Figure 1. Pressure-Enthalpy Diagram for Refrigerant 11

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