Minerals Council South Africa

MEMORANDUM

SUBJECT:**CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN MINE ENVIRONMENTAL CONTROL** **PAPER 2 – THERMAL ENGINEERING** SUBJECT CODE: **COMMEC2** EXAMINATION DATE: **11 May 2022** TIME: **<u>14:00 – 17:00 (3 HOURS)</u>**	EXAMINER**: JJ Pienaar** MODERATOR: **Marthinus v/d Bank** TOTAL MARKS: **[100]** 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 Gibbs-Dalton Law of Partial Pressures. (3)

This law implies that each gas behaves as if the others were not present (½). Thus, the total pressure (½) of a mixture of gases (½) is the sum of the partial pressures (½) of each component gas (½), calculated as if the other gases were not present (½)

1.1.2 Dalton's law. (4)

This law states that the pressure exerted (½) by a mixture of gases (½) present in a container of given volume (½), and at a given temperature (½), is equal to the sum (½) of the pressures exerted (½) by the individual components of the mixture (½) if each alone filled the container at the same temperature (½).

1.1.3. Heat stress. (2)

Heat stress is the net load on the human body (½) from the combined contributions (½) of metabolic heat production (½) and external environmental factors (½).

1.1.4. Pressure-enthalpy diagram (3)

The two independent properties (½) of absolute pressure (½) and enthalpy (½) conveniently indicate (½) the thermodynamic state (½) of a refrigerant (½) in a pressure-enthalpy diagram

1.1.5. Thermal capacity ratio (2)

Thermal capacity ratio is defined as the ratio (½) of the thermal capacity (½) of the water stream (½) to that of the airstream (½)

1.2. Give the metabolic heat production of the human body for the following work being performed: (4)

1.2.1.	At rest	90 to 115 W	(1)
1.2.2.	Light work rate	200 W	(1)
1.2.3.	Moderate work rate	275 W	(1)
1.2.4.	Hard work rate (intermittent)	470 W	(1)

1.3. Give typical conductivity values (W/m˚C) for the following materials: (3)

1.3.1.	Copper	380 W/m˚C	(1)
1.3.2.	Steel	45 W/m˚C	(1)
1.3.3.	UPVC	0.14 W/m˚C	(1)

1.4. List four properties of a good insulant. (4)

Any four of the following:

- Must be effective i.e. low thermal conductivity.
- Must not be a fire hazard.

- Must be resistant to “waterlogging”.
- Must be robust (able to withstand rough handling).
- Must be as inexpensive as possible.
- Easy and cheap to install

Total Marks: (25)

QUESTION 2 (General Calculations)

2.1 A clerk in a metallurgical plant complains that the office in which she works is hot. One wall in particular appears to radiate heat into this office, this wall separates the office from an adjoining furnace room. (10)
The wall adjoining with the furnace room measures 4m (W) x 2m (H).
This wall comprises of a 200mm thick, double-brick wall with a 15mm thick layer of plaster on either side of the wall.
The surface temperature of this wall is measured to be 115°C (on the furnace side of the wall and 55ºC (on the office side of the wall).
An air conditioner maintains the air temperature inside the office at a constant 26.5°C.

Given that:

- The thermal conductivity of brick is 0.7 W/mºC.
- The thermal conductivity of plaster is 0.93 W/mºC.
- The surface (skin and clothes) temperature of the clerk averages 28ºC.
- That side of the clerk’s body facing the “hot” wall has a surface area of 0.8m².
- That side of the clerk’s body facing the “hot” wall has an emissivity and view factor with the wall of 0.95.

Determine the following:

2.1.1. At what rate does heat pass through the wall by means of conduction?

Heat passes through the wall by means of conduction.

$Q = kA(t1 – t2)/B$ (1)

where;

Q = conductive heat transfer rate through the wall (W).

k = conductivity of wall (W/mºC).

A = cross-sectional area of the wall (m²).

t1 = temperature of the wall on furnace side (ºC).

t2 = temperature of the wall on office side (ºC).

B = thickness of the wall (m).

1st determine conductivity value for the wall;

k = ((0.2×0.7)+(2×0.015×0.93)) / (0.015+0.2+0.015)W/mºC.

k = ((0.14)+(0.0279)) / 0.23 W/mºC.

conductivity of wall (k) = 0.73 W/mºC. (1)

Q = (0.73 x (4 x 2) x (115 – 55)) / 0.23

Q = (0.73 x 8 x 60) / 0.23

rate of heat conducted through wall (Q) = 1523.5 W (1)

2.1.2. The convective heat transfer co-efficient for the wall.

q = hcA (t_1 – t_2). (1)

where;

q = convective heat transfer rate (W).

hc = convective heat transfer coefficient (W/m²).

A = contact surface area (m²).

t_1 = temperature of hotter body (ºC).

t_2 = temperature of hotter body (ºC).

Assume all heat conducted through wall is convected into adjacent air.

q = Q (a – above) = 1523.5 W. (1)

hc = q / A (t_1 – t_2).

hc = 1523.5 / (4 x 2) x (55 – 26.5). (1)

hc = 1523.5 / (8 x 28.5).

convective heat transfer coefficient (hc) = 6.682 W/m². (1)

2.1.3. How much radiated heat does the clerk receive.

q = 5,67 x 10-8 A_1F_{ev} (T_1^4 - T_2^4) (1)

where;

q = radiative heat transfer rate (W).

A_1 = exposed area of smaller body (m²).

F_{ev} = emissivity and view factor.

T_1 = absolute temperature of hotter body (K).

T_1 = (273.15 + 55) = 328.15 K. (½)

T_2 = absolute temperature of cooler body (K).

T_2 = (273.15 + 28) = 301.15 K. (½)

q = 5,67 x 10^{-8} x 0.8 x 0.95 x (328.15^4 – 301.15^4).

q = 5,67 x 10^{-8} x 0.8 x 0.95 x 3.371 x 10^9.

radiated heat received by clerk (q) = 145 W. (1)

2.2. It takes a natural gas burner 30 minutes to heat 10kg of ice to water at 50˚C. If the calorific heat value of the natural gas is 38.302GJ/m^3 Assuming all the heat produced by the gas burner is used to heat the ice / water, calculate the volumetric flow rate, in cubic centimeters per minute(cm^3/min) of the natural gas to the gas burner. (5)

Latent heat of fusion for ice = 335 kJ/kg

To heat 10 kg of ice (at 0˚C) to 10 kg water (at 0˚C) = 10 x 335 kJ/kg = 3350 kJ (1)

To heat 10 kg of water from 0°C to 50˚C = 10 x 4.187 x (50 – 0) = 2093.5 kJ (1)

Total heat required to heat 10 kg ice (at 0˚C) to 10 kg water (at 50˚C) = 5443.5 kJ If 1m^3 of natural gas has a calorific heat content of 38.302 GJ (38.302 x 10^6kJ) (1)

Calculate amount of gas required to heat 10 kg ice (at 0˚C) to 10 kg water (at 50˚C)

Amount gas required = (5443.5 / 38.302 x 10^6) m^3

Amount gas required = 0.000142 m^3

Amount gas required = 142.121 cm^3 (1)

This heating process occurs over 30 minutes, therefore volumetric flow rate required

= 142.121 / 30

Volumetric flow rate of natural gas required = 142.121 cm^3/min (for 30 minutes) (1)

2.3. An underground load-haul-dump (LHD) vehicle consumes 0.3 litres of diesel fuel per rated kW per hour. The calorific heat content of the fuel is 38MJ/l. (5)

2.3.1. Determine the average heat output of this vehicle (kW/per rated kW).

q = Fuel consumption rate (L/kW/hour) x Calorific value) / hour (1)

q = (0.3 x 38 x 1000) / 3600

Heat production rate (per rated kW) per hour (q) = 3.1667kW (1)

2.3.2. How would the heat output of a similarly sized electric LHD compare to the unit above (question 2.3.1.).

Assume a typical overall efficiency of 95% for the electric LHD, (1)

so it would have a heat output of [1 x 100/95] kW = 1.05 kW (per rated kW) at full power. (1)

Therefore it could be seen that when both LHD's operate under full power, the electric LHD would release 3 times less heat than that of the diesel driven LHD. (1)

Total Marks: (20)

QUESTION 3 **(Psychrometry)**

3.1. An air / water vapour mixture has the following properties:

Wet bulb temperature: 27.5°C

Dry bulb temperature: 32.5°C

Barometric pressure: 110kPa

Using first principles, calculate the following barometric properties:

3.1.1. Vapour pressure (pw) (2)

First calculate saturated vapour pressure (SVP)

SVP = 0.6105exp ((17.27 x Twb) / (237.3 + Twb))

Where: Twb = wet bulb temperature = 27.5˚C

= 0.6105exp ((17.27 x 27.5) / (237.3 + 27.5)) kPa

= 0.6105exp (1.7911) kPa

SVP = 3.661 kPa (1)

(pw) = SVP – A x p(Tdb – Twb) kPa

Where A = Psychrometric constant = 0.000644˚C

Twb = wet bulb temperature = 27.5˚C

Tdb = dry bulb temperature = 32.5˚C

p = barometric pressure = 110kPa

= 3.661 – ((0.000644 x 110) x (32.5 – 27.5)) kPa

= 3.661 – (0.0708 x 5) kPa

= (3.661 – 0.354) kPa

(pw) = 3.307kPa (1)

3.1.2. Dew point temperature (Tdp) (2)

Tdp = ((237.3x) / (17.27 – x)

Where x = ln ((pw) / 0.6105)

Where (pw) = 3.307 kPa

x = ln(3.307 / 0.6105)

x = ln 5.4169

x = 1.6895 (1)

Thus:

Tdp = ((237.3 x 1.6895) / (17.27 – 1.6895)

= 400.9184 / 15.5805

$T_{dp} = 25.73^\circ C$ (1)

3.1.3. Density (w) (2)

First calculate apparent specific volume (v)

v = 0.287 (273.15 + Twb) / (p - pw)

Where Twb = wet bulb temperature = 27.5˚C

p = barometric pressure = 110kPa

pw = vapour pressure = 3.307kPa

$v = 0.287 (273.15 + 27.5) / (110 - 3.307) m^3/kg$

$= 0.287 (300.65) / (106.693) m^3/kg$

$= 0.287 (2.8179) m^3/kg$

$v = 0.8087\ m^3/kg$ (1)

Then calculate apparent specific humidity (ASH):

ASH = 0.622 pw / (p - pw)kg/kg

Where p = barometric pressure = 110kPa

pw = vapour pressure = 3.307kPa

ASH = (0.622 x 3.307) / (110 – 3.307)kg/kg

= (2.0570) / (106.693)kg/kg

ASH = 0.0193kg/kg

$w = ((1 + ASH) / v) kg/m^3$

$= ((1 + 0.0193) / 0.8087) kg/m^3$

$w = 1.2538\ kg/m^3$ (1)

3.1.4. Sigma energy (S) (4)

S = cpatdb + ASH (cpv(tdb – twb) + LH)

Where cpa = specific heat content – dry air = 1.005kJ/kg˚C

cpv = specific heat content – water vapour = 1.884 kJ/kg˚C (1)

ASH = apparent specific humidity = 0.0193kg/kg

tdb = dry bulb temperature = 32.5˚C

twb = wet bulb temperature = 27.5˚C

LH = latent heat of vaporisation of water (must be determined)

LH = (2501 – 0.00259twb) kJ/kg (1)

Where

twb = wet bulb temperature = 27.5˚C

LH = (2501 – (0.00259 x 27.5)) kJ/kg

LH = 2500.9288 kJ/kg (1)

Thus

S = (1.005 x 32.5) + 0.0193 (1.884(32.5 – 27.5) + 2500.9288)

= (32.6625) + 0.0193 (9.42 + 2500.9288)

= (32.6625 + 48.4497)kJ/kg

S = 79.937kJ/kg (1)

3.2. 70 m^3/s of air at a temperature of 27.5/31˚C enters a stoping section at a barometric pressure of 115 kPa. If the maximum allowable wet-bulb temperature in the stopes is 29.5˚C, determine the heat absorption capacity of the air. (8)

From the 115 kPa chart, conditions at inlet to the stopes are:

S = 77.5kJ/kg (1)

V = 0.784m^3/kg (1)

Mass flow of air, M = Q/v (1)

=70/0.784

= 89.3kg/s (1)

On the same Chart, the maximum allowable sigma heat content @ 29.5˚C wb

S = 86kJ/kg (1)

The air can absorb (86– 77.5) kJ/kg

= 8.5kJ/kg (1)

Heat absorption capacity,

q = M C delta S (1)

= 89.3 x 8.5

=759 kW of heat (1)

3.3. 49m^3/s of air at a temperature of 24.5/27.5˚C is mixed with 24.7m^3/s of air at a temperature of 32/33.5˚C. The barometric pressure is 115kPa. Determine the temperature of the mixture. (17)

Using the 115 kPa chart

	Airstream A (49m^3/s)	Airstream B (24.7m^3/s)
wb/db ˚C	24.5/27.5	32/33.5
s (kJ/kg)	66 (½)	97 (½)
r (g/kg)	16 (½)	26.5 (½)
v (m^3/kg)	0.78 (½)	0.812 (½)
Q (m/s)	49 (½)	24.7 (½)
M (Q/v)	62.82 (½)	30.42 (½)

Sc = (MA x SA) + (MB x SB) / (MA + MB) (1)

= (62.82 x 66) + (30.42 x 97) / (62.8 + 30.42) (1)

=(4146.12) + (2950.74) / (93.22)

= 76.1kJ/kg (1)

rc = (MA x rA) + (MB x rB) / (MA + MB) (1)

= (62.82 x 16) + (30.42 +x26.5) / (62.82 + 30.42) (1)

= (1005.12) + (806.13) / (93.22)

= 19.4g/kg (1)

Now from the 115 kPa chart, where the line corresponding to a sigma heat content of 76.1kJ/kg cuts the 19.4g/kg moisture content line, read off the temperature of the mixture:

= 27.2/28˚C (1)

Alternative method

Total mass flow = (62.82 + 30.42)

= 93.24kg/s (1)

A's proportion of total mass = 62.28/93.24

= 0.67 (1)

B's proportion of total mass = 30.42/93.24

= 33 (1)

C Lies (1 – 0.67) x length AB from A

Or C lies (1 – 0.33) x length AB from B

Length A – B = 41mm (1)

C lies (1 – 0.67) x 41 from A

= (0.33 x 41) from A

= 13.53mm from A (1)

C lies (1 – 0.33) x 41 from B

= (0.67 x 41) from B

= 27.47mm from B (1)

By measuring 11.22mm from A or 22.8 from B, point C can now be plotted on the chart and the temperature read off = 27.2/28˚C (1)

Total Marks: (35)

QUESTION 4 (Refregiration)

4.1 The following measurements were taken at a surface refrigeration plant (using refrigerant R134A).

Barometric Pressure in plant room = 85kPa
Evaporating pressure = 202kPa (guage)
Compressor outlet temperature = 50°C
Condensing pressure = guage is faulty
Condensing temperature = 29.0°C
Condenser water flow rate = 270 l/s
Condenser inlet water temperature = 22.0°C
Condenser outlet water temperature = 27.5°C

NB: The attached pressure enthalpy chart (R134A) will be required to answer the following questions.
On this chart, clearly indicate all points plotted to obtain your answer; remember to submit this chart with your answer book(s).

4.1.1. Plot the refrigeration cycle on this ph chart, indicating the main components of the cycle, briefly describe what happens to the refrigerant at each component of the cycle. (6)

From this pressure enthalpy chart calculate the following: (14)

4.1.2. Carnot COP of this refrigeration plant.

Carnot COP = $T_{(evap)} / (T_{(cond)} - T_{(evap)})$

Where;

$T_{(evap)}$ = evaporating temperature (°K); From chart = (-1 + 273) °K = 272°K

$T^{(evap)}$ = condensing temperature (°K);From chart = (29 + 273) °K = 302°K

Carnot COP = 272 / (302 - 272)

Carnot COP = 272 / 30

Carnot COP = 9.1 (1)

4.1.3. The cycle COP of this refrigeration plant.

Cycle COP = heat exchange in evaporator / compressor input energy

Cycle COP = change in enthalpy in evaporator / change in enthalpy over compressor

Cycle COP = (398 - 239) / (438 - 398)

Cycle COP = 159 / 40

Cycle COP = 4.0 (1)

4.1.4. The cycle efficiency of this refrigeration plant.

Cycle efficiency = Cycle COP / Carnot COP

Cycle efficiency = 4.0 / 9.1

Cycle efficiency = 0.44 (or 44%) (1)

4.1.5. The compressor efficiency of this refrigeration plant.

Compressor efficiency = ideal work of compression / actual work of compression

Compressor efficiency = (418 – 398) / (438 – 398)

Compressor efficiency = 20 / 40

Compressor efficiency = 0.5 or 50% (1)

4.1.6. The percentage (%) flash gas in the evaporator of this refrigeration plant.

% flash gas = (239 – 199) / (398 – 239) x 100

% flash gas = 40 / 159 x 100

% flash gas = 25.2 % (1)

4.1.7. The cycle PCR of this refrigeration plant.

Cycle PCR = actual work of compression / heat exchange in evaporator

Cycle PCR = (438 – 398) / (398 – 239)

Cycle PCR = 40 / 159

Cycle PCR = 0.252 (1)

4.1.8. The mass flow rate of the refrigerant in circulation in this refrigeration plant.

The following information relevant to the condenser was given;

Condenser water flow rate = 270 l/s, Condenser inlet water temperature = 22.0˚C and Condenser outlet water temperature = 27.5˚C

First calculate duty of condenser

q = m x cp x dt

Where;

q = duty of condenser (kW)

m = mass flow of water through condenser (kg/s)

dt = increase in water temperature over condenser (˚C)

q = 270 x 4.187 x (27.5 – 22)

q = 270 x 4.187 x 5.5

q = 6218 kW (1)

Mass flow of refrigerant mR = duty of condenser / change in enthalpy over condenser

mR = 6218 / (438 - 239)

mR = 6218 / 199

mR = 31.25 kg/s (1)

4.1.9. The volumetric flow rate of refrigerant entering the compressor of this refrigeration plant.

From pressure / enthalpy chart, density of the refrigerant entering compressor is

13.7 kg/m^3. (1)

Volumetric flow of refrigerant = mass flow of refrigerant / density of refrigerant

Volumetric flow of refrigerant = 31.25 / 13.7

Volumetric flow of refrigerant = 2.28 m^3/s (1)

4.1.10. The volumetric flow rate of refrigerant leaving the compressor of this refrigeration plant.

From pressure / enthalpy chart, density of the refrigerant entering compressor is

32 kg/m^3. (1)

Volumetric flow of refrigerant = mass flow of refrigerant / density of refrigerant

Volumetric flow of refrigerant = 31.25 / 32

Volumetric flow of refrigerant = 0.97 m^3/s (1)

4.1.11. The plant duty of this refrigeration plant.

Plant duty = evaporator duty

Evaporator duty = heat exchange in evaporator (kJ/kg) x mass flow of refrigerant (kg/s)

Evaporator duty = (398 -239) x 31.25

Evaporator duty = 159 x 31.25

Evaporator duty = 4969 kW (1)

4.1.12. The power consumed by the compressor of this refrigeration plant.

Power consumed by compressor = heat exchange across compressor x mass flow of refrigerant

Power consumed by compressor = (438 – 398) x 31.25

Power consumed by compressor = 40 x 31.25 power consumed by compressor

= 1250 kW (1)

Total Marks: (20)

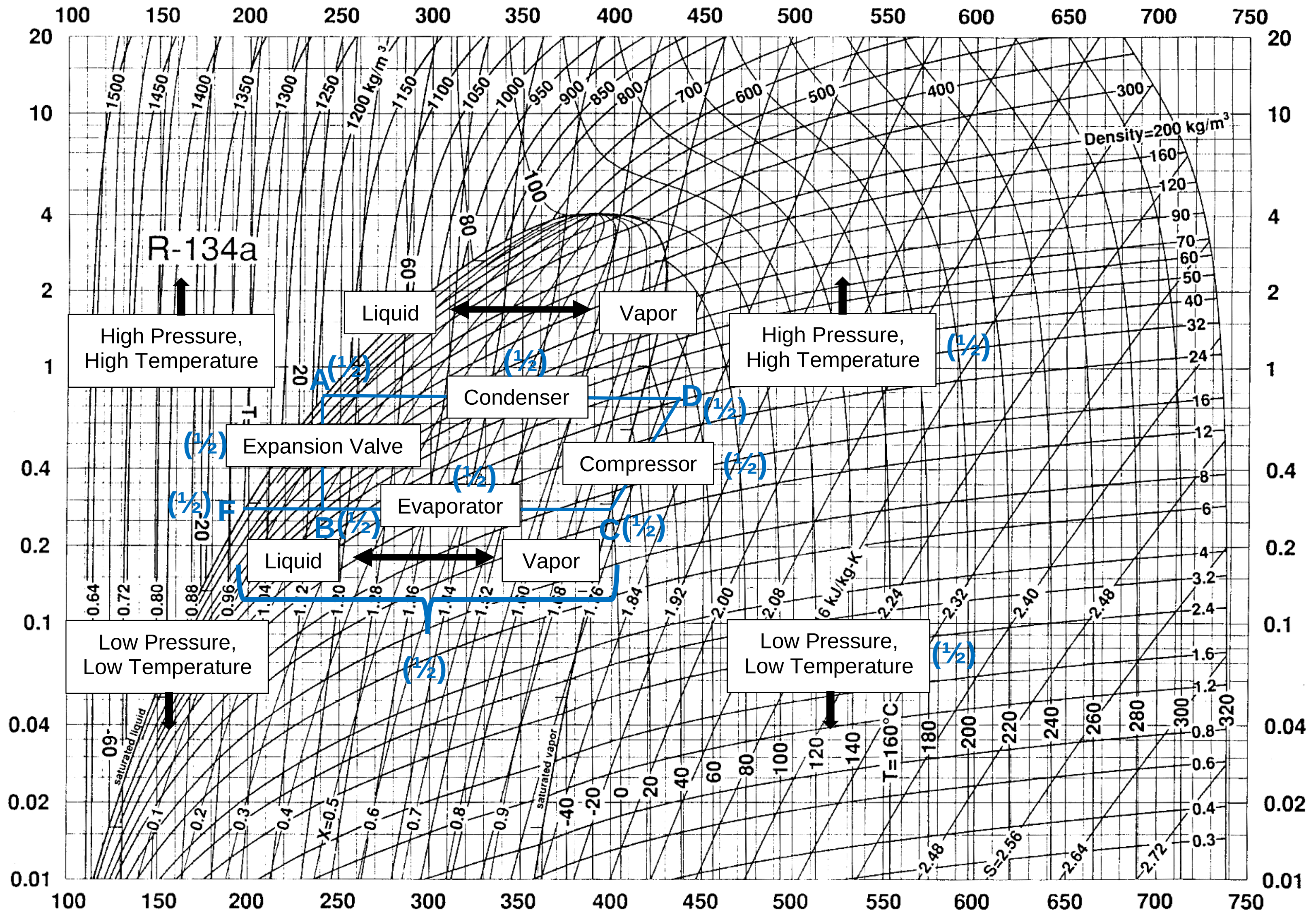
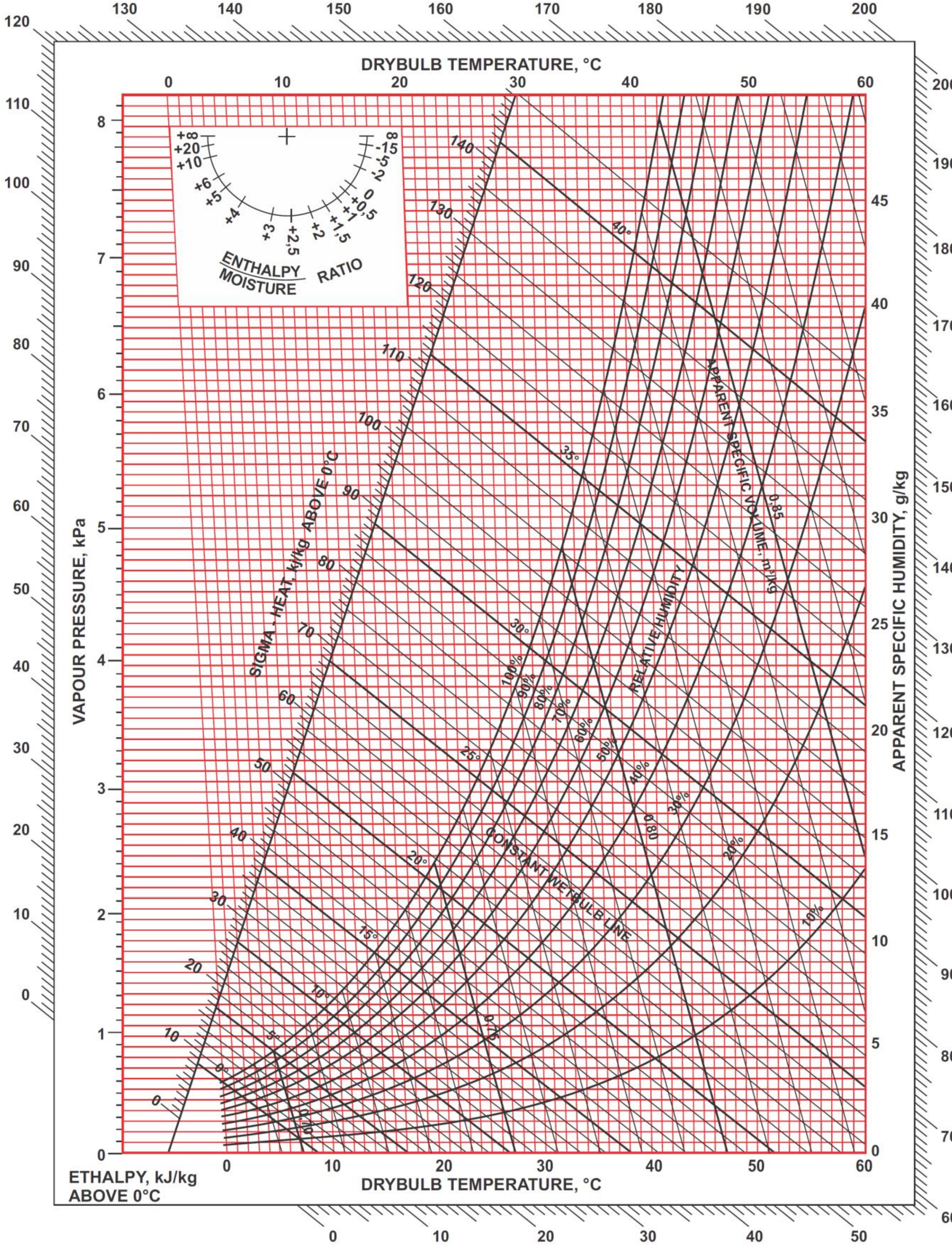


Figure 5. Pressure-Enthalpy Diagram for Refrigerant 134a

PSYCHROMETRIC CHART
115,0 kPa



A.W.T.B.

CHART NO 16
115,0 kPa