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: **08 May 2019** TIME: **<u>14:30 – 17:30 (3½ HOURS)</u>**	EXAMINER**: Marthinus v/d Bank** MODERATOR: **Marco Biffi** TOTAL MARKS: **[100]** PASS MARK: **(60%)**

NUMBER OF PAGES: **19**

SPECIAL REQUIREMENTS:

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

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

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

3. Show all calculations and **<u>check calculations on which the answers are based</u>**.
4. Hand-held electronic calculators may be used for calculations.
5. Write **<u>legibly</u>** in ink on the **<u>right hand page</u>** only – **<u>left hand pages will not be marked</u>**.
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.

<u>NB</u>: 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 **<u>NOT</u>** allowed in the examination room. **<u>Only Calculator</u>**
10. **<u>The following charts to be included: PH Diagram 134a; Psychrometric charts: 85.0kPa, 95.0kPa, 97.5kPa, 100.0kPa, 105.0kPa and 115kPa.</u>**

QUESTION 1.

1.1 The heat production in a stope is 2kW/m of face when the entering stope wet-bulb temperature is 26ºC. Air enters the stope at 26/29ºC.

Assume that the wet-bulb temperature in the stope is 1ºC lower than the temperature of the air leaving the stope. It is considered essential that a wet-kata of 12 is to be maintained at the mean stope face wet-bulb temperature.

It has been determined empirically that the mean stope face velocity can be expressed as:

$V = 0,2 \times \sqrt{Q}$

where V = mean stope face velocity (m/s)

Q = quantity entering the stope (m^3/s)

Consider stope quantities between 10 and 20 m^3/s and determine what is the minimum quantity of air that should be supplied to the stope to meet the conditions required without refrigeration, if the stope face length is 150 m. Assume that the difference between the ventilated and unventilated wet-bulb is insignificant. Barometric pressure is 100 kPa.

In your calculations you have to write the Sigma heat gain in the stope in terms of a Q value. (**Hint**: You have to eventually draw a graph of the Wet kata versus various entering quantities, to be able to read off the actual quantity required, graph paper attached).

The following formulas for Ø and wet-kata to be used (V the velocity):

Ø = 36,5ºC - twb
Kata = 0,7 Ø + Ø √V (15)

Answer:

Heat production in the stope face	=	2 kW/m x length of face
	=	2 x 150
	=	300 kW ✓✓

From the psychrometric chart the following conditions of the air can be read off:

Sigma heat of air into stope	=	78,8 kJ/kg
Specific volume of air (<)	=	0,896 m^3/kg ✓✓

The Sigma heat of the air leaving the stope can be expressed as follows:

$$\text{Sao} = \frac{\text{heat in stope(kW)}}{\text{mass flow of air(kg/s)}} + \text{Saoi}$$

But m $= \frac{Q}{v}$ ✓✓

therefore
$$\text{Sao} = \frac{300 \text{ x v air into stope}}{\text{Q air into stope}} + \text{Saoi}$$

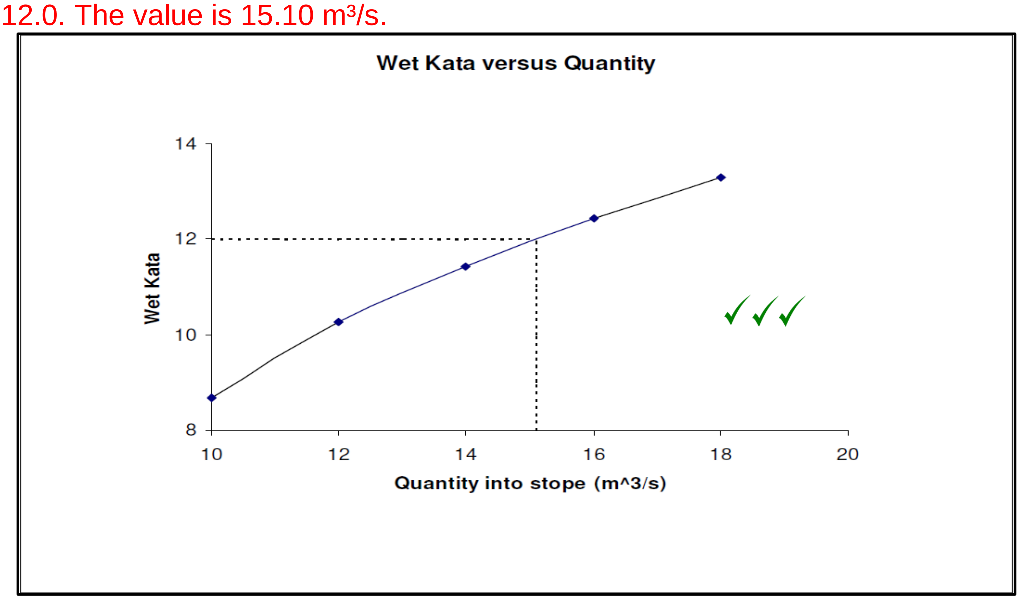
$$= \frac{300 \times 0.896}{Q \text{ air into stope}} + 78.8$$ ✓✓✓

$$= \frac{268.8}{Q} + 78.8 \text{kJ/kg}$$

This formula can now be used to determine the Sigma heat of the air out of the stope for different quantities of air flowing into the stope. It is also known that the if we have the Sigma heat content of the air that it is a direct indication of the wet-bulb temperature for that specific heat content and can the Sigma heat of the air (with the barometric pressure known), be read off from a psychrometric chart.
The wet-bulb temperature of the air in the stope is also given as 1ºC less than the exit temperature, which means that the in-stope temperatures for different Q values can be established and the Kata values be calculated. The results for different values of Q can be tabulated as follows:

Q into stope m³/s	**Sout kJ/kg**	**twb out °C from chart**	**twb in stope 1°C less in stope**	**36.5-twb °C**	**V m/s**	**Kata** ✓✓✓
10	105.7	31.7	30.7	5.8	0.63	8.7
12	101.2	30.8	29.8	6.7	0.69	10.3
14	98.0	30.2	29.2	7.3	0.75	11.4
16	95.6	29.7	28.7	7.8	0.80	12.4
18	93.7	29.3	28.3	8.2	0.85	13.3

Plot the above values for Kata versus Q on a graph and read off the value for Q needed for a Kata of 12.0. The value is 15.10 m³/s.



1.2 Give brief explanation for the following terms:

- Dry-bulb Temperature

  ✓ Is the temperature indicated by a conventional dry-bulb thermometer and is a degree of the sensible heat content of the air.

- Wet-Bulb Temperature

  ✓ Is the temperature as indicated by a thermometer with the bulb covered with a wet muslin or cotton wick exposed to an air current of more than 3 m/s and shielded from radiation greater than the dry-bulb temperature.

- Dew-point temperature

  ✓ Is the temperature at which condensation of water takes place. The saturation vapour pressure equals the actual vapour pressure at this temperature.

- Super Heat

  ✓ Is the heat which raises the temperature of a gas vapour above its saturation temperature at the existing pressure.

- Enthalpy

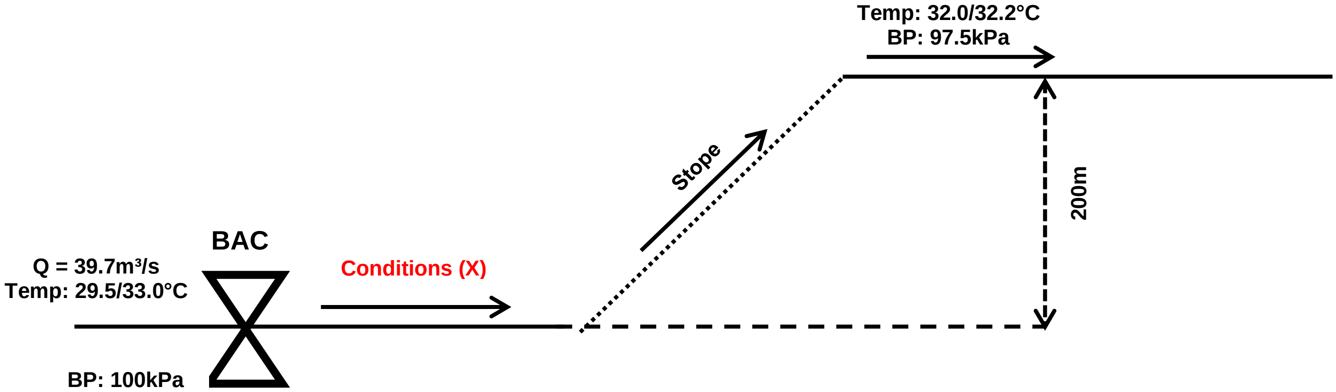
  ✓ Enthalpy or total heat is the sum of the sensible heat latent heat and super heat of an air-water vapour mixture calculated above an arbitrary datum. This datum is 0°C. The units of enthalpy or total heat is (kJ/kg)

(5)

(20)

QUESTION 2.

2.1



The above sketch shows various measurements made in a section of a mine.
Determine:

2.1.1 The duty of the bulk cooling installation
2.1.2 The amount of water condensed in the bulk cooling installation
2.1.3 The heat sources in the stope
2.1.4 The amount of water evaporated into the air in the stope

NOTE: Air conditions (X) at outlet from the bulk air cooler are:
BP: 100kPa; Temp: 25.0/25.0ºC (15)

Answer:

2.1.1 From the 100 kPa psychrometric chart, at 29.55/33.0ºC

S = 90.0 kJ/kg ✓
v = 0.917m3/kg ✓
r = 25.5g/kg ✓

Mass flow of dry air M = $\frac{Q}{v}$
= $\frac{39.7\text{m}^3/\text{s}}{0.917\text{kg/m3}}$
= 43.3kg/s ✓

From the 100 kPa psychrometric chart, at 25.0/25.0ºC
S = 74.7 kJ/kg ✓
r = 20.4g/kg ✓
Change in sigma heat content
ΔS = (90.0 -74.4)kJ/kg
= 15.6 kJ/kg ✓
Heat transferred
q = M x ΔS
= 43.3 x 15.6
= 675.38kW ✓

2.1.2 Amount of water condensed from the air in the bulk cooling installation

Δr = 25.5 – 20.4
= 5.1 g/kg
R = M x Δr
= 43.3 x 5.1
= 220.83g/s
220.83/1000
= 0.220 l/s of water ✓

2.1.3 S = 74.7 kJ/kg
M = 43.3 kg/s
q = M x ΔS
= 43.3 x (109.0 – 74.7)
= 1485.19kW ✓

Due to the air that has up-casted through the stope, it has undergone cooling due to auto-decompression.

q = 0.979 x 200/100 x 43.3
= 63.58 kW
Heat sources in the stope = 1485.19+63.58
= 1549kW ✓✓

2.1.4 From the sketch r at outlet of stope is 31.7 g/kg ✓
R = *M x Δr*
= *43.3 x (31.7 – 20.4)*
= *489.29g/s or 0.489l/s* ✓✓

2.2 The following measurements were taken at an underground booster fan inlet:

Intake air volume	236 m³/s
Fan pressure	5.0 kPa
Temperature	24.0/27.0ºC
Barometric pressure	115 kPa
Power input to fan motor	1 775 kW
Motor efficiency	95%

2.2.1 Determine the conditions at the fan discharge (10)

Answer:

From the 115 kPa psychrometric chart, the characteristics of the air:

The specific volume of the air in main airway	=	0,762 m^3/kg
The quantity of air in the main airway	=	236 m^3/s ✓✓
Sigma heat of the air entering fan	=	64,5 kJ/kg
Apparent specific humidity of air entering fan	=	15,3 g/kg

Mass flow of dry air M = $\frac{Q}{v}$

= $\frac{236}{0.762}$

= 310kg/s ✓✓

The increase in heat of the air, per kg of mass flow of air, can be determined as follows:

Unit increase in heat = $\frac{kW}{m}$

= $\frac{1775}{310}$

= 5.73 kJ/kg ✓✓

Sigma heat of air leaving fan (Sout) = Sin + S

= (64.5 + 5.73)

= 70.2 kJ/kg ✓✓

The barometric pressure fan outlet = 115 + 5

= 120 kPa

The temperature of the air can be read off the 120 kPa psychrometric chart, Sigma heat of 70,2 kJ/kg and assuming the specific humidity remains constant (*note, 120 kPa not the 115 kPa, a common mistake made by students*) ✓✓

Temperature of the air leaving the fan is 26,0/32,2ºC

2.2.2 What are the efficiency and overall efficiency of the fan (5)

Answer:

Fan air power = pQ

= 5 x 236 ✓

= 1 180 kW

Fan motor input power = 1 775 kW (given)

Fan input power = fan motor input power x motor efficiency

= 1 775 x 0,95

= 1 686 kW

Fan Efficiency = $\frac{\text{air power}}{\text{fan motor input power}}$ x 100%

= $\frac{1180}{1686}$ x 100%

= 70% ✓✓

The fan efficiency can now be determined as follows:

The fan overall efficiency can now be determined as follows:

Fan Overall Efficiency = $\frac{\text{air power}}{\text{fan motor input power}}$ x 100%

= $\underline{1180}$ x 100%

$$= \frac{}{1775} \quad 66\%$$

1775
= 66% ✓✓

(30)

QUESTION 3.

3.1 The following measurements were taken at a condenser cooling tower:

Quantity entering tower	230 m^3/s
Air temperature entering	31.5/32.0ºC
Air temperature leaving	38.0ºC saturated
Water temperature entering	47.0ºC
Water temperature leaving	40.0ºC
Barometric pressure	105 kPa

Assume heat added to air is hear removed from water.

Determine:

3.1.1 Total heat added to the air
3.1.2 The water flow rate through the tower
3.1.3 Has water evaporated or condensed
3.1.4 How much water has evaporated or condensed in litres per day.

Answer:

Psychrometric conditions:

Intake: Quantity = 230 m^3/s
Temperature = 31.5/32.0ºC
Sigma heat = 100.8 kJ/kg ✓✓✓✓
Moisture = 28.2 g/kg
AS Volume = 0.874 m^3/kg
Mass flow = $\frac{230}{0.874}$
= 263.16 kg/s

Return: Quantity = 230 m^3/s
Temperature = 38.0/38.0ºC
Sigma heat = 139 kJ/kg ✓✓✓✓
Moisture = 42 g/kg
Mass flow = 263.16 kg/s

3.1.1 Sigma heat difference = 139 – 100.8
= 38.2 kJ/kg

Heat removed = 38.2 x 263.16
= 10052.6 kJ/s or kW ✓✓

3.1.2. Water flow rate :
Heat removed = $\frac{10052.6}{4.187 \times (47 - 40)}$ ✓✓

= 342.9 l/s ✓

3.1.3 Water evaporates into the air

3.1.4 Evaporation $= \frac{263.16 \times (42 - 28.2)}{1000}$

$= 3.63$ l/s ✓✓

or 24x 3600 x 3.63 = 313632 l/24 hours. (15)

3.2 Calculate the density of the dry air at 95 kPa and a temperature of 30.0ºC dry bulb using the ideal gas law
(5)

Answer:

$\frac{P\,V}{T} = R$ or $PV = RT$

$R = 0.2871$ kJ/kgK ✓

$= 30 + 273 = 303$ ✓

$V = \frac{R\,T}{P}$

$= \frac{0.2871 \times 303}{95}$

$= 0.9156\ m^3/kg$ ✓

$= \frac{1}{0.9156}$ ✓

$w = 1\,092\ kg/m^3$ ✓

(20)

QUESTION 4.

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

Barometric Pressure in plant room = 85kPa
Evaporator water flow rate = 98 l/s
Evaporator inlet water temperature = 18.8^{O}C
Evaporator outlet water temperature = 6.1^{O}C
Evaporating pressure = 202 kPa (gauge)
Condensing pressure = 661 kPa (gauge)
Condensing temperature = 29.0^{O}C
Evaporator inlet temperature = -1.0^{O}C
Compressor outlet temperature = 52.0^{O}C

NB: Attached chart 4 (ph 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 w answer book(s).

4.1.1 Plot the refrigeration cycle on this ph diagram, indicating the main components of the cycle. (10)
Briefly describe what happens to the refrigerant at each component of the cycle.

4.1.2 From the ph diagram, calculate the heat balance of this refrigeration plant. (10)

4.1.3 From the ph diagram, calculate the Carnot COP of this refrigeration plant. (2)

4.1.4 From the ph diagram, calculate the Cycle COP of this refrigeration plant. (2)

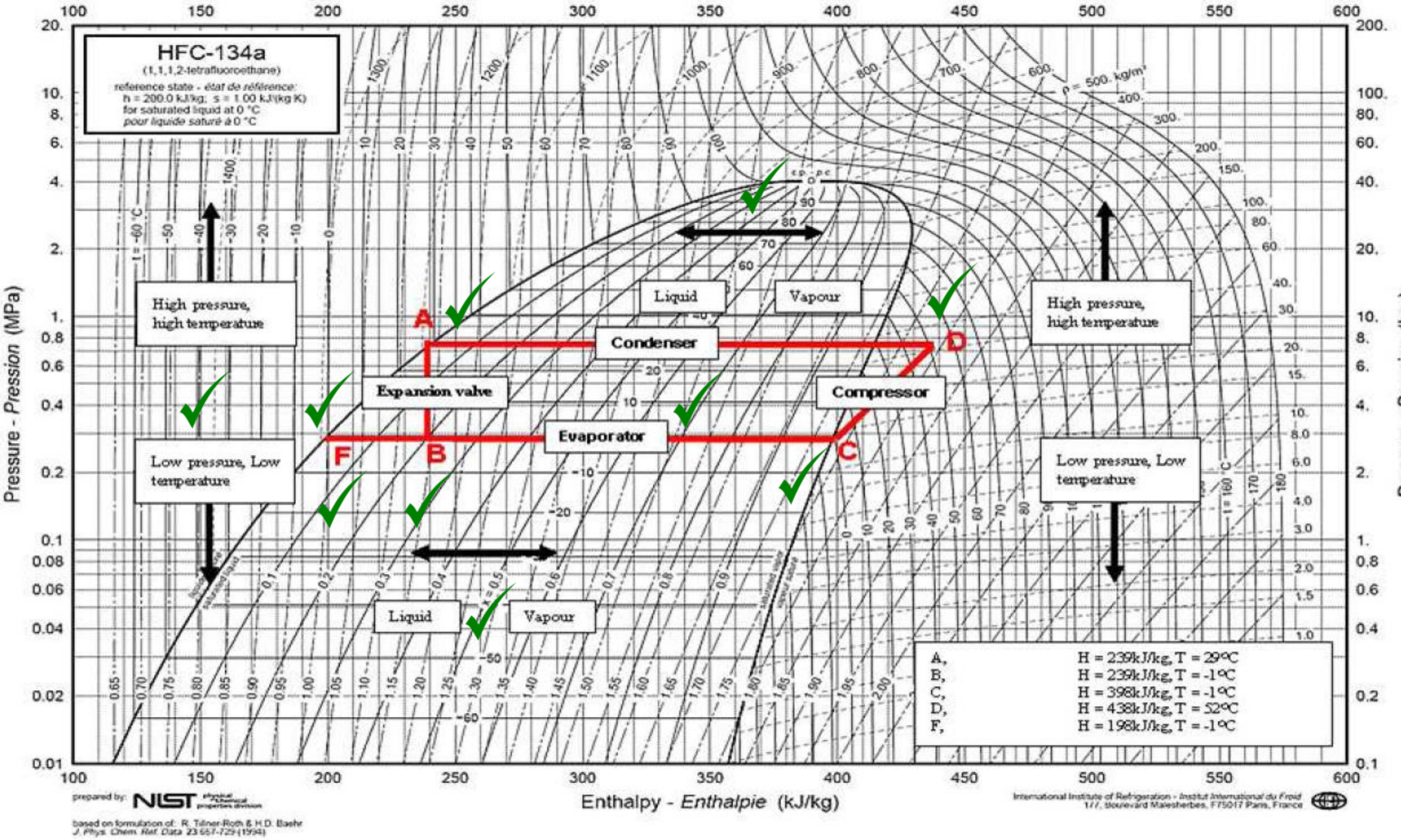
4.1.5 From the ph diagram, calculate the Cycle efficiency of this refrigeration plant. (2)

4.1.6 From the ph diagram, calculate the percentage (%) flash gas in the evaporator of this refrigeration plant. (2)

4.1.7 Briefly comment on the differences (if any) between your answers to 4.1.3 and 4.1.4 (2)

Answer:

Question 4.1.1



4.1.2
First we need to calculate the mass flow of refrigerant MR;
qevap. = duty of evaporator (kW)
qevap. = Mw x Cpw x (twi – two)

where;
Mw = mass flow of water through evaporator = 98 l/s
Cpw = thermal capacity of water = 4.187 kJ/kg OC
twi = temperature of water into evaporator = 18.8 OC ✓✓
two . = temperature of water out of evaporator = 6.1 OC
qevap. = 98 x 4.187 x (18.8 – 6.1)
qevap. = 5211 kW (duty of the evaporator)

From the ph diagram determine change in enthalpy (dH) across evaporator
dH = H(C) – H(B)

From ph diagram;
H(C) = 398 kJ/kg
H(B) = 239 kJ/kg
dH = 159 kJ/kg ✓✓
qevap. = MR x dH
(MR) = qevap. / dH
MR = 5211 / 159
MR = 32.8 kg/s (mass flow rate of refrigerant passing through evaporator)
qcond. = duty of condenser (kW)
From the ph diagram determine change in enthalpy (dH) across condenser
dH = H(D) – H(A)
from ph diagram;
H(D) = 438 kJ/kg
H(A) = 239 kJ/kg
dH = 199 kJ/kg ✓✓
qcond. = MR x dH
qcond. = 32.8 x 199
qcond. = 6527 kW (duty of condenser)
qcomp. = duty of compressor (kW)

From the ph diagram determine change in enthalpy (dH) across compressor
dH = H(D) – H(C)
From ph diagram;
H(D) = 438 kJ/kg
H(C) = 398 kJ/kg
dH = 40 kJ/kg ✓✓
qcomp. = MR x dH
qcomp. = 32.8 x 40
qcomp. = 1312 kW (duty of compressor)

Heat balance:
qcond. = qevap. + qcomp.
6527 kW = (5211 + 1312)kW

Plant heat balance, 6527 kW = 6523kW (less than 5% error, balance acceptable)

✓✓

4.1.3
Carnot COP = tabs.evap / (tabs.cond –tabs.evap)

where;
tabs.evap = absolute evaporating temperature = (– 1 + 273)OK = 272 OK
tabs. cond = absolute condensing temperature = (29 + 273)OK = 302 OK
COP = 272 / (302 – 272) ✓✓
Carnot COP = 9.1

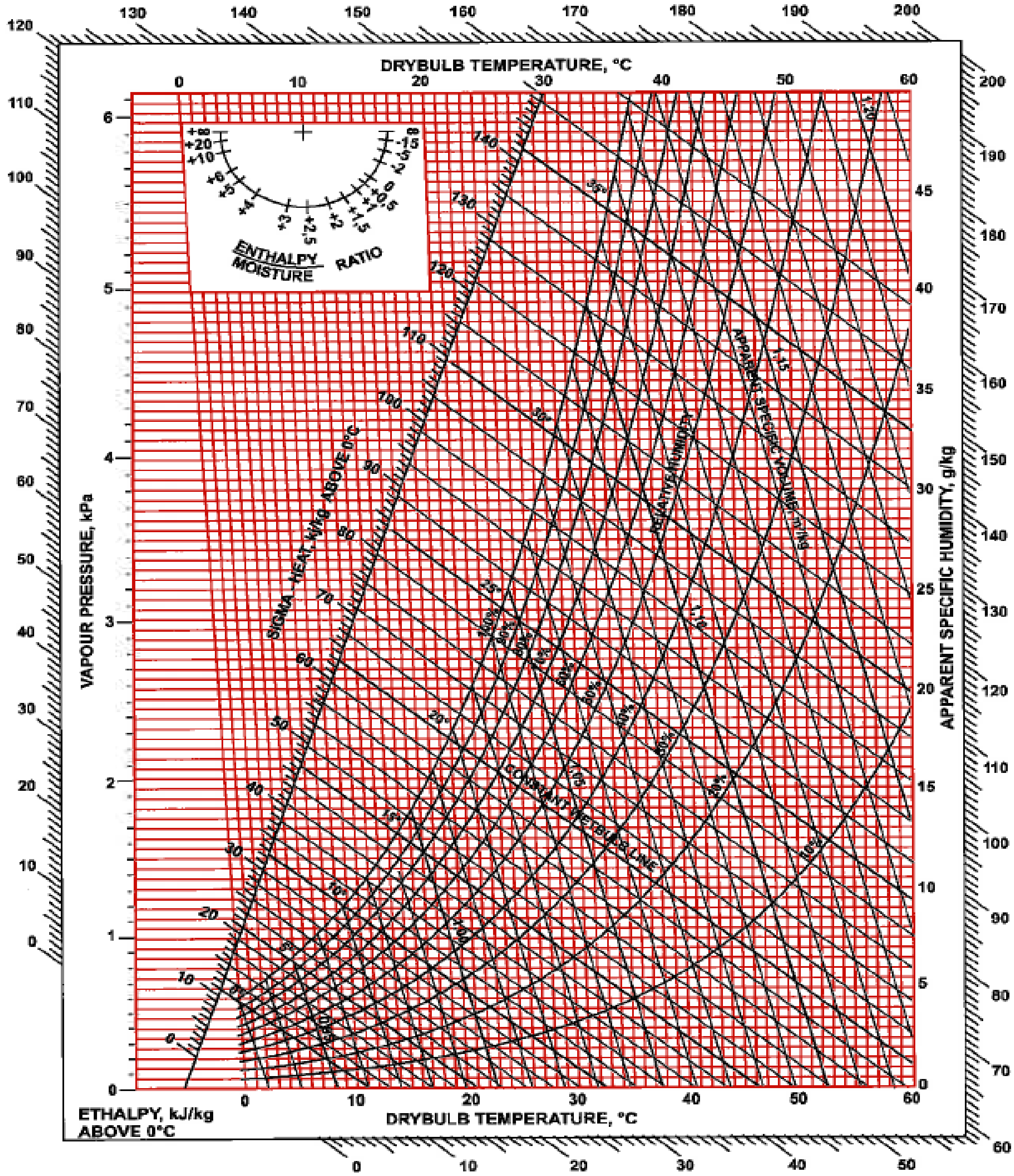
4.1.4
Cycle COP = qevap ./ ql comp
where;
qevap = evaporator duty (kW)
ql comp = compressor input energy (kW)
Cycle COP = (H(C) – H(B)) ./ (H(D) – H(C))
= (398 – 239) / (438 – 398)
= 159./ 40
Cycle COP = 4.0 ✓✓

4.1.5
Cycle efficiency = Cycle COP / Carnot COP
= 4.0 / 9.1
Cycle efficiency = 0.44 or 44 % ✓✓

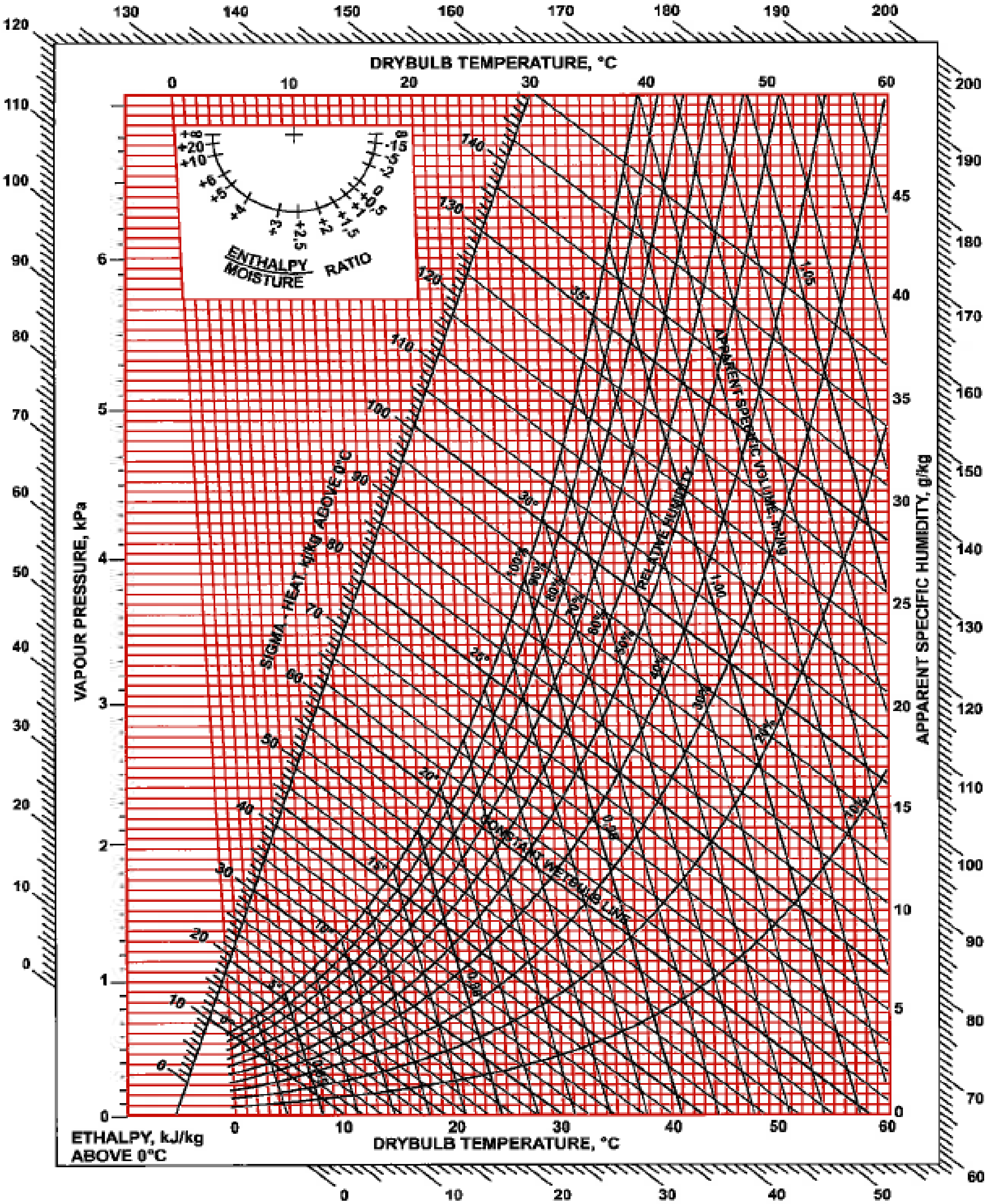
4.1.6
% flash gas = (H(B) – H(F))/ (H(C) – H(F))x100
= (239 – 198)/ (398 – 198) x100
= 41/ 200 x 100
flash gas = 20.5 % ✓✓

4.1.7
4.1.3 Represents the maximum possible COP for this refrigeration plant, 4.1.4 Represents the actual COP of the refrigeration plant – the difference indicates the actual inefficiencies of the plant. ✓✓

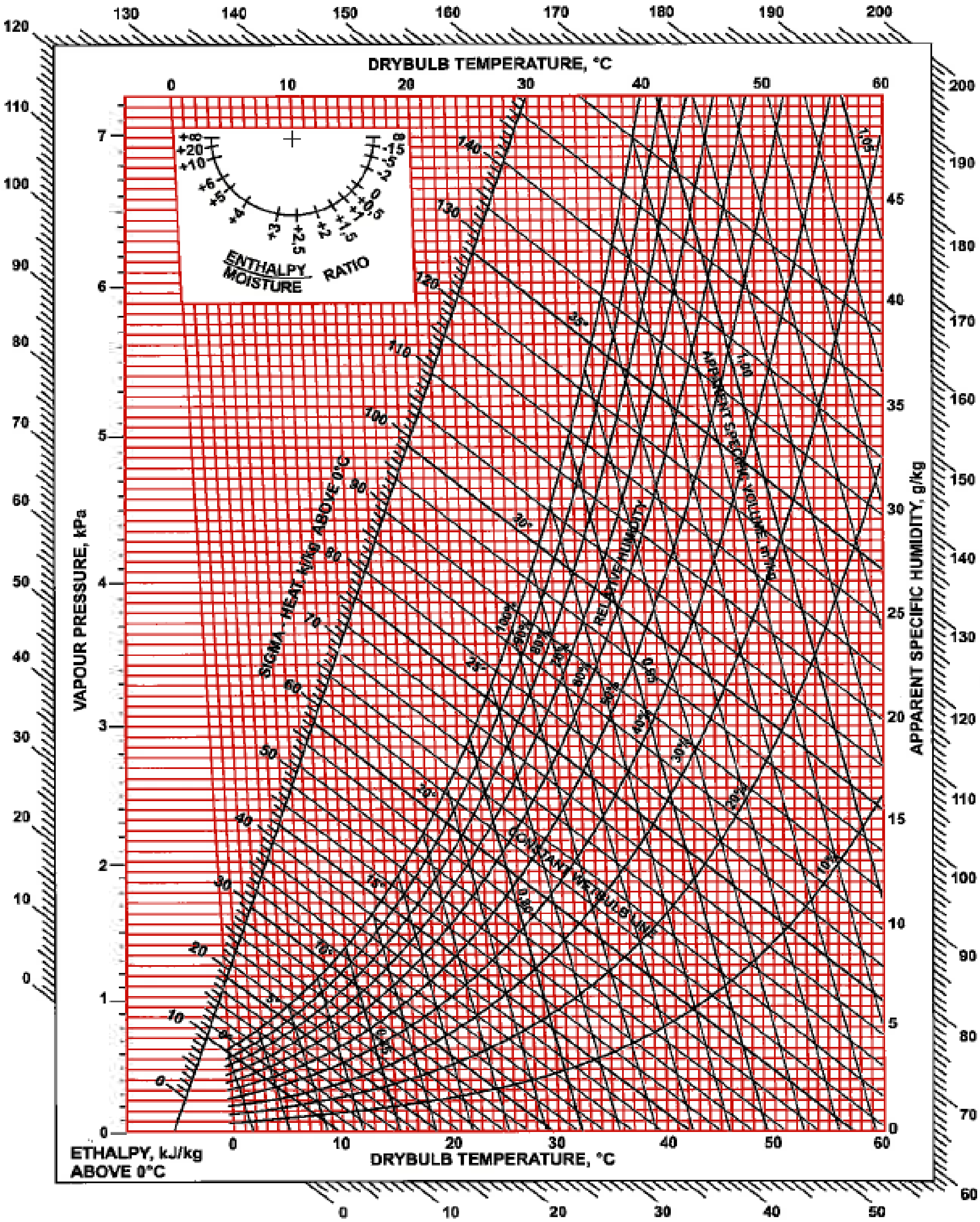
PSYCHROMETRIC CHART
85,0 kPa



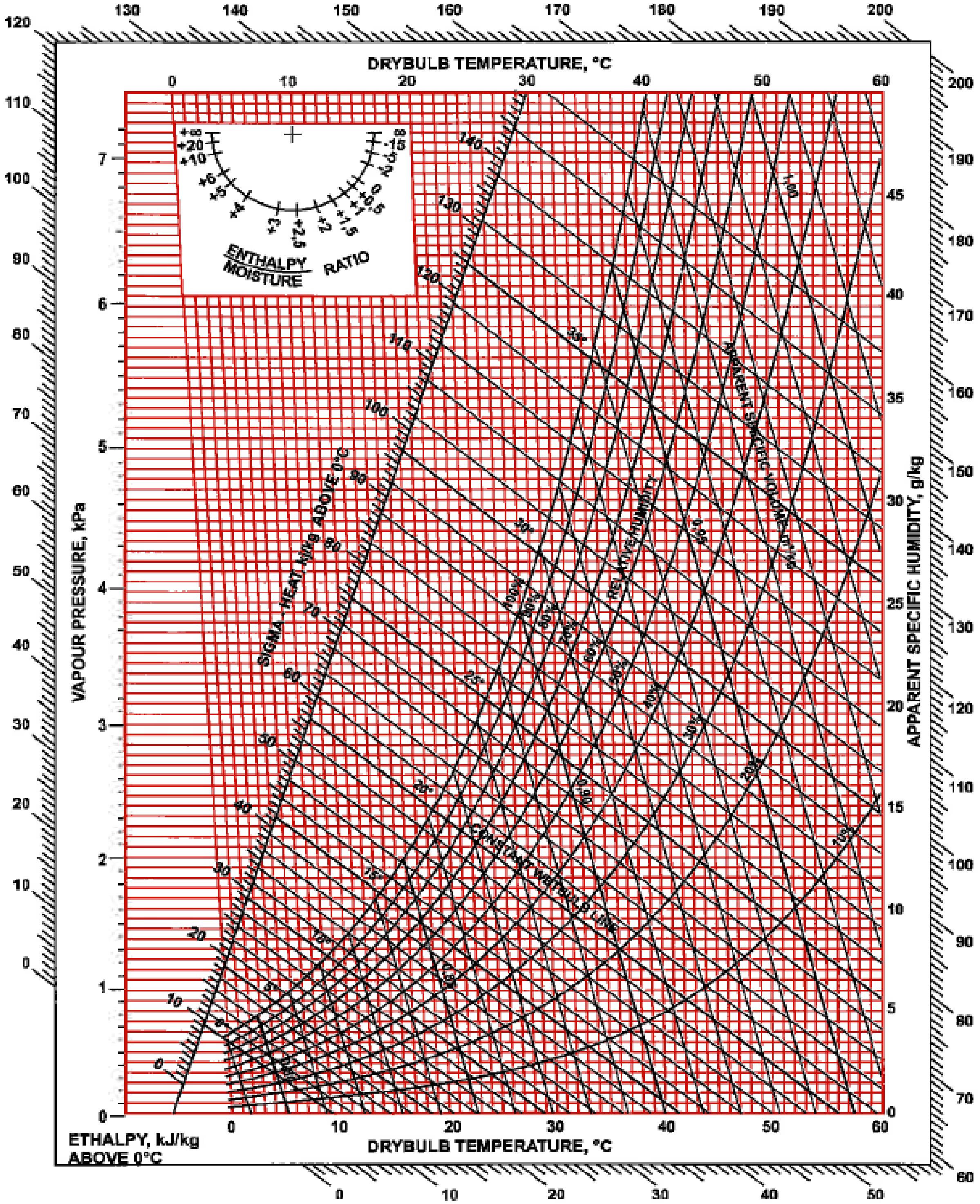
PSYCHROMETRIC CHART
95,0 kPa



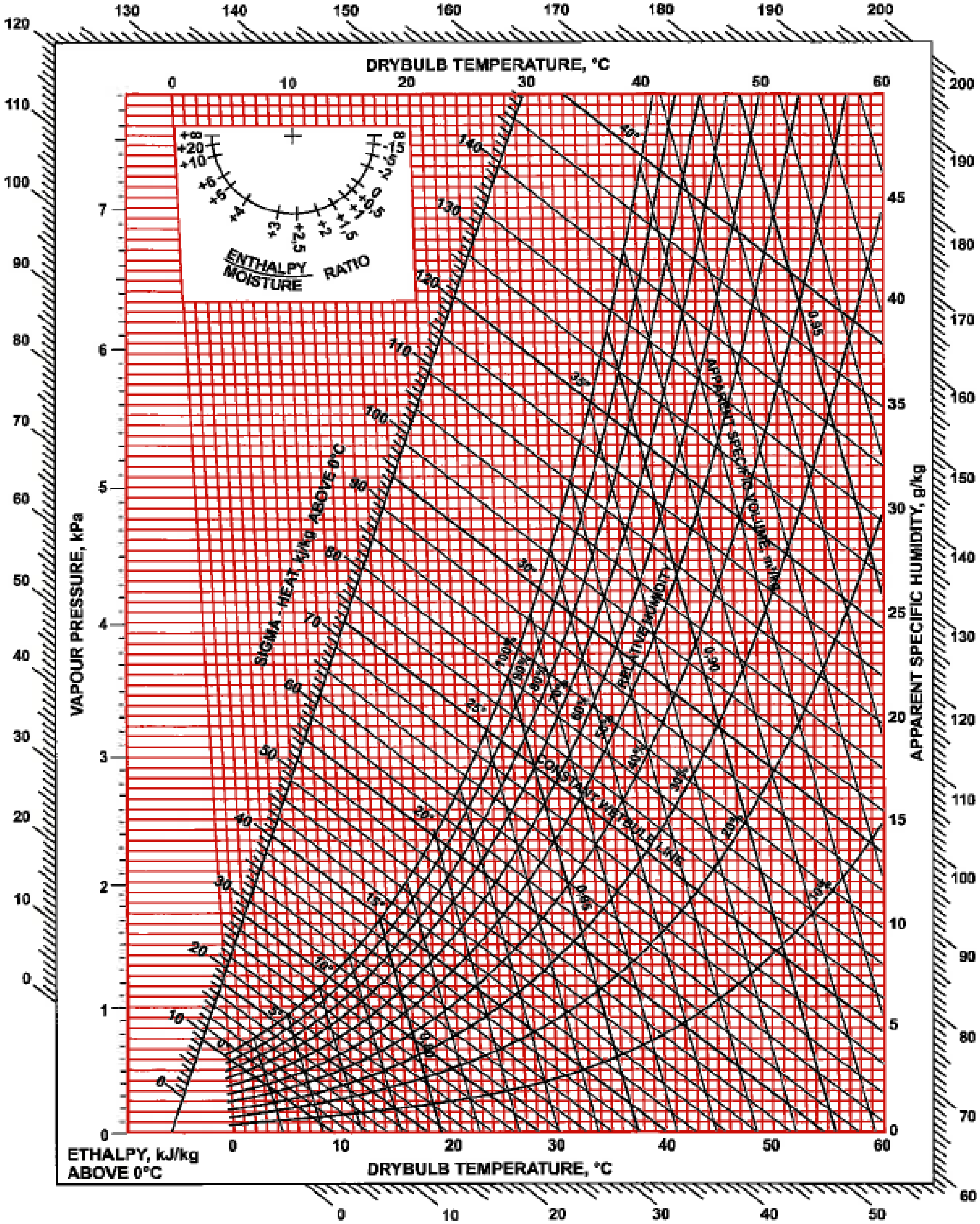
PSYCHROMETRIC CHART
97,5 kPa



PSYCHROMETRIC CHART
100,0 kPa



PSYCHROMETRIC CHART
105,0 kPa



PSYCHROMETRIC CHART
115,0 kPa