Minerals Council South Africa

MEMORANDUM

SUBJECT:**CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN MINE ENVIRONMENTAL CONTROL**	EXAMINER**: Marthinus v/d Bank**
PAPER 2 – THERMAL ENGINEERING	MODERATOR: **Dave Farlam**
SUBJECT CODE: **COMMEC2**	
EXAMINATION DATE: **06 October 2020**	TOTAL MARKS: **[100]**
TIME: **<u>14:00 – 17:00 (3 HOURS)</u>**	PASS MARK: **(60%)**

NUMBER OF PAGES: **14**

SPECIAL REQUIREMENTS:

THIS IS **<u>NOT</u>** AN **<u>OPEN BOOK EXAMINATION</u>**.
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.

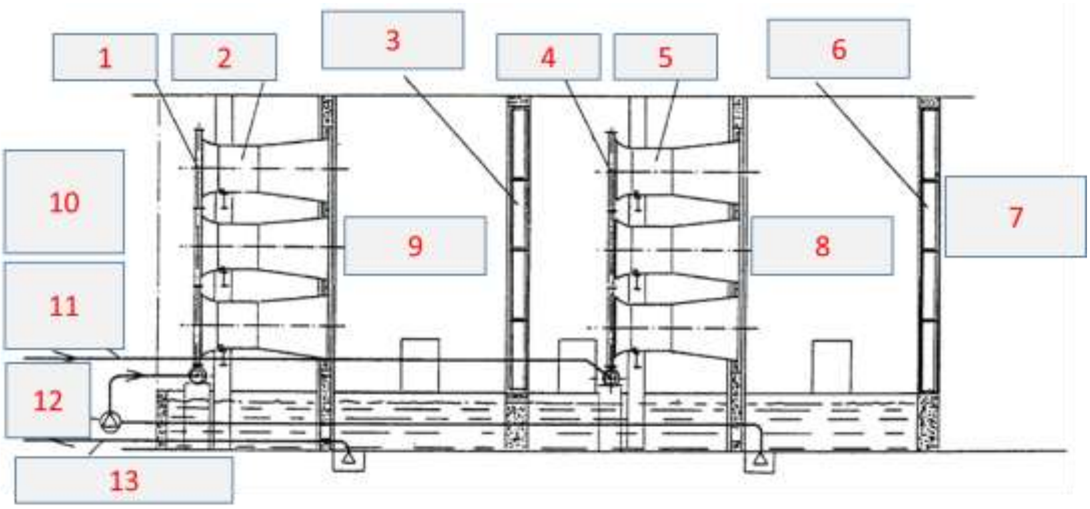
3. Show all calculations and **<u>check calculations on which the answers are based</u>**.
4. Hand-held electronic calculators may be used for calculations.
5. Write **<u>legibly</u>** in ink on the **<u>right hand page</u>** only – **<u>left hand pages will not be marked</u>**.
6. Illustrate your answers 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: Psychrometric charts: 82.5 kPa, 102.5 kPa, 105 kPa, 115 kPa and 120 kPa.</u>**

QUESTION 1

1.1 Given in the figure below is a typical two-stage venturi-type bulk air cooler. Please name the elements numbered from 1 to 13 (13)



Answers 1 to 13: Data Book RE-DC8 Page 246

1. Nozzles
2. Venturi
3. Drift Eliminators
4. Nozzles
5. Venturi
6. Drift Eliminators
7. Cool air leaving
8. Water fall out zone
9. Water fall out zone
10. Warm air entering
11. Chilled water in
12. Inter stage pump
13. Warm water out

1.2 Briefly describe the following terms:

- Stefan-Boltzmann Law (3)

  Answer:
  The total radiation emitted by a black body is proportional to the fourth power of the absolute surface temperature.
  $E_b = \sigma T4$
  σ = Stefan-Boltzmann constant 5,67 x 10^{-8} W/m²K⁴

- Planck's Law (3)

  Answer:
  The distribution of wavelengths of emitted radiation for a given temperature is:
  $E_{b\lambda} = [3{,}74 \times 10^8\ \lambda^{-5}] / [\exp(1{,}44 \times 10^4 / \lambda T) - 1]$

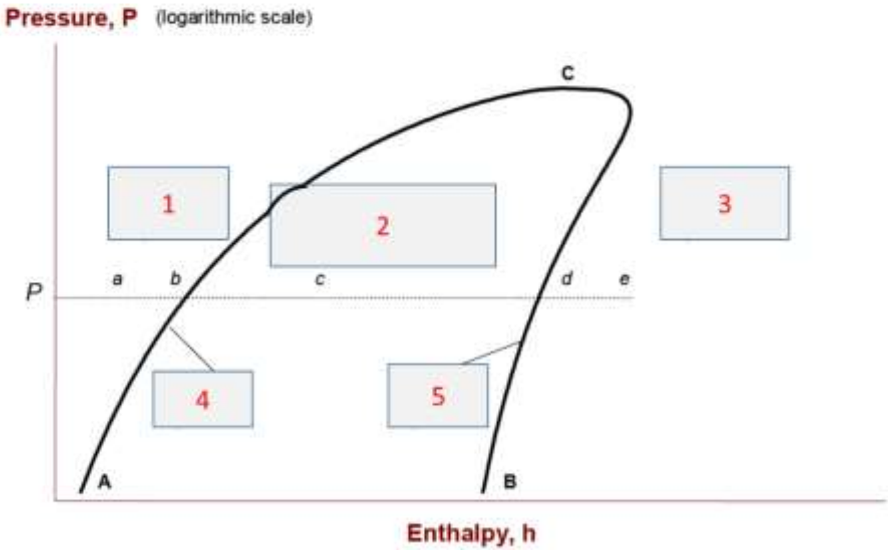
- Wien's Displacement Law (3)

Answer:
The wavelength of the maximum emitted radiation is inversely proportional to the absolute temperature. ✓✓
λ maxT = 2 898 ✓

- Kirchoff's Law (3)

Answer:
The emissivity (ε) of a surface is equal to the absorptivity of the surface ✓✓
$\alpha = \varepsilon$ ✓

1.3 At any given pressure, there is only one corresponding temperature at which the refrigerant will evaporate from liquid to vapour or condense from vapour to liquid.
In the Pressure-Enthalpy Diagram for a Refrigerant figure below, briefly describe the state of the refrigerant at points 1 to 5: (5)



Answer: Env Eng Handbook Chapter 23 Refrigeration Theory and Equipment

Figure 23.1 Page 7

1. Subcooled liquid ✓

2. Liquid-vapour region (liquid-vapour mixtures) ✓

3. Superheated vapour ✓

4. Saturated liquid line ✓

5. Saturated vapour line ✓

(30)

QUESTION 2

2.1 The following measurements were made during a routine check on the performance of an underground cooling plant.

Evaporator
Water flow rate 39,7 l/s
Inlet water temperature 22,8 ºC
Delivery water temperature 7,7 ºC
Evaporating pressure (absolute) 341 kPa

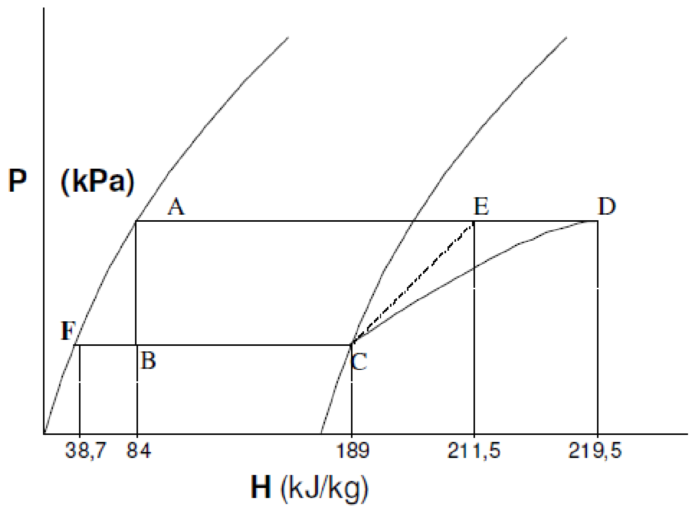
Condenser
Water flow rate 70,2 l/s
Inlet water temperature 37,3 ºC
Delivery water temperature 44,8 ºC
Condensing pressure (absolute) 1 201 kPa

Barometric pressure 116 kPa

Electric input power to compressor motor 645 kW
Compressor discharge temperature 66ºC

The plant is a single stage refrigeration machine. The compressor is driven via a gearbox and gearbox and motor efficiencies are 98% and 94% percent respectively. Previous measurements on this cooling plant have indicated that *waterflow rate measurements in the condenser and evaporator are suspect*, but that the electrical input power is known to be a reliable measurement as are the condensing and evaporating pressures.

The values as plotted on a Pressure-Enthalpy diagram is as follows:
HA 84 kJ/kg HD 219,5 kJ/kg
HB 84 kJ/kg HE 211,5 kJ/kg
HC 189 kJ/kg HF 38,7 kJ/kg



The specific volume of the refrigerant at the compressor inlet is 0,052 m³/kg. Using the results from the pressure-enthalpy diagram and calculate the following:

2.1.1. The gauge pressures for the condenser and evaporator (3)
2.1.2. The compressor efficiency (3)
2.1.3. The actual work of compression (in kW) (3)
2.1.4. The ideal work of compression and heat losses in compressor expressed in kW (2)
2.1.5. The refrigerant mass flow (2)
2.1.6. The refrigerant volume flow rate at the compressor inlet (2)
2.1.7. The plant duty (kW) (2)
2.1.8. The correct evaporator and condenser water flow rate expressed in litres/second (7)
2.1.9. The correct final heat balance with correct waterflow rates (1)

(25)

Answer: Reference from Old exam Paper 2 - Oct 2006 (New value calculations)

2.1.1

Condenser absolute pressure = $P_{meter} + P_{atmosphere}$

$P_{meter} = P_{abs} - P_{atmosphere}$

$= 1201 - 116$ ✓

$= 1085$ kPa

Evaporator absolute pressure = $P_{meter} + P_{atmosphere}$ ✓

$P_{meter} = P_{abs} - P_{atmosphere}$

$= 341 - 116$

$= 225$ kPa ✓

2.1.2

Compressor efficiency $= \frac{Hf - Hc}{Hd - Hc} \times 100\%$ ✓

$= \frac{211{,}5 - 189{,}0}{219{,}5 - 189{,}0} \times 100\%$ ✓

$= 73{,}8\%$ ✓

2.1.3

Electric motor output power $= 645 \times \text{Efficiency}_{\text{compressor motor}}$

$= 645 \times 0{,}94$

$= 606{,}3$ kW ✓

Compressor power in $= 606{,}3 \times \text{Efficiency}_{\text{gearbox}}$

$= 606{,}3 \times 0{,}98$ ✓

$= 594{,}2$ kW *(Actual work of compression)* ✓

2.1.4 *NB:*

Compressor power in = ideal work of compression + heat losses

594,2 = (594,2 x 0,738) + (594,2 x 0,262)

= 438,5 + 155,7

= 594,2 kW (actual work of compression)

2.1.5

Massflow of refrigerant can be determined as follows:

Massflow refrigerant $= \frac{594{,}2}{(HD - HC) \text{Actual work of compression}}$

$= \frac{594{,}2}{30{,}5}$

= 19,5 kg/s

2.1.6

Refrigerant volume flowrate = V_R x specific volume(v) compressor inlet

= 19,5 kg/s x 0.052 m³/kg

= 1,014 m³/s

2.1.7

Plant Duty = M_R x (H_C – H_B)

= 19,5 x (189 – 84)

= 2 048 kW

2.1.8

A heat balance of the measurements made in the water circuits of the condenser and the evaporator and the electrical input power confirm that the water flow measurements are suspect. This is shown below:

Condenser duty = evaporator duty + heat of compression

70,2 x 4,187 x 7,5 * 39,7 x 4,187 x 15,1 + 594,2

2 204 * 3104

<u>The difference is well in excess of the 5% which is normally accepted</u>. Therefore the water flow rates must be calculated by using the figures obtained from the P-H diagram together with the water temperatures.

Thus:

Massflow of water condenser = $\frac{kW\ in\ condensor}{c\ x\ .6t}$

$= \frac{mR\ x\ (HD-HA)}{4{,}187\ x\ (44{,}8-37{,}3)}$

$= \frac{19{,}5\ x\ (219{,}5-84{,}0)}{4{,}187\ x\ (44{,}8-37{,}3)}$

= 84,1 l/s or kg/s

Massflow of water evaporator = $\frac{kW\ in\ evaporator}{c\ x\ .6t}$

$= \frac{2\ 048}{4{,}187\ x\ (22{,}8-7{,}7)}$

= 32,4 kg/s

= 32,4 l/s

2.1.9

These values differ considerably from those measured. The new heat balance will show the difference:

Condenser duty	= evaporator duty + heat of compression
84,1 x 4,187 x 7,5	= 32,4 x 4,187 x 15,1 + 594,2
2 641 kW	= 2 643kW

QUESTION 3

3.1. 275 m³/s of upcast air leaves the top of a condenser water cooling tower situated at the bottom of a vertical upcast shaft 2.25 km deep. The air temperature is 38ºC saturated. The barometric pressure is 105 kPa. At this point this air is joined by a further 100 m³/s at 30,0/31,0ºC.

All this air travels 2 250 m up the shaft to the main fan on surface. This fan operates at 5,5kPa. The shaft diameter is 5,5 m. The barometric pressure outside the fan drift is 88.0 kPa.

Heat flows from the upcast air to the shaft wall as the air passes up the shaft.

The coefficient of heat transmission may be taken as 30 W/m² ºC temperature difference.

Assuming that the air is 5ºC hotter than the shaft walls, calculate the following:

3.1.1	The massflow of air at the mixing point	(8)
3.1.2	The temperature of the air entering the fan	(10)
3.1.3	The apparent air density at the fan inlet	(4)
3.1.4	The air volume handled by the fan	(3)
		(25)

Answer: Reference from Old exam Paper 2 - Oct 2006 (New value calculations)

This part of the equation will be broken into steps:

3.1.1

From the 105 kPa psychrometric chart at 38ºC saturated:

S = 139,0 kJ/kg ✓

r = 42,0 g/kg ✓

v = 0,909 m^3/kg ✓

Massflow of air = $\frac{Q}{v}$

$= \frac{275}{0.909}$

= 302,5 kg/s ✓

Also from the 105 kPa psychrometric chart at 30,0/31,0ºC saturated:

S = 93,6 kJ/kg ✓

r = 25,7 g/kg ✓

v = 0,867 m³/kg ✓

Massflow of air = $\frac{Q}{v}$

= $\frac{100}{0.867}$

= 115,3 kg/s

The total massflow of the air at the mixing point can be determined as follows:

Massflow of air at mixing point = $m_A + m_B$

= 302.5 + 115,3

= 417,8 kg/s ✓

3.1.2

The Sigma heat value and the moisture content of the mixing air must be determined and can be done as follows:

Sigma heat of air at mixing point = $\frac{(MA\ x\ SA)+(MB\ x\ SB)}{MC}$ ✓

= $\frac{(302.5\ x\ 139)+(115.3\ x\ 93.6)}{417.8}$

= 126,5 kJ/kg ✓

Moisture content of air at mixing point = $\frac{(MA\ x\ RA)+(MB\ xRB)}{MC}$

= $\frac{(302.5\ x\ 42)+(115.3\ x\ 15.7)}{417.8}$

= 34,74 kJ/kg ✓

Heat loss to the shaft walls = 30 W/m²

But the air is 5ºC hotter than the shaft walls and the area of the shaft wall (surface area):

Surface area = ¶DL

= 3.14 x 5.5 x 2 250

= 38 877 m² ✓

Therefore the heat loss to the wall = 30 W/m² °C x 5 °C x 38 877 m²

= 5831,6 kW ✓

Heat lost to the shaft walls can therefore be determined as follows:

Heat lost to the shaft walls $= \frac{q}{Massflow\ of\ air}$

$= \frac{5831,6}{417.8}$

= 13.96 kJ/kg ✓

Heat lost due to auto-decompression $= \frac{9,79}{1\ 000}$ X 2 250

= 22.0 kJ/kg ✓

Sigma Heat = (126,5 – 13.96 – 22.0)

= 90.54 kJ/kg ✓

Barometric pressure inside the fan drift = 88.0 – 5.5

= 82.5 kPa ✓

The temperature of air is read off as 25,8/25,8°C ✓

3.1.3

The asv of the air at the fan intake is = 1,045 m^3/kg ✓

Density(w) of air at the fan intake $= \frac{1,00}{1,045}$ ✓

= 0,957 kg/m^3 ✓ ✓

3.1.4

Massflow at top of shaft as determined before = 417,8 kg/s ✓

Quantity of air $= \frac{m}{w}$

$= \frac{417,8}{0,957}$ ✓

= 436,5 m^3/s ✓

QUESTION 4

4.1 Air flows down a 3 600 m deep shaft. Determine the increase in temperature of the air given that for moist air a change in enthalpy ΔH (kJ/kg) is equal to $c_p\Delta t$. for moist air, an average value of the constant pressure specific heat c_p is 1,38 kJ/kg°C. (2)

Answer: Reference from Old exam Paper 2 - Oct 2006 (New value calculations)

ΔH = gΔz / 1000

= 9,79 x 3600 / 1000

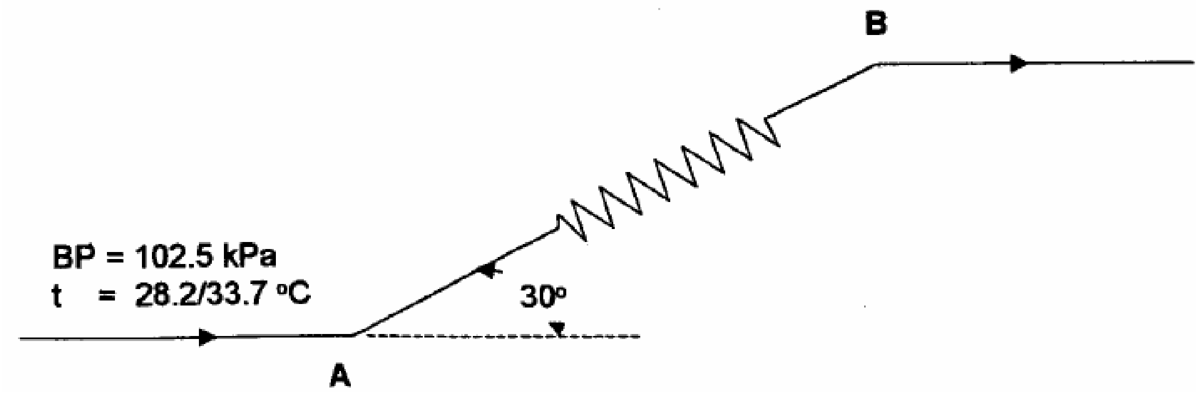
= 35,24 kJ/kg of moist air ✓

Thus Δt = ΔH/cp

= 35,24/1,38

= 25,5 °C ✓

4.2 The sketch below shows a section of a mine. Determine the enthalpy of the air leaving the stope at B. *Note distance is 1 200m.* (3)



Answer: Reference from Old exam Paper 2 - Oct 2006 (New value calculations)

First, calculate the vertical distance through which the air travels. Using the sine formula,

Δz = 1200 sin 30°

= 600m ✓

The decrease in enthalpy is therefore

ΔH = 9,79 x 600/1000

= 5,87 kJ/kg. ✓

Using a psychrometric chart for a barometric pressure of 102,5 kPa, we find that the enthalpy of the air entering the stope is 89,7 kJ/kg. Thus, the enthalpy of the air leaving the stope is

89,7 – 5,87 = 83,83 say 83,8 kJ/kg ✓

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

Intake air volume 268 m^3/s

Fan pressure 6 kPa

Temperature 24/27ºC

Barometric pressure 115 kPa

Power input to fan motor 2 200 kW

Motor efficiency 90%

4.3.1 Determine the conditions at the fan discharge (10)

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

(20)

Answer: Reference from Old exam Paper 2 - Oct 2006 (New value calculations)

4.3.1 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 = 268 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 ✓

Massflow of air = $\frac{Q}{v}$

$= \frac{268}{0.762}$

= 351.7 kg/s say 352 kg/s ✓

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

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

$= \frac{2200}{352}$

= 6.25 kJ/kg ✓

Sigma heat of air leaving fan (S_{out}) = S_{in} +)S

= (64,5 + 6.25)

= 70,75 kJ/kg ✓

The barometric pressure fan outlet = 115 + 6

= 121 kPa ✓

The temperature of the air can be read off the 120 kPa psychrometric chart, Sigma heat of 70,75 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 26,3/32,7ºC ✓

4.3.2 Fan air power = pQ

= 6 x 268

= 1 608 kW ✓

Fan motor input power = 2 200 kW (given)

Fan input power = fan motor input power x $motor_{efficiency}$

= 2 200 x 0,90

= 1 980 kW ✓

Fan efficiency $= \frac{air\ power}{fan\ input\ power}$ x 100%

$= \frac{1608}{1980}$ x 100%

= 81,2% ✓

The fan efficiency can now be determined as follows:

The fan overall efficiency can now be determined as follows:

Fan overall efficiency $= \frac{air\ power}{fan\ motor\ input\ power}$ x 100%

$= \frac{1608}{2200}$ x 100%

= 73,1% ✓ ✓

The following Psychrometric charts are included:
82.5 kPa, 102.5 kPa, 105 kPa, 115 kPa and 120 kPa.