1Minerals 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: **04 November 2020** TIME: **14:00 – 17:00 (3 HOURS)**	EXAMINER**: Marthinus v/d Bank** MODERATOR: **Dave Farlam** 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).

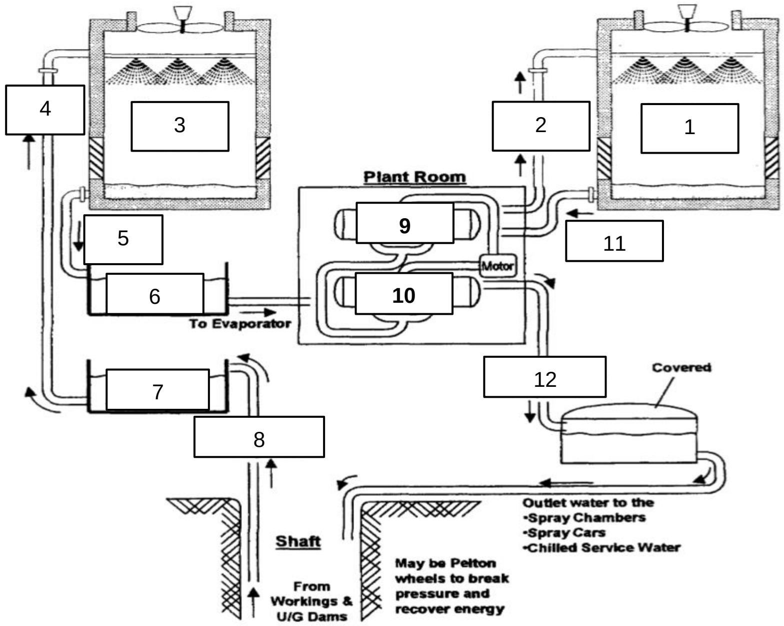
8. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
9. Cell phones and any other electronic devices are **NOT** allowed in the examination room. **Only Calculator**
10. **The following charts to be included: Psychrometric charts: 100.0kPa and 112.5kPa.**

QUESTION 1

1.1 The diagram below indicates the typical layout of a surface refrigeration plant.

1.1.1 Explain the typical components of a surface cooling plant as indicated in the diagram below which are numbered from 1 to 12.

1.1.2 When all components are identified explain the full function of the pre-cooling towers and the condenser cooling towers.



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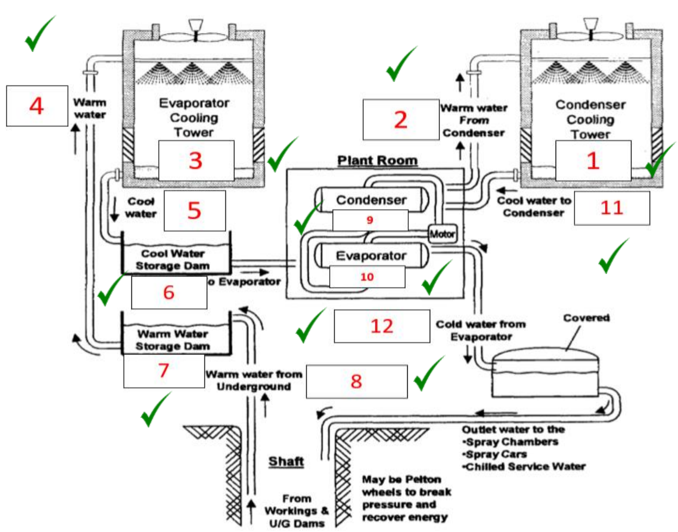
Answers: **Workbook Pg 56&57** **(75 – 76, w/book edition Sept 2012)**

1.1.1



1	Condenser Cooling Tower
2	Warm water from Condenser
3	Evaporator Cooling Tower
4	Warm water
5	Cool water
6	Cool water storage dam
7	Warm water storage dam
8	Warm water from underground
9	Condenser
10	Evaporator
11	Cool water to condenser
12	Cool water from Evaporator

1.1.2
Pre-Cooling Towers

The process of pre-cooling warm underground water in a cooling tower provides a simple and inexpensive way of cooling it. It is often called 'free' cooling because it does not entail the expense of a refrigerator to provide the same amount of cooling which would otherwise be needed. ✓ ✓

The extent to which a pre-cooling tower can cool water is dictated by the wet-bulb temperature of the air. Generally, it is possible to cool the water to about 2°C above wetbulb. This means that pre-cooling towers are more useful and effective in the Highveld regions than they are in the Bushveld, say. Also, ironically, they are very effective in winter, when there is less need for cooling in the mines. Pre-cooling tower need very little power input. Some pumping may be required, and a small motor will be needed to drive the main fan at the top of the tower.

Condenser Cooling Towers

These devices are essentially the same as pre-cooling towers in design and construction, the main difference being that their purpose is to cool the condenser water circulating through the refrigeration plant rather than underground water. ✓ ✓

1.2 Give brief explanation for the following terms: Psychrometry chart book

- **Normal temperature and pressure (N.T.P.)** ✓
  This is a temperature of 0 ºC and an absolute pressure of 101,325 kPa

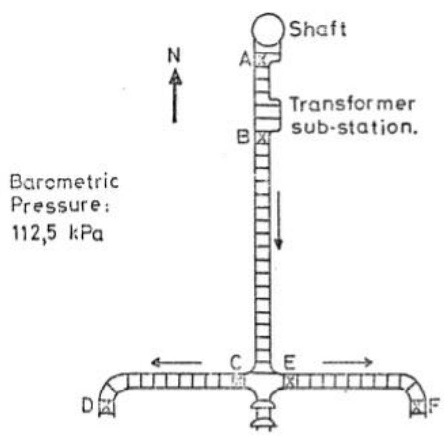
- **Standard vair**
  Standard vair is vair which has a true density of 1,2 kg/m³. This is a definition of convenience that is adopted widely. The actual values of temperature, pressure and moisture content are not important.
- **Temperature of adiabatic saturation**
  In an adiabatic saturation process during which the reduction in the sensible heat of vair is exactly equal to the latent heat of the evaporating water, the temperature finally reached by the vair at saturation is known as the "adiabatic saturation temperature". It is important that the water supplied for evaporation should be at the saturation temperature. The temperature of adiabatic saturation is almost equal to the wet-bulb temperature.
- **Enthalpy (total heat)**
  The summation of sensible heat, latent heat and superheat between an arbitrary datum point and the temperature and state under consideration (kJ/kg). The arbitrary datum point in these psychrometric charts is taken as 0 ºC for both vair and water.
- **Humid thermal capacity of vair**
  The amount of heat, in kJ, required to raise the temperature of one kilogram of air by one degree Celsius. The humid thermal capacity takes into account the sensible heat of both the air and the water vapour.

(8)

(24)

QUESTION 2

The sketch below shows measurements made in a crosscut and footwall drive system where an air split has been established to supply air to a stope from a sub-vertical shaft.



Point	Air temperature		Q (m^3/s)
	wet-bulb (ºC)	dry-bulb (ºC)	
A	28,5	37,7	-
B	29.0	39,7	16,8
C	29,8	34,5	8,1
D	32,1	33.0	-
E	29,8	34,5	7,8
F	31,1	33.0	24.9

Answer the following questions: **(Q&A) 6 Pg 20** Chart 112.5kPa

2.1 Do a mass flow of air calculation for the air at points B, C and E and comment on your answer. (7)

Answer:

From the 112.5 kPa psychrometric chart, the following conditions can be established.

	A	B	C	D	E	F
Sigma Heat S (kJ/kg)	84.0	85.2	88.2	99.2	88.2	94.4
Moisture content,r (g/kg)	18.7	18.7	22.2	27.2	22.2	25.2
Specific volume ASV (m3/kg)	-	0.822	0.813	-	0.813	-

The mass flow of air for the various positions can be determined as follows:

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

$= \frac{16.80}{0.822}$

$=$ 20.44 kg/s

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

$= \frac{8.10}{0.813}$

$=$ 9.96 kg/s

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

$= \frac{7.80}{0.813}$

$=$ 9.59 kg/s

Since the total mass of the air at B is greater than the sum of the masses at C and E (9,96 + 9,59 = 19,55 kg/s), there must be a leakage across the ventilation doors to the amount of 0,89 kg/s (20,44 – 19,55).

2.2 Calculate the rate at which the air gains heat and moisture (in kW and litres/second respectively):

Answer:

2.2.1 At the transformer sub-station;

Heat gained at transformer sub station $= m \times \Delta S$

$= 20.44 \times (85.2 - 84.0)$

$= 24.5$ kW

There is no moisture change.

2.2.2 In the crosscut

Heat gained in the crosscut	$= m \times \Delta S$
	$= 20.44 \times (88.2 - 85.2)$
	$= 61.3$ kW ✓
Moisture gained in the crosscut	$= m \times \Delta r$
	$= 20.44 \times (22.2 - 18.7)$
	$= 71.5$ g/s $= 0.072$ litres/second ✓

2.2.3 In the footwall drive east

Heat gained in footwall drive east	$= m \times \Delta S$
	$= 9.59 \times (94.4 - 88.2)$
	$= 59.5$ kW ✓
Moisture gained in footwall drive east	$= m \times \Delta r$
	$= 9.59 \times (25.2 - 22.2)$
	$= 28.77$ g/s $= 0.029$ litres/second ✓

2.2.4 In the footwall drive west.

Heat gained in the footwall drive west	$= m \times \Delta S$
	$= 9.96 \times (99.2 - 88.2)$
	$= 109.6$ kW ✓
Moisture gained in footwall drive west	$= m \times \Delta r$
	$= 9.96 \times (27.2 - 22.2)$
	$= 49.8$ g/s ✓

(7)

2.3 At what temperature would you expect the air to reach the ends of the footwall drives should the air split to be increased from 16.8 m³/s to 28.0 m³/s? This change is not likely to affect the temperature of the air at the shaft station.

Answer:

If the air split was increased from 16,8 m³/s to 28 m³/s, the new mass flow rates of the air can be determined at points B, C and E:

Massflow of air at B $= \frac{Q_2}{Q_1} \times m_B$ ✓

$= \frac{28.0}{16.80} \times 20.45$

$= 34.1$ kg/s

Massflow of air at C = $\frac{Q_2}{Q_1} \times m_C$

= $\frac{28.0}{16.80}$ x 9.96

= 16.6 kg/s ✓

Massflow of air at E = $\frac{Q_2}{Q_1} \times m_E$

= $\frac{28.0}{16.80}$ x 9.59

= 16.0 kg/s ✓

With the increased flow, the rate of heat pick up will be increased in all the airways. The heat increase from the transformer substation will remain constant.

Assume that the heat and moisture pick in the airways increases by 5 per cent with the increased flow (Note: This information was not given in the question and shows the student's understanding of the problem).

At the crosscut

Conditions at A

The substation heat increase = 24,5 kW

Increase in heat per kg = $\frac{24.5}{34.1}$

= 0.71 kJ/kg

The increase in moisture at substation = 0.0g/kg ✓

Crosscut heat increase = 61.3 x 1.05

= 64.37kJ/kg

Increase in heat per kg = $\frac{64.37}{34.1}$

= 1.89 kJ/kg

✓ ✓

Crosscut moisture increase = 71.5 x 1.05

= 75.1 g/s

Increase in moisture per kg = $\frac{75.1}{34.1}$

= 2.2 g/kg

The conditions of the air at C and E is the summation of the relevant heat contents and moisture contents as determined above:

Total heat content of the air C and E = 84.0 + 0.71 + 1.89

= 86,6 kJ/kg

Total moisture content of the air C and E = 18.7 + 2.2 ✓

= 20.9 g/kg

From the 112.5 kPa psychrometric chart, temperature at C and E can be read off:

Temperature of the air at C and E is 29.3/35.1ºC ✓

Footwall drive west

Conditions at C

The drive heat increase = 109.6 x 1.05

= 115.1 kW ✓

Increase in heat per kg = $\frac{115.1}{16.6}$

= 6.93 kJ/kg

Drive moisture increase = 49.8 x 1.05 ✓ ✓

= 52.29 g/s

Increase in moisture per kg = $\frac{52.29}{16.6}$

= 3.2 g/kg

The conditions of the air at D is the summation of the relevant heat contents and moisture contents as determined above:

Total heat content of the air at D = 86.6 + 6.93

= 93.53 kJ/kg

Total moisture content of the air D = 20.9 + 3.2 ✓

= 24.1 g/kg

From the 112,5 kPa psychrometric chart, temperature at D can be read off:

Temperature of the air at D is 31.0/34.5ºC

Footwall drive east

Conditions at E

The drive heat increase = 59.5 x 1.05

= 62.5 kW ✓

Increase in heat per kg = $\frac{62.5}{16.0}$

= 3.9 kJ/kg ✓ ✓

Drive moisture increase = 28.8 x 1.05

= 30.2 g/s

Increase in moisture per kg = $\frac{30.2}{16.0}$

= 1.9 g/kg

The conditions of the air at F is the summation of the relevant heat contents and moisture contents as determined above:

Total heat content of the air at F = 86,6 + 3.9 ✓

= 90.5 kJ/kg

Total moisture content of the air F = 20,9 + 1,9 ✓

= 22,8 g/kg

From the 112,5 kPa psychrometric chart, temperature at F can be read off:

Temperature of the air at F is 30,2/34,7ºC ✓

Note: Although the rate of the heat flow has increased, due to the higher mass flow the increase per unit mass along the system is lower, giving a lower temperature. (18)

(32)

QUESTION 3 Q&A Q11 Pg34 Chart 100.0kPa

3.1 The air in an intake airway has the following temperature and specific humidity:

Temperature 25.0/30.0ºC

Specific humidity 18.2 g/kg

Calculate (i.e. do not use psychrometric charts) the following:

3.1.1 The Sigma heat (kJ/kg) (8)

Answer:

Using the 4 step method, and assuming a mass of 1.0 kg of dry air,

1. q = m x cp x Δt

= 1.0 x 1.005 x 30 (use the dry-bulb temperature)

= 30.15 kJ ✓

2. q = m x cp x Δt

= $\frac{18.2}{1000}$ x 4.187 x 25

(use the wet-bulb temperature)

= 1.91 kJ ✓

3. q = m x ʎ

= $\frac{18.2}{1000}$ x 2 400 (latent heat of evaporation used)

= 44.41 kJ ✓

4. q = m x cp x Δt

= $\frac{18.2}{1000}$ x 1.884 x 5 (cp moist air and Δttdb-twb)

= 0.17 kJ ✓

Sigma heat content per kg = 1 + 3 + 4

= 30.15 + 44.41 + 0.17

= 74.73 kJ/kg ✓✓

3.1.2 The total heat content of the air (kJ/kg)

Total heat per kg = 1 + 2 + 3 + 4

= 30.15 + 1.91 + 44.41 + 0.17

= 76.64 kJ/kg ✓✓

3.2. A quantity of 75m³/s flows along an airway. The barometeric pressure is 100kPa. The temperature is 24.0/29.0°C.The temperature at the first stope entrance is 28.5/30.0°C.

3.2.1 If the maximum permissable wet-bulb temperature is 32.0°C, what rate of heat pick-up (kW) can the air absorb in the stope?

Assume that the quantity of 75.0 m³/s was measured at the station.

From the 100 kPa psychrometric chart,

Specific volume of the air at the station (v) = 0,892 m³/kg ✓

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

= $\frac{75.0}{0.892}$

= 84.1 kg/s ✓

Maximum S of air in stope = 107,2 kJ/kg

Sigma heat of air entering stope = 89,8 kJ/kg ✓

The S of heat absorbed = 17.4 kJ/kg ✓

The kW heat absorbed (kW) = m x ΔS

= 84.1 x 17.4

= 1 463 kW ✓

3.2.2 If the dry-bulb temperature entering the first stope remains at 30.0°C, but the quantity of water evaporated between the station and the stope entrance is reduced by 50%, what will the wet-bulb temperature of the air entering the stope be?

Using the 100 kPa psychrometric chart:

Moisture content of air at station (r) = 16.9 g/kg ✓

Moisture content of air entering stope (r) = 24.5 g/kg

Δr = 24.5 – 16.9

= 7.6 g/kg ✓

If this value was reduced by 50% = 7,6/2 (increase of r in air)

The moisture content of the air entering the stope would then be:

= 16,9 + 3,8

= 20,7 g/kg ✓

Where the 20.7 g/kg moisture content line cuts the 30.0ºC dry-bulb temperature line on the 100 kPa chart, read off the new wet-bulb temperature of the air entering the stope: ✓

The wet-bulb temperature of the air entering the stope is 26.5ºC

3.2.3 What will the new rate of heat pick-up (kW), for the same maximum permissible wet-bulb temperature in the stope be?

Maximum sigma heat content of air = 107,2 kJ/kg ✓

New S of air entering stope (twb = 26,5ºC) = 81,0 kJ/kg

ΔS = 107,2 – 81,0 ✓

Each kg of air can absorb = 26,2 kJ/kg

The 84,1 kg/s of air can absorb = m x ΔS

= 84,1 x 26,2

= 2 203 kW of heat ✓✓

(12)

(20)

QUESTION 4 Q&A Q26 Pg59 and Q30 Pg70 Chart 112.5kPa

4.1 What are the symptoms of condenser tube fouling?

Answer:

- Reduced duty of the condenser ✓
- Increase in condenser pressure ✓
- Increase in load on the compressor. ✓

(3)

4.2 Whatever materials are used for insulation of pipes, they should meet the following requirements:

Answer:

- Be effective, that is, a good insulator. ✓
- Not be a fire hazard. ✓
- Exclude water and water vapour effectively. ✓
- Capable of withstanding rough handling. ✓
- As inexpensive as possible. ✓
- Easy and cheap to install. ✓

(6)

4.3 A quantity of 75.0 m³/s of air enters a bulk air cooler at 29.5/33.8°C. The barometric pressure is 112.5 kPa and the total heat removed from the air is 3 850 kW. The water flow rate through the bulk air cooler is an amount of 80.0 litres/second and the temperature of the water entering the cooler is 9.5°C.

Calculate the following:

4.3.1 The temperature of the air leaving the bulk air cooler. (State any assumptions)

Answer:

Mass flow of air entering the cooler

$$M_{\text{air intake}} = \frac{Q}{v} = \frac{75.0}{0.811} = 92.5 \text{ kg/s}$$ ✓

(Where ASV = 0,811 m³/kg read off from the 112,5 kPa chart at 29.5/33.8°C)

But Total heat (kW) = Mass flow x ΔS

$$\Delta S = \frac{\text{kW}}{\text{m}} = \frac{3850}{92.5} = 41.6 \text{ kJ/kg}$$ ✓

Sigma heat of the air entering the cooler = 87.4 kJ/kg

Sigma heat of the air leaving the cooler = 87.4 – 41.6

= 45.8 kJ/kg ✓✓

Assuming that the air that is leaving the cooler is saturated then the temperature read off from the 112.5 kPa psychrometric chart is as follows:

17.7/17.7°C (air is saturated) ✓

4.3.2 The quantity of air leaving the bulk air cooler.

Answer:

Mass flow of air entering the cooler = 92.5 kg/s

Mass flow of air exiting the cooler = 92.5 kg/s

mass flow constant

ASV of air leaving the cooler at 17.7/17.7°C from 112.5 kPa chart = 0.755m³/kg ✓

Therefore the Quantity of air leaving the cooler can be determined as follows:

$Q_{air\ exit}$ = m x v

= 92.5 x 0.755

= 69.8 m³/s ✓

4.3.3 How much water has evaporated or condensed in litres per day.

Answer:

Moisture content of air entering the cooler = 21.9 g/kg ✓

(from 112.5 kPa chart at 29.5/33.8°C)

Moisture content of air leaving the cooler = 11.4 g/kg

(from 112.5 kPa chart at 17.7/17.7°C) ✓

Amount of water condensed in litres per day (l/day):

Δr = 21.9 – 11.4

= 10.5 g/kg ✓

The amount of water condensed can be determined as follows:

Amount of water condensed = $\frac{m \times \Delta r}{1000 (\text{to convert g to kg})}$

= $\frac{92.5 \times 10.5}{1000}$

= 0.969 l/s ✓✓

(assuming 1l = 1kg)

Amount of water condensed per day can be determined as follows:

Amount of water condensed per day = 0,969 x 60 x 60 x 24

= 83 721.6 say 83 722 l/day ✓

4.3.4 The temperature of the water leaving the cooler.

Answer:

$$q = m \times cp_{water} \times \Delta t$$

$$= m \times cp_{water} \times (t_o - t_i)$$

$$= \frac{q}{m \times cp} + t_{in}$$

$$= \frac{3850}{80 \times 4.187} + 9.5$$

Water leaving the cooler = 21,0°C ✓✓

(15)

(24)

Add psychrometric charts 100.0 and 112.5