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: ***12 May 2021*** TIME: **<u>14:00 – 17:00 (3 HOURS)</u>**	EXAMINER**: Marthinus v/d Bank** MODERATOR: **Dave Farlam** TOTAL MARKS: **[100]** 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.

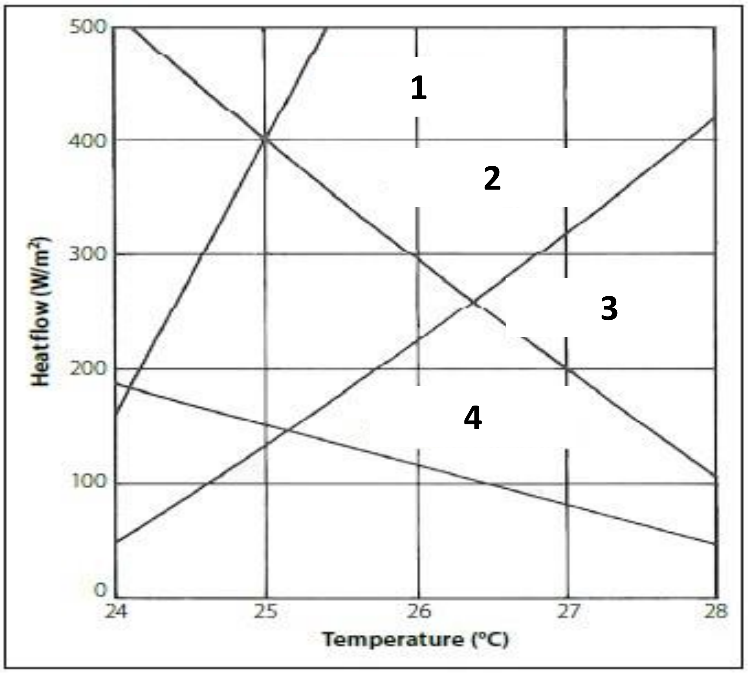
3. Show all calculations and **<u>check calculations on which the answers are based</u>**.
4. Hand-held electronic calculators may be used for calculations.
5. Write **<u>legibly</u>** in ink on the **<u>right hand page</u>** only – **<u>left hand pages will not be marked</u>**.
6. Illustrate your answers 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: 100.0kPa, 120.0kPa, 125.0kPa and 130.0kPa.</u>**

QUESTION 1

1.1 The Wet-bulb temperature is a very much more complex situation, for the thermometer bulb now gains heat both by convection from the air and by radiation from the surroundings and loses heat by evaporation from the sock. Please explain the heat gains and losses from the graph below at 0.5m/s and 3.0 m/s. *Answer at Number 1 to 4* (4)



Answer: (Blue Book page 335)

1. Heat Losses (3.0m/s) ✓
2. Heat Losses (0.5m/s) ✓
3. Heat gains (3.0m/s) ✓
4. Heat Gains (0.5m/s) ✓

1.2 Give a brief explanation for the following terms:

- Dalton's law *Blue book pg. 343* (4)

  Answer:

  Dalton's law <u>states that the pressure exerted by a mixture of gases</u> ✓ present in a container of <u>given volume, and at a given temperature, is equal to the sum of the pressures exerted by the individual components of the mixture if each alone filled the container at the same temperature</u> ✓.

  It is as if each gas were unaffected by the presence of the other gases.

  If there are k gases present in a mixture, then for each of these gases the universal ideal gas equation can be written as: ✓

  $P_i V = n_i R^* T$ ✓

- Thermodynamic wet-bulb temperature *BBook pg347* (4)

  Answer:

  The thermodynamic wet-bulb temperature is a <u>thermodynamic property of air that is of great importance in psychrometry</u> ✓. The thermodynamic wet-bulb temperature is defined <u>through an ideal process, in which problems such as extraneous sources of</u> ✓ ✓

heat are excluded. It provides a precisely defined temperature which can be used in the calculation of psychrometric properties, and which provides a yardstick against which the performance of actual instruments can be measured.

- Overall coefficient of heat transfer *BBook pg 376* (3)

  Answer:

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

1.3 The calculation procedures are easily programmed for computer use and can be summarised as shown below, where it is assumed that the barometric pressure and the wet-bulb and dry-bulb temperatures are known. Both temperatures are assumed to be according to IPTS-68, and the wet-bulb temperature is assumed to be the thermodynamic wet-bulb temperature. Explain the 9 steps required for the Hyland and Wexler's calculations method for equations and numerical values needed to calculate psychrometric properties of temperatures and pressures? (9)

Answer: BBook page: 352

Full details of Hyland and Wexler's work will not be presented here. Their publications provide all the equations and numerical values needed to calculate psychrometric properties over a very wide range of temperatures and pressures. The calculation procedures are easily programmed for computer use and can be summarised as shown below, where it is assumed that the barometric pressure and the wet-bulb and dry-bulb temperatures are known. Both temperatures are assumed to be according to IPTS-68, and the wet-bulb temperature is assumed to be the thermodynamic wet-bulb temperature.

1. Correct the wet-bulb and dry-bulb temperatures to the thermodynamic temperature scale.
2. Calculate the vapour pressure at the wet-bulb temperature.
3. Using the enhancement factor, calculate the mole fraction of water vapour. This is a trial-and-error procedure because the value of the enhancement factor depends on the mole fraction of water vapour. An initial value of 1 is assumed for the enhancement factor and this then leads to a value for the mole fraction, which in turn leads to a value for the enhancement factor. This is repeated until successive values of the enhancement factor differ by less than one part per million.
4. Calculate the enthalpy of saturated air at the wet-bulb temperature.
5. Calculate the enthalpy of water (or ice) at the wet-bulb temperature.
6. Use simple psychrometry to obtain a first estimate of the mole fraction of water vapour for the moist air at the measured wet-bulb and dry-bulb temperatures.
7. Calculate the enthalpy and specific volume of the moist air.
8. Use the steady-flow energy equation for the thermodynamic wet-bulb temperature process to calculate the moisture content of the moist air and hence the mole fraction of the water vapour.
9. Repeat steps 7 and 8 until the two mole fraction values agree sufficiently well.

(24)

QUESTION 2

2.1 The age of an excavation, and the properties of the rock surrounding that excavation, play an important role in the flow of heat from the rock into the air within that excavation.
Consider the case of two identical tunnels with a DE = 3.66m, one is developed through quartzite, the other is developed through lava. The VRT through which these tunnels has been developed is 50°C. The ambient air temperature in both tunnels is a constant 28/30°C

These two different rock types have the following properties:

Rock property	Rock type	
	quartzite	lava
Density (kg/m³)	2670	2900
thermal conductivity (W/m°C)	6	3
specific heat content (J/kg°C)	850	900

Given that:
The rate of heat flow into an excavation, $q = 2\pi kT\ (tvrt - ts)$
where:

q	= heat flow from rock (W/m)
tvrt	= VRT (°C)
ts	= rock surface temperature (°C)
k	= thermal conductivity of rock (W/m°C)
T	= age factor
T	$= 0.685/Fo^{0.146}$
Fo	= Fourier number
Fo	$= \Theta a\ /\ (D/2)^2$
Θ	= *age* (s)
a	= thermal diffusivity (m²s)
a	$= k/wC$
w	= rock density (kg/m³)
C	= rock specific heat (J/kg°C)

2.1.1. Complete the table below:

1 year (Θ_{1YR}) = 3.2 x 10^7 seconds
10 years (Θ_{10YR})= 3.2 x 10^8 seconds

<u>Thermal diffusivity (*a*):</u>
quartzite; *a* $= k/wC = 6/(2670*850)$ = 2.6 x 10^{-6}
lava; *a* $= k/wC = 3/(2900*900)$ = 1.1 x 10^{-6}

<u>Fourier number (*Fo*)</u>:
Quartzite (1 year); *Fo* $= \Theta a\ /\ (D/2)^2 = (3.2 \times 10^7 * 2.6 \times 10^{-6})/(3.66/2)^2 = 25$
Quartzite (10 year); *Fo* $= (3.2 \times 10^8 * 2.6 \times 10^{-6})/(3.66/2)^2 = 249$
Lava (1 year); *Fo* $= (3.2 \times 10^7 * 1.1 \times 10^{-6})/(3.66/2)^2 = 11$
Lava (10 year); *Fo* $= (3.2 \times 10^8 * 1.1 \times 10^{-6})/(3.66/2)^2 = 108$

<u>Age factor (*T*)</u>:
Quartzite (1 year); *T* $= 0.685/Fo^{0.146}$ $T = 0.685/25^{0.146} = 0.428$
Quartzite (10 year); *T* $= 0.685/249^{0.146}$ = 0.306
Lava (1 year); *T* $= 0.685/11^{0.146}$ = 0.484
Lava (10 year); *T* $= 0.685/108^{0.146}$ = 0.346

Heat flow rate (W/m):
Quartzite (1 year); $q = 2\pi kT\ (tvrt - ts)$ = 2*π*6*0.428*(50-30) = 323W/m
Quartzite (10 year); q = 2*π*6*0.306*(50-30) = 231W/m
Lava (1 year); q = 2*π*3*0.484*(50-30) = 182W/m
Lava (10 year); q = 2*π*3*0.346*(50-30) = 130W/m

Age	Property	Rock Type	
		Quartzite	Lava
1 year	Fourier number	25	11
	age factor	0.428	0.484
	Heat flow rate (W/m)	323	182
10 year	Fourier number	249	108
	age factor	0.306	0.346
	Heat flow rate (W/m)	231	130

(6)

2.1.2. Comment on the heat flow rate from the two different rock types, also comment on the effect of age on heat flow rates from these two rock types.
As the age of the excavation increases, the heat flow rate from the surrounding rock decreases. Heat flows from the quartzite rock into the excavation at a much greater rate (almost double). (2)

2.2 At The heat production in a stope is 2kW/m of face when the entering stope wet-bulb temperature is 26.0ºC. Air enters the stope at 26.0/29.0ºC. 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 12.0 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:

Use the equation details below:

$$v = 0.2 \text{ x } \sqrt{\text{Q}}$$

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

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

Consider stope quantities between 10.0 and 20.0 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 for various entering quantities, to be able to read off the quantity required.)

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

$$\emptyset = 36.5°C - twb$$

$$Kata = 0.7\emptyset + \emptyset\sqrt{\text{v}}$$

Answer: Q&A Question 3 pg11

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 (v) = 0,896 m³/kg

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

$$S_{ao} = \frac{heat\ in\ stope\ (kW)}{mass\ flow\ of\ air\ (\frac{kg}{s})} + S_{aoi}$$

$$\text{But } m = \frac{Q}{v}$$

$$\text{Therefore } S_{ao} = \frac{300\ x\ v\ air\ into\ stope}{Q\ air\ into\ stope} + S_{aoi}$$

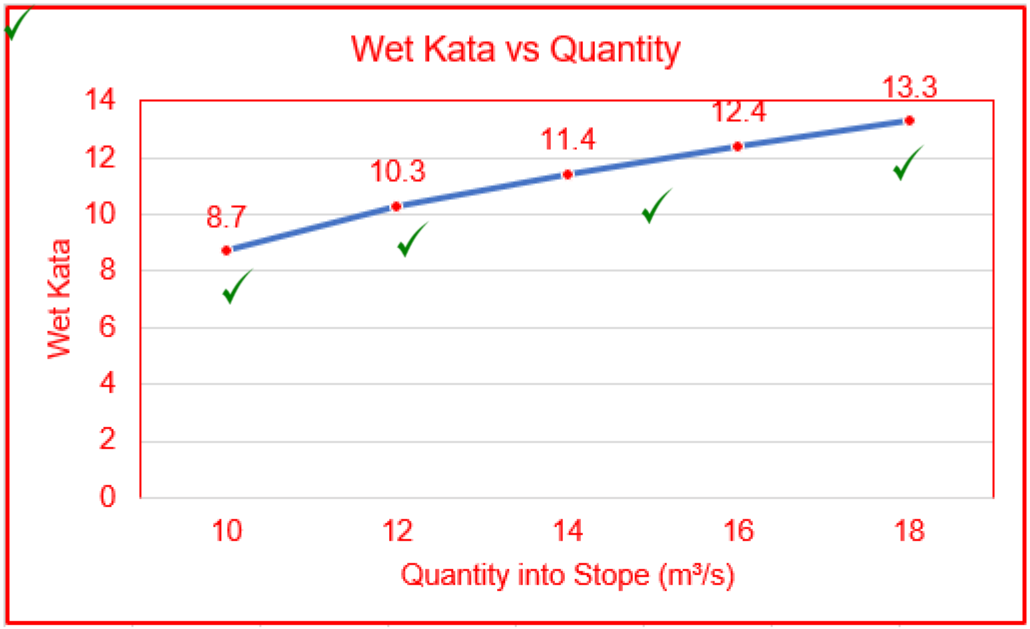
$$= \frac{300\ x\ 0.896}{Q} + 78.8$$

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	**S_{out} kJ/kg**	**t_{wb} out ºC from chart**	**t_{wb} in stope 1ºC less in stope**	**36,5-t_{wb} ºC**	**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. The value is 15.1 m³/s.


Wet Kata vs Quantity
14
12
10
8
6
4
2
0
Wet Kata
8.7
10.3
11.4
12.4
13.3
10
12
14
16
18
Quantity into Stope (m³/s)

(22)

(30)

QUESTION 3

3.1. 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: *Q&A Q20 pg52*

3.1.1 The amount of fuel consumed in litres/second

Answer:

Amount of fuel consumed = Rated power x utilization % x rate of fuel consumption

$= 187 \times 0.8 \times \frac{0.178}{3600}$ ✓

= 0.007397 l/s or 26.6 l/h ✓

3.1.2 The amount of water produced in litres/second

Answer:

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

3.1.3 The total amount of heat produced (kW)

Answer:

Amount of heat produced = fuel consumption in litres/second x Calorific value of diesel ✓
= 0,007397 x 35 000 ✓
= 259 kW

3.1.4 The heat factor for the machine

Answer:

Heat factor $= \frac{\text{heat produced}}{\text{rated kW power}}$ ✓

$= \frac{259}{187}$ ✓

= 1.39 rounded to 1.4

3.1.5 The split in latent and sensible heat produced by the machine (kW)

Answer:

Latent heat produced water = Amount of water x latent heat of water

= 0.007397 x 2450 ✓

= 18.1 kW ✓

Total heat produced = latent heat produced + sensible heat produced ✓

Sensible heat produced = Total heat – Latent heat ✓

= 259 – 18.1

= 240.9 kW ✓

(12)

3.2. A quantity of 75.0m³/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. *Q&A 30 p70*

3.2.1 If the maximum permissible wet-bulb temperature is 32.0°C, what rate of heat pick-up (kW) can the air absorb in the stope? (5)

Answer:

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 30.0°C 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 26.5°C

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 = 26,5°C) = 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)

(24)

QUESTION 4 *Q&A No.3 pg 83*

4.1 What A section of a mine is to be ventilated with a booster fan installed in the return. A cooling installation serving the section will reject its heat into the return air handled by the fan. The fan duty is 80 m³/s at 5.0 kPa at an inlet air density of 1.4 kg/m³ and the fan has an overall efficiency of 78%. The booster fan is situated in the RAW a distant away from the workings.

Air leaves the section at 31.5/32.3ºC at a barometric pressure of 125.0 kPa. The cooling installation has a rated duty of 4 800 kW, and an actual compressor COP of 3.6.

4.1.1 Calculate the air temperatures at fan inlet, fan discharge, cooling tower inlet and cooling tower discharge for the situations when the fan is installed on the inlet side of the tower and when the fan is installed on the discharge side of the tower. Ignore the effect of density changes on the fan duty.

Answer:

Evaporator duty given = 4 800 kW ✓

Overall compressor COP given = 3.6

Compressor input power $= \frac{Evaporator\ duty}{\text{Actual compressor COP}}$ ✓

$= \frac{4800}{3.6}$

= 1 333 kW ✓

The condenser duty = Evaporator duty + compressor input power (Heat balance)

= 4800 + 1333

= 6 133 kW ✓

Heat added by the Fan $= \frac{Air\ Power(Wa)}{Overall\ Efficiency\ of\ Fan}$

$= \frac{5.0\ x\ 80.0}{0.78}$

512.8 kW ✓

Using the psychrometric chart, the sigma heat and specific volume (v) of the air leaving the section, i.e. 31,5/32/3ºC at 125 kPa:

Sigma heat of air = 89.5 kJ/kg ✓

Specific volume (v) = 0,729 m³/kg ✓

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

$= \frac{80.0}{0.729}$

= 109.7 kg/s ✓

Fan at the inlet of the tower *<u>(assuming no change in moisture content and the value for r = 23,5 g/kg)</u>*

Sigma heat at inlet to fan = 89.5 kJ/kg ✓

Sigma heat increase across fan $= \frac{Heat\ added\ by\ the\ fan\ (kW)}{Massflow\ of\ air}$

$= \frac{512.8}{109.7}$

= 4.7 kJ/kg ✓

Sigma heat at fan outlet = 89.5 + 4.7

= 94.2 kJ/kg ✓

Sigma heat increase across tower $= \frac{Heat\ added\ in\ Tower\ (kW)}{Massflow\ of\ air}$

$= \frac{6133}{109.7}$

= 55.9 kJ/kg ✓

Thus Sigma heat at Tower outlet = 94.2 + 55.9

= 150.1 kJ/kg

The temperature at the inlet of the fan at 31.5/32.3°C at 125.0kPa

From the psychrometric charts and the information above:

At the outlet of fan = 33.2/37.5ºC at **<u>NB: 130 kPa</u>** ✓

At the inlet of tower = 33.2/37.5ºC at **<u>NB: 130 kPa</u>** ✓

At the outlet of the tower = 43.0/43.0ºC at **<u>NB: 130 kPa</u>** ✓

<u>Fan at the discharge of the tower (assuming no change in moisture content)</u>

Sigma heat at inlet to tower = 89,5 kJ/kg

Sigma heat increase across tower $= \frac{Heat\ added\ in\ Tower\ (kW)}{\text{Massflow of air}}$

$= \frac{6133}{109.7}$

= 55.9 kJ/kg ✓

Sigma heat at tower outlet = 89.5 + 55.9

= 145.4 kJ/kg

Sigma heat increase across fan $= \frac{Heat\ added\ across\ Fan\ (kW)}{\text{Massflow of air}}$ ✓

$= \frac{512.8}{109.7}$

= 4.7 kJ/kg

Sigma heat at fan outlet = 145.4 + 4.7

= 150.1 kJ/kg ✓

The temperatures at the inlet of tower = 31.5/32.3ºC at 125 kPa

From the psychrometric charts and the information above:

At the outlet of tower	= 41.8/41.8ºC at **125 kPa**	✓
At the inlet to the fan	= 41,8/41,8ºC at **125 kPa**	✓
At the outlet of the fan	= 43,0/46,2ºC at **NB: 130 kPa**	✓

4.1.2 What are the advantages and disadvantages of the two fan sites?

Answer:

The main advantage of positioning the fan at the inlet to the tower is that it operates in air, which is not saturated. Hence there will be less damage to the fan and fan motor. When the fan is situated at the outlet of the tower it operates in saturated air and the motor would normally have to be positioned in drier air. ✓

(22)

(22)

The following charts to be included: Psychrometric charts:

100.0kPa, 120.0kPa, 125.0kPa and 130.0kPa.