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: **Marco Biffi**
SUBJECT CODE: **COMMEC2**	
EXAMINATION DATE: **09 October 2019**	TOTAL MARKS: **[100]**
TIME: **14:30 – 17:30 (3½ HOURS)**	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 **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: 85.0kPa, 95.0kPa, 97.5kPa, 100.0kPa, 105.0kPa, 115.0kPa and 120.0kPa.**

QUESTION 1.

1.1 300 m^3/s of air at a temperature of 13,6/20ºC enters a 1 800m deep downcast shaft. The barometric pressure is 85.0 kPa. During its passage down the shaft the air picks up heat from the surroundings at a rate of 1,15 kJ/kg per 300m and moisture from the surroundings at a rate of approximately 0,5 g/kg per 200m.

At the bottom of the shaft, where the barometric pressure is 105.0 kPa, the air passes through a haulage that is 1 600 m long (horizontal). In the horizontal airway the air picks up 2 890 kW of heat and 1,8 litres/second of water evaporates into the air. No air leakage takes place.

Assume the barometric pressure remains constant in the horizontal airway.

1.1.1 Determine the wet-bulb and dry-bulb temperature of the air at the end of the airway.

Answer: Q&A Question 5

From the 85 kPa psychrometric chart at 13,6/20ºC read off the properties of the air:

Specific volume of air entering shaft = 1,005 m^3/kg ✓

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

$= \frac{300}{1.005}$

$=$ 298.5kg/s ✓

Changes to the condition of the air in the shaft, three aspects to be considered, heat of compression (9,79 kJ/kg/1000 m), heat from surroundings (as given) and moisture pick up from surroundings (as given):

heat of compression $= \frac{9.79}{1000} \times 1800$

$=$ 17.62 kJ/kg ✓

heat of surroundings $= 1.15 \times \frac{1800}{300}$

$=$ 6.9 kJ/kg ✓

moisture pickup $= 0.5 \times \frac{1800}{200}$

$=$ 4.5 kJ/kg ✓

Changes to the condition of the air in horizontal airway, two aspects to be considered , heat from surroundings (as given) and moisture pick up from surroundings (as given, remember 1,8 litres/second is 1800 g/s if we assume 1 litre of water is 1 kg):

heat of surroundings $= \frac{2890}{298.5}$

$=$ 9.68 kJ/kg ✓

moisture pickup = $\frac{1800}{298.5}$
= 6.03 g/kg ✓

Conditions of the air at the top of the shaft:
Heat content of the air = 42,4 kJ/kg
Moisture content of air = 9,0 g/kg ✓

Condition of the air at the end of the airway:
Heat content = 42,4 + 17,62 + 6,9 + 9,68
= 76,6 kJ/kg
Moisture content = 9,0 + 4,5 + 6,03
= 19,5 g/kg ✓

Therefore from the 105 kPa psychrometric chart read off the temperature at the end of the air way:

Temperature of the air at the end of the 1 600 m airway is 26,1/28,8ºC ✓

(10)

1.1.2 Determine the heat increase in the shaft due to auto compression in kW and what percentage does it make up of the total amount of heat added to the air in the shaft?

Answer:

Heat increase due to auto-compression:
q = m x heat of compression
= 298,5 x 17,62
= 5 260 kW ✓✓

Total heat increase in heat in the shaft:
= 17,62 + 6,9
= 24,52 kJ/kg ✓✓

Increase in heat due to auto-compression:

% increase in heat due to auto compression = $\frac{17.62}{24.52}$ x 100%
= 71.9% ✓

(5)

1.2 Give brief explanation for the following terms:
Answers: Data Book 2 - Heat

- Effective temperature
  This is defined as the temperature of a saturated environment with no air movement which would produce the same immediate temperature sensation as the environment being considered. Effective temperature is

a function of wet-bulb temperature, dry-bulb temperature and air movement. ✓✓

- Metabolic rate
  Metabolic rate is the rate at which energy is generated by various chemical processes of the body to do work and sustain life, and is associated with the production of heat and the consumption of oxygen. ✓✓

- Heat Tolerance Screening (HTS)
  The objective of HTS is to identify gross heat intolerance. It is not to be confused with heat tolerance testing. It applies to all employees routinely exposed to wet-bulb temperatures ≥ 27,5°C. ✓✓

- Natural Acclimatization
  This is the development of heat tolerance over a period of 12 consecutive underground shifts. No restrictions are applicable to the job or work category. ✓✓

- Deterministic effects
  Deterministic effects are those for which a threshold of radiation dose exists, and the severity of the effect increases with radiation dose above this level eg, cataract formation, fibrosis of lung tissue. ✓✓

(10)

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QUESTION 2.

2.1 Use the Steady Flow Energy equation to discuss the heat that is added to the air by the use of electrical machinery underground, that perform thermodynamic work (e.g. Hoists) and those that do not (e.g. auxiliary fans).

Answers: Q&A 16

If the work done by a machine is work against friction, then all of the input energy will be given off as heat. If the machine does work against gravity, that is where the energy used is converted into potential energy, then the energy not used to do the work is converted to heat. Example, if a machine is 90% efficient, then 10% of the energy will input will be given off as heat. ✓✓

From the steady flow energy equation, the following:

$$W + q = m\left(dH + \frac{dv^2}{2} + gdz\right)$$

$$dH = \frac{q + W}{m} - \left(\frac{dv^2}{2} + gdz\right) \quad ✓$$

Where W = rate of work entering control envelope (kW)

q = rate of heat flow into the envelope (kW)

H = Enthalpy of the air (kJ/kg)

G = gravitational acceleration (m/s²)

v = velocity of air (m/s) ✓

z = elevation (m)

m = mass flow of air (kg/s)

For a fan, q = 0, because there is no external heat sources, the difference between the

inlet and outlet velocity (dv) is negligible and dz = 0. Therefore dH as follows:

$$dH = \frac{W}{m} \quad ✓$$

For a hoist, if the velocity change is small and there are no external heat sources, dH as follows:

$$dH = \frac{W}{m} - (g(-dz))$$

$$= \frac{W}{m} + gdz$$

Note: dz = negative for rock hoisted out of the mine.

(6)

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

Intake air volume 236 m³/s

Fan pressure 5 kPa

Temperature 24/27ºC

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.

Answers:

Using the 115 kPa psychrometric chart, the characteristics of the air can be determined

The specific volume of the air in main airway = 0,762 m³/kg

The quantity of air in the main airway = 236 m³/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(system $= \frac{Q}{v}$

$= \frac{236}{0.762}$

$=$ 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 $= \frac{kW}{m}$

$= \frac{1775}{310}$

$=$ 5.73kJ/kg

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

$=$ (64.5+5.73)

$=$ 70.2kJ/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.

Answers:

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 $\text{motor}_{\text{efficiency}}$

= 1 775 x 0,95

= 1 686 kW ✓

The fan efficiency can now be determined as follows:

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

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

= 70% ✓

The fan overall efficiency can now be determined as follows:

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

= $\frac{1180}{1775}$ x 100%

= 66% ✓

(11)

2.3 The following measurements were taken at the inlet of an underground hoist chamber.

Temperature 26,3/29,5ºC

Barometric pressure 115 kPa

Hoist motor input power 2 170 kW

Motor efficiency 87%

How much air must be supplied to the hoist chamber to ensure that the wet-bulb temperature in the chamber does not exceed 28,5ºC wet-bulb? State any assumptions you make in giving your answer.

Answers:

Using the 115 kPa psychrometric chart, the characteristics of the air can be determined:

The specific volume of the air entering chamber	=	0,778 m^3/kg	✓
Sigma heat of the air entering chamber (26,3ºC)	=	72,8 kJ/kg	✓
Sigma heat of the air leaving chamber (28,5ºC)	=	83,5 kJ/kg	✓
Specific humidity of air entering chamber	=	17,5 g/kg	✓
The allowable increase in Sigma heat	=	83,5 – 72,8	
	=	10,7 kJ/kg	✓

The waste heat given off to the air by the motor can be determined as follows:

Waste heat to air $= \frac{100-87}{100} \times 2170$

$= 0.13 \times 2170$

$= 282$kW ✓

Massflow to air $= \frac{282}{10.7}$

$= 26.4$kg/s ✓

Air volume = m x v

$= 26.4 \times 0.778$

$= 20.5 m^3/s$ ✓

That all energy provided to the hoist by its motor is converted to-thermodynamic work.

(8)

(25)

QUESTION 3.

3.1 You are the Ventilation Engineer on a shaft and you have to make an estimate of the heat load potential of a new kind of explosive to be tested on your shaft. The following technical details of the explosive are available.

- ANFO Explosives heat release 3 700 kJ/kg of explosives
- The charge density of ANFO explosives 0,8 kg/ton of rock blasted

It is known that the heat generated by the explosives will be removed in two stages, namely with the blasting fumes and some will be retained in the rock as heat. With high fragmentation it is assumed that 45% of the heat will be removed with the fumes. It is also estimated that 20% of the heat will be removed within the first hour after blasting. The amount of rock to be blasted is 2000 tons and assume the Cp of rock as 950 J/kg^{o}C.

Determine the following:

3.1.1 The total amount of heat produced by the explosives (kJ)

Answers: Q&A 23

The total amount of heat produced can be calculated as follows:

Heat produced by explosives = mass of explosives used x heat release rate of explosives

= (2 000 x 0,8) x 3 700

= 5 920 000 kJ ✓

3.1.2 How much of the total heat produced remains in the rock and is not removed with the fumes (kJ)

Answers:

Heat remaining in the rock = total amount of heat released x percentage remaining

= (5 920 000) x (100-45)%

= 3 256 MJ ✓

3.1.3 The rate at which heat energy is removed removed with the fumes within the first hour after blasting

Answers:

Rate at which heat energy is removed in first hour = $\frac{\text{total amount of heat released}}{60\text{x}60}$ x 0.2

= $\frac{5\ 920\ 000}{3600}$ x 0.2

$$= \quad 329 \text{ kW} \quad ✓✓$$

3.1.4 The rise in temperature of the rock blasted within the first hour

Answers:

Amount of Heat in rock(kJ) = mass of rock x $C_{p\ rock}$ x Δt

$$\Delta t = \frac{heat\ in\ rock(kJ)}{\text{mass of rock x Cp rock}}$$

$$= \frac{5\ 920\ 000\ x\ 80/100}{2000 \text{ x } 1000 \text{ x } 0.950}$$

$$= 2.49 \text{ say } 2.5^{o}C \quad ✓✓$$

3.1.5 What would be the rise in temperature in the rock be (within the first hour) if the explosives used were a nitro glycerine based explosive with a heat release rate of 5800 kJ/kg explosive used assume same charge density.

Answers:

Amount of Heat in rock(kJ) = mass of rock x $C_{p\ rock}$ x Δt

$$\Delta t = \frac{heat\ in\ rock(kJ)}{\text{mass of rock x Cp rock}}$$

$$= \frac{2000\ x \frac{0.8kg}{kg} x\ 5800x\ 0.8\%\ remaining}{2000 \text{ x } 1000 \text{ x } 0.950}$$

$$= 3.9^{o}C \quad ✓✓$$

With all factors remaining the same the temperature could also have been calculated as a ratio. With ANFO used (3 700 kJ/kg) the rise in temperature was 2.49ºC. With nitroglycerine based explosives used the rise would be:

$$= \frac{5800\ x\ 2.49}{3\ 700}\ ^{o}C$$

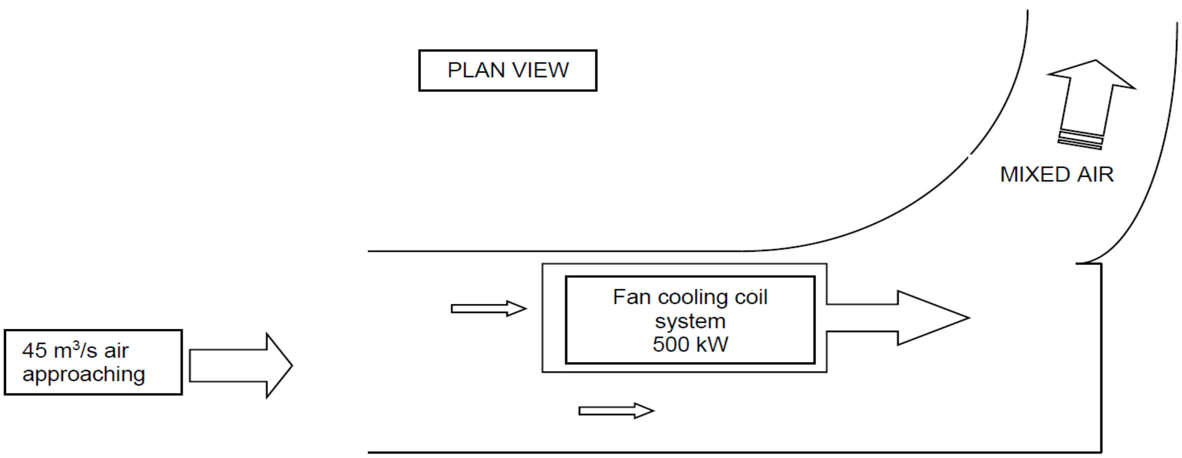
$$= 3.9^{o}C \quad ✓✓$$

(10)

3.2 A cooling unit has been suggested to improve the working conditions in a workplace on a mine. The current intake air temperature is 30.0/32.0ºC at a barometric pressure of 102.5 kPa. It is suggested that the cooling unit/cooling coil that is made up of the combination of a fan and chilled water reticulation system will be able to draw air through the system at an intake quantity of 20m³/s and the duty of the cooling coil is 500 kW. A 45 kW fan is used in the cooling coil. The cooling coil will be installed in the main haulage and no recirculation is expected. The main airflow quantity in the haulage is 45.0m³/s.

Determine the exit conditions of the air after mixing of the air took place. Mine management expects that through this arrangement that they will be able to offer an intake wet-bulb temperature of 28.0ºC to the work place (ignore the increase pressure effect of the cooling coil fan). Use the 102.5 kPa psychrometric chart to help you to determine the various properties of the air for this scenario.

Comment on your answer based on the expectation. How can the conditions be improved further if need to. The drawing below will help to understand the problem.



(15)

Answers: Q&A 29

From chart/check with calculations entry conditions into haulage:

Temperature of air in the haulage = 30.0/32.0ºC

Barometric pressure = 102,5 kPa

The specific volume read off chart = 0,890 m³/kg ✓

The moisture content in the haulage = 26.0 g/kg ✓

The Sigma heat in the haulage = 95,4 kJ/kg ✓

$$\text{Massflow}_{\text{air intake}} = \frac{Q}{v}$$

$$= \frac{45.0}{0.890}$$

= 50.6kg/s ✓

Massflow air intake air cooling coils $= \frac{Q}{v}$

$$= \frac{20.0}{0.890}$$

= 22.5kg/s ✓

Massflow of air past coils = 50.6 – 22.5

= 28.1kg/s ✓

The total mass flow however after mixing still 50.6 kg/s

Now determine the ΔS over the cooiling coils

kW duty cooiling coils = m x ΔS

$$\Delta S = \frac{kW}{m}$$

$$= \frac{500}{22.5}$$

= 22.2 kJ/kg ✓

Heat exchanged in kJ/kg for fan $= \frac{kW}{m}$

$$= \frac{45.0}{22.5}$$

= 2.0 kJ/kg ✓

The fact that the air splits into the coil the S_{out} of cooler can be determined as follows:

S_{out} of coil therefore = S_{in} – ΔS_{cooler} + ΔS_{fan}

= 95,4 – 22,2 + 2.0

= 75,2 kJ/kg ✓

Assume that the air leaving the coil will be saturated, read off the temperature of the air from the 102.5kPa psychrometric chart so as to determine the moisture content as well.

Temperature read of as 25.5/25.5 ºC
The moisture content read off the 102.5 kPa psychrometric chart as 20.5 g/kg
The total mass flow of the air at mixing point as determined before 50.1 kg/s

The Sigma heat value and the moisture content of the mixing air must be determined:

Sigma Heat air at mix point $= \dfrac{(\text{m coil x S out coil})+(m\ bypass\ air\ x\ (S\ bypass\ air\ assume\ unchanged)}{\text{m mix}}$

$= \dfrac{(22.5 \text{ x } 75.2l)+(28.1\ x\ 95.4)}{50.6}$

= 87.3 kJ/kg ✓ ✓

Moisture content of air at mix point $= \dfrac{(\text{m coil x r out coil})+(m\ bypass\ air\ x\ (S\ bypass\ air\ calculated)}{\text{m mix}}$

$= \dfrac{(22.5 \text{ x } 20.5l)+(28.1\ x\ 26.0)}{50.6}$

= 23.7 kJ/kg ✓ ✓

From the 102.5 kPa Psychrometric chart, where 87,3 kJ/kg intersects the r line at 23,7g/kg, the temperature can be read off:

The temperature of the air at mixing point is approximately 28.2/28.2ºC ✓

The conditions can be further improved by ensuring that the air is kept as dry as possible by avoiding excessive water in the haulage as well as to maybe consider putting more air through the cooling coil so as to reduce the temperature of the mixing air even further. ✓

(25)

QUESTION 4.

4.1 List at least 5 advantages and disadvantages of using ice as a medium for providing cooling in a deep mine (> 3000m).

(10)

Answers: Q&A 28a

Advantages	Disadvantages
- Water for cooling can be delivered at extremely low temperature (< 5OC) to cooling installations far from surface. (Excellent PE) - Relatively low volumes of water (ice) circulated from surface – greatly reduced pumping cost. - Capacity of installation virtually unlimited, modular can be expanded relatively easily. - Situated on surface – can use freely available refrigerants (ammonia) - On surface, maintenance and supervision is more effective	- Very expensive capital outlay makes this technology on suitable to very deep or long lived mining operations - Requires a relatively large surface installation (large "footprint") with complicated and expensive delivery system to the shaft head. - Relatively large plastic conveying piping required from surface through shaft infrastructure to melting dam. - Large excavations required for melting ice underground. - Large piping infrastructure required to circulate cooling water.

4.2 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.

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 115ºC (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 26,5ºC. 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:

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

Answers: Q&A 31

At what rate does heat pass through the wall by means of c onduction?

Heat passes through the wall by means of conduction.

$$q = \frac{kA(t1-t2)}{B} \checkmark$$

Where; q = conductive heat transfer rate through the wall (W)

k = conductivity of wall (W/m°C)

A = cross-sectional area of the wall (m^2)

t1 = temperature of the wall on furnace side (°C)

t2 = temperature of the wall on office side (°C)

B = thickness of the wall (m)

First determine the overall conductivity value for the wall (k = W/m°C) (answer will be in W/m °C)

$$k = \frac{(Wbrickwall\ x\ kbrick)+(Wplaster\ x\ kplaster)}{\text{Wwall}} \checkmark$$

$$= \frac{(0.2\ x\ 0.7)+(2.0\ x\ 0.015\ x\ 0.93)}{(2.0\ x\ 0.015)+0.2}$$

$$= 0.73\ \text{W/m°C} \checkmark\checkmark$$

$$q = \frac{kA(t1-t2)}{B}$$

$$= \frac{0.73 \text{ x } (4 \text{ x } 2) \text{ x } (115-55)}{0.23}$$

$$= 1523.5\ \text{W} \checkmark\checkmark$$

4.2.2 The convective heat transfer co-efficient for the wall

Answers:

The convective heat transfer co-efficient for the wall can be determined as follows:

$q_c = h_c A (t_1 – t_2)$

Where;

q = convective heat transfer rate (W)

h_c = convective heat transfer coefficient (W/m^2)

A = contact surface area (m^2)

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 = 1523.5 W

$q_c = h_c A (t_1 – t_2)$

$$h_c = \frac{q_c}{A(t_1 - t_2)}$$

$$= \frac{1523.5}{(4 \times 2) \times (55 - 26.5)}$$

= 6.682 W/m^2

4.2.3 How much radiated heat is experienced by the clerk

Answers:

The amount of radiated heat received/experienced by the clerk

q = 5,67 x 10-8 A1 Fev(T14 - T24)

Where; q = radiative heat transfer rate (W)

A1 = exposed area of smaller body (m^2)

Fev = emissivity and view factor

T1 = absolute temperature of hotter body (K)

T1 = (273.15 + 55)

= 328.15 K

T2 = absolute temperature of cooler body (K)

T2 = (273.15 + 28)

= 301.15 K

q = 5,67 x 10-8 x 0.8 x 0.95 x (328.154 – 301.154)

= 5,67 x 10-8 x 0.8 x 0.95 x 3.371 x 109

= 145 W

(15)

(25)

Colin add psychrometric charts 85.0, 95.0, 97.5, 100, 105, 115 and 120