Chamber of Mines of South Africa

EXAMINATION PAPER

SUBJECT: CHAMBER OF MINES OF SOUTH AFRICA – INTERMEDIATE CERTIFICATE IN MINE ENVIRONMENTAL CONTROL PAPER ~~1~~2	**EXAMINER:** E Botha **MODERATOR:** M Biffi
SUBJECT CODE: **COMIMEC** **EXAMINATION DATE:** **TIME**: 14:30 – 17:30	**TOTAL MARKS:** [100] **PASS MARK:** (60%)

NUMBER OF PAGES: 6

SPECIAL REQUIREMENTS:

THIS IS NOT AN **OPEN BOOK EXAMINATION**. THERE IS NO FORMULA HANDOUT

INSTRUCTIONS TO CANDIDATES:

1. Answer all 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) are recorded as marks will be deducted from answers if the incorrect unit is used. (even if the calculated value is correct).
8. In answering the questions, full advantage should be taken of your practical experience as well as data given.
9. Please note that you are not allowed to contact your examiner or moderator regarding this examination.
10. Cell phones are **NOT** allowed in the examination room.

QUESTION 1

1.1 Briefly define each of the following terms and state the units in which these terms are expressed.

1.1.1 Dew point temperature (2)

Dew point temperature (symbol = tdp1, units = °C) of an air vapour mixture is that temperature to which the air must be cooled (at a constant pressure) in order for condensation to begin. At this temperature the air becomes saturated.

1.1.2 Apparent specific volume (2)

Apparent specific volume (symbol = v, units = m^3/kg) of and air / vapour mixture is the volume per unit mass of dry air.

1.1.3 Apparent specific humidity (2)

Apparent specific humidity (symbol = ASH, units kg/kg) of an air vapour mixture is the mass of water vapour present per unit of dry air.

1.1.4 Density (2)

Density (symbol = w, units = kg/m^3) of an air vapour mixture is the mass of vair (dry air and water vapour) per unit volume of vair.

1.1.5 Enthalpy (2)

Enthalpy (symbol e, units = kJ/kg) is the sum of internal energy and pressure energy of the dry air and water vapour components of and air water vapour mixture.

1.1.6 Vapour pressure (2)

Vapour pressure (symbol = pw, units kPa) of an air / vapour mixture is the partial mixture pressure of the water vapour in that mixture.

1.2 15 m^3/s of air with a temperature of 29.0/31.0°C with a barometric pressure of 110 kPa is flowing in a tunnel. A cooling coil with a 22 kW fan is installed in the haulage. Water enters the coil at 6° and leaves at 15°C. The fan delivers 7.2 m^3/s of air. The intake temperature of the fan is 29.0/31.0°C. The delivery temperature of the cooling coil is 23.0/23.0°C.

Commented [BM1]: 110KPa psychrometric chart is required.

1.2.1 Calculate the heat removed from the air. (3)

Condition of the air before entering the cooling coil at 110 kPa barometric pressure and a temperature of 29.0/31.0

Sigma heat content, S_1 = 86.276 kJ/kg

A.S.V of the air (v) = 0.822 m^3/kg

Mass flow of the air through cooling coil (m_1) = Q / v

= 7.2 / 0.822

= 8.8 kg/s (1)

Conditions at 23.0/23.0°C

Sigma heat content, S_2 = 69.972 kJ/kg

The heat removed from the air = m_1 x (S_1-S_2)

=8.8 x (86.276 - 69.972)

= 204.0 kW (1)

There is a 22kW fan supplying the air through the cooling coil.

Heat removed from the air is thus 204.0 kW + 22 kW = 226 kW (1)

1.2.2 Calculate the water flow rate (2)

Mass flow (water) = heat removed / ((4.187 x (16.0 – 5.0)) (1)

= 6.0 l/s (1)

1.2.3 Calculate the amount of water condensate from the air. (2)

Moisture content of the air before entering the cooling coil ASH_1 = 22.632 g/kg

Moisture content of the air after exiting the cooling coil ASH_2 = 16.294 g/kg

Condensate from the air = mass flow of air x ($ASH_1 - ASH_2$) (1)

= 8.8 kg/s x (22.632 g/kg – 16.294 g/kg)

= 55.47 g (1)

Psychro results

Wet-bulb temperature °C	29.00
Dry-bulb temperature °C	31.00
Pressure kPa	110.0
Enthalpy kJ/kg	89.34
Sigma Energy kJ/kg	86.57
Apparent Specific Humidity g/kg	22.75
Relative humidity %	86.03
True density kg/m^3	1.2437
Apparent density kg/m^3	1.2160
Dry density kg/m^3	1.2603
Saturated vapour pressure kPa	4.004
Vapour Pressure kPa	3.863
Dew point °C	28.38

Psychro results

Wet-bulb temperature °C	23.00
Dry-bulb temperature °C	23.00
Pressure kPa	110.0
Enthalpy kJ/kg	64.75
Sigma Energy kJ/kg	63.17
Apparent Specific Humidity g/kg	16.37
Relative humidity %	100.00
True density kg/m^3	1.2821
Apparent density kg/m^3	1.2614
Dry density kg/m^3	1.2945
Saturated vapour pressure kPa	2.808
Vapour Pressure kPa	2.808
Dew point °C	23.00

1.3.1 Briefly describe a closed loop cooling system and list its advantages. (4)

When cooling water (from the outlet of the evaporator) of a cooling plant is pumped through a piping system that is connected to cooling coils and the water then return to the inlet of the evaporator. (1)

Advantages- a) Less pumping costs, (1)

b) no water is discharged from the system, (1)

c) less cost for water treatment as the water is not exposed to the air. (1)

1.3.2 Briefly describe an open loop cooling system and list its advantages. (2)

a) When the cooling water (from the outlet of the evaporator) of a cooling plant is pumped through a piping system that is connected to cooling coils or open spray system. (1)

b) Advantages- Initially less expensive than a closed loop water system. (1)

[25]

QUESTION 2

2.1 Describe the design considerations for the construction of an underground condenser tower. (8)

a) Use as much air as possible but keep the velocity of air below 8 m/s. (1)

b) Optimum velocity to be 4 – 6 m/s range, (air). (1)

c) Water loading to be kept as low as possible (but never above 16 l/s per m^2) (1)

d) The barrel of the tower, i.e. sprays to the base of the tower should be 12 to 20m. (1)

e) Tower should extend two times the diameter above the sprays. (1)

f) Air should enter the tower radially at a velocity not exceeding 5 m/s. (1)

g) Water system should be maintenance free and ensure a uniform spray distribution. (1)

h) Smooth concrete walls should be avoided as this allows water to run down the surface of the tower barrel. (1)

2.2 The following conditions were measured at an underground cooling tower;

Air temperature in:	T= 30.5/31.3 °C
Air temperature out:	T= 40.5/40.5°C
Water temperature in:	T= 43.7°C
Water temperature out:	T= 36.5°C

2.2.1 Determine the water efficiency of this cooling tower. (2)

$\underline{W}_{eff} = [(t_{wi} – t_{wo}) / (t_{wi} – t_{wbi})]$ (1)

Where

t_{wi} = temperature of water entering the tower

t_{wo} = temperature of water leaving the tower

t_{wbi} = wet bulb temperature of air entering the tower (°C)

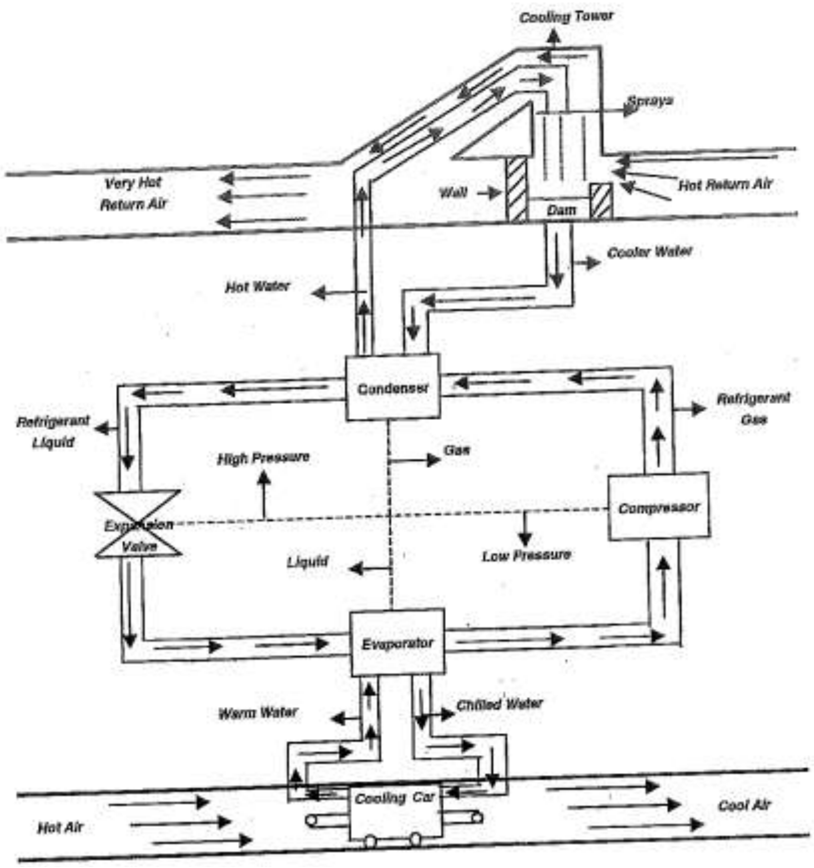
$W_{eff} = [(43.7-36.5) / (43.7 – 30.5)]$

Water efficiency of this cooling tower is 0.55 (1)

2.2.2 Comment your answer. (2)

The ratio would indicate that the heat transfer process in this tower is not particularly efficient (it is typical of the efficiency of an "un-packed" (1)underground condenser cooling tower) the closer this ratio is to 1 the better the level of performance of the tower. (1)

2.3 Sketch the complete Refrigeration cycle for an underground cooling plant including the Hot water cycle to the cooling towers and the Cold Water cycle to the cooling cars or bulk air coolers. Show all the key components and indicate areas of high or low temperatures for air, water and refrigerant cycles. (12)



2.4 Briefly explain the term COP used in refrigeration (1)

Coefficient of performance is used to quantify the performance of refrigeration cycles. COP is defined as the ratio of the desired cooling output to the required electrical power input. (1)

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QUESTION 3

3.1 The effects of heat on the underground personnel depend on a number of factors. List seven of these factors. (7)

a) Temperature $_{(1)}$

b) Humidity$_{(1)}$

c) Air velocity$_{(1)}$

d) Amount of heat radiated from the surrounding walls$_{(1)}$

e) Duration of exposure$_{(1)}$

f) Amount and type of clothing worn$_{(1)}$

g) State of health$_{(1)}$

h) Degree of acclimatization$_{(1)}$

3.2 Briefly describe six factors that influence the rate of heat flow from rock. Also give four methods to reduce the rate of heat flow from rock. (8)

a) Area of rock exposed $_{(1)}$

b) Conductivity of the rock $_{(1)}$

c) Temperature difference between the rock and air $_{(1)}$

d) Degree of wetness of the rock $_{(1)}$

e) Time of contact between the rock and air $_{(1)}$

f) The size of the excavations to be ventilated must be kept as small as possible. Reduce or prevent leakages through worked out areas $_{(1)}$

g) Ensure that contact time with the surrounding rock is reduced (i.e. increase air velocity over exposed rock surfaces) $_{(1)}$

h) Maintain intake airways as dry as possible $_{(1)}$

i) Insulate exposed rock surfaces in main intake airways $_{(1)}$

3.3 Discuss three significant sources of heat in a mine. (3)

a) Heat flow from rock. – Heat flow from exposed rock surfaces and from broken rock into the ventilating air. The rate of heat flow is primary driven by virgin rock temperature (VRT) and production rate (tons broken per month). (1)

b) Auto compression,- As an air mass descends it loses some of its potential energy, this energy is converted into heat. (1)

c) Heat from machinery,- This is dependent on the type of power used (the usual sources are electrical and diesel). Energy is required to lift or transport material (i.e. gravity or friction). In lifting material (e.g. hoisting or pumping) most energy supplied is converted to potential energy; the energy lost due to inefficiency is converted to heat. In transporting material horizontally all work done is to overcome friction and thus becomes heat. In diesel machinery, the heat generation is a function of fuel consumption rate and the calorific value of that fuel. (1)

3.4 Briefly discuss seven factors which can contribute towards heat intolerance in an underground worker. (7)

a) Physiological work capacity: - This is determined by physiological, biochemical and anatomical factors of each individual and cannot be changed significantly, Energy consumed by the metabolism is a function of oxygen consumption, and an energy inefficiency metabolism will produce relatively more heat in these individuals- as the work rate of these individuals increases so does their heat production rate. (1)

b) Dehydration- Prolonged periods of heat exposure can lead to excessive loss of water through perspiration. Consumption of diuretics such as alcohol and certain medication can also lead to dehydration. Dehydration comprises physiological response to heat stress. Dehydration also causes elevated heart rate, headaches, loss of appetite, behavioural changes and loss of morale. (1)

c) Body size- Body size (height and mass) determines the amount of surface area of the skin. Smaller persons are more likely to be heat intolerant. (1)

d) Age- Historic data indicates that heat tolerance decrease with age. Oxygen uptake as well as sweat production decrease with age. (1)

e) Illness- People who are ill usually have an elevated body temperature before being exposed to heat stress. Such persons are usually heat intolerant. Once recovered these persons usually regain their heat tolerance. (1)

f) Nutrition- Poor nutrition can contribute to heat tolerance. (1)

g) Inadequate thermoregulatory response- If the conductance of heat from the person's core or rate of sweat production is reduced then that person is at risk of being heat intolerant. (1)

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QUESTION 4

4.1 Briefly discuss the properties of an ideal refrigerant. (5)

a) The relationship between its temperature and pressure properties should be such that when at the upper and lower ranges of temperature, its pressure should be within the range of normal engineering practice. (1)

b) It should be abundant and inexpensive. (1)

c) Should not negatively affect lubricants used in the compressor. (1)

d) Should be environmentally friendly (not damage the ozone layer) (1)

e) Should be non-toxic. (1)

f) Should be non-flammable and non-explosive.

g) Leaks should be easily detected.

h) Should have a high latent heat of vaporisation.

4.2 List the properties of a good insulant. (5)

a) Must be effective (1)

b) Must not be a fire hazard (1)

c) Must be resistant to water logging (1)

d) Must be robust (1)

e) Must be inexpensive (1)

f) Easy to install

4.3 The following measurements were taken at a surface refrigeration plant using refrigerant R134. (15)

Barometric Pressure in the plant room	85kPa
Evaporator water flow rate	153 l/s
Evaporator inlet water temperature	16.0 °C
Evaporator outlet water temperature	5.0 °C
Evaporating temperature	0.4 °C
Condenser water flow rate	357 l/s
Condensing water temperature inlet	19 °C
Condensing water temperature outlet	24 °C
Condensing temperature	29.3 °C
Compressor:	
Motor current	100 A
Voltage	6590 V
Power factor	0.95
No. of phases	3
Motor efficiency	97%

Commented [BM2]: 85kPa psychrometric chart required

4.3.1 Determine the plant duty. (2)

$q_E = m \times Cp \times (Twi - Two)$ (1)

where;

m = mass flow rate of water through evaporator = 153 l/s

Cp = thermal capacity of water = 4.187 kJ/kg °C

Twi = inlet water temperature 16 °C

Two = outlet water temperature 5 °C

q_E = 153 x 4.187 x (16 – 5)

plant duty = evaporator duty = 7047 kW (1)

4.3.2 Determine the input power to the compressor motor.(2)

q_{MOTOR} = kV x I x p_F x √ ph (1)

q_{MOTOR} = motor input power

V = voltage (V)

I = current (amp)

p_F = power factor

ph = no. of phases

q_{MOTOR} = 6.59 x 100 x 0.95 x √3

q_{MOTOR} = 1084 kW (1)

4.3.3 Determine the heat balance. (5)

Evaporator duty (q_E) + compressor heat (q_{COMP}) = condenser heat (q_{COND})

Where evaporator heat q_E = 7047 kW

Assuming drive losses after the motor is negligible.

Compressor heat (q_{COMP}) = q_{MOTOR} x motor efficiency

Compressor heat (q_{COMP}) = 1084 x 0.97

Compressor heat (q_{COMP}) = 1051 kW (1)

(q_{COND}) = m x Cp x (Twi – Two) (1)

Where;

m = mass flow rate of water through condenser = 357 l/s

Cp = thermal capacity of water = 4.187 kJ/kg°C

Two = outlet water temperature 24.4 °C

Twi = inlet water temperature 19.0 °C

q_E = 357 x 4.187 x (24.0~~4~~ – 19.0)

condenser duty = 7474~~8072~~ kW (1)

Balance = (7047 + 1051) kW = 7474~~8072~~ kW (1)

8098~~8098~~ kW = 7474~~8072~~ kW, balance has an accuracy of 8.3~~0.3~~% (is less~~more~~ than 95% accurate and is thus not acceptable) (1)

Commented [BM3]: 24.0

Commented [BM4]: 7473kW

Commented [BM5]: 12.6%

4.3.4 Determine the Carnot COP (1)

Carnot COP = $T_1 / (T_2 - T_1)$

Where T_1 = absolute temperature of evaporation = 273.55 K

Where T_2 = absolute temperature of condensation = 302.45 K

Carnot COP = 273.55 / (302.45 – 273.55) (½)

Carnot COP = 9.5 (½)

4.3.5 Determine the overall (or plant) COP (1)

Overall ~~compressor~~ COP = cooling at evaporator / compressor motor input power

Overall ~~compressor~~ COP = 7047 kW / 1084 kW (½)

Overall ~~compressor~~ COP = 6.5 (½)

4.3.6 Explain the difference between Carnot COP and overall compressor COP (1)

The difference indicates how much the actual cycle performance differs from the ideal performance also known as the Carnot efficiency. (1)

Commented [BM6]: Also known as the Carnot efficiency

4.3.7 Determine the actual compressor COP (1)

Actual compressor COP = cooling at evaporator / compressor input power

Actual compressor COP = 7047 kW / 1051 kW

Actual compressor COP = 6.7 (½)

4.3.8 Determine the overall cycle efficiency (1)

Overall cycle efficiency = overall ~~compressor~~ COP / Carnot COP

Overall cycle efficiency = 6.5 / 9.5 (½)

Overall cycle efficiency = 68.4 % (½)

4.3.9 Determine the actual cycle efficiency. (1)

Actual cycle efficiency = actual compressor COP / Carnot COP

Actual cycle efficiency = 6.7 / 9.5 (½)

Actual cycle efficiency = 70.5 % (½)

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