Minerals Council South Africa

EXAMINATION MEMORUNDUM

SUBJECT: **CHAMBER OF MINES OF SOUTH AFRICA – CERTIFICATE IN MINE ENVIRONMENTAL CONTROL**	EXAMINER**: George Mapele**
PAPER 3 – ECONOMICS, PLANNING AND TECHNICAL LITERATURE	MODERATOR: **Aldo Oosthuizen**
SUBJECT CODE: **COMMEC3**	TOTAL MARKS: **[100]**
EXAMINATION DATE: **12 May 2022**	PASS MARK: **(60%)**
TIME: **14:30 – 18:00 (3 HOURS & 30 MINUTES)**	

NUMBER OF PAGES: 19

SPECIAL REQUIREMENTS:

THIS IS **NOT** AN **OPEN BOOK EXAMINATION**.

FORMULA HANDOUTS ARE AVAILABLE 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 your 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 measurement (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 the examiner or moderator regarding this examination.
9. Cell phones and any other electronic devices are **NOT** allowed in the examination room.

QUESTION 1 (20 POINTS)

1.1 Name five (5) factors that govern the air volume requirements when designing a shaft system. **(5)**

Answer

1.1.1 Desired working conditions (1) ✓

1.1.2 Depth of mining (1) ✓

1.1.3 Development programme (1) ✓

1.1.4 Down and up-cast facilities (1) ✓

1.1.5 Economics (1) ✓

1.2 During the planning stage of mine certain requirements for effective ventilation are to be considered as control measures and for economic viability. Describe briefly at least five (5) of the engineering requirements. **(5)**

Answer

1.2.1 To prevent fires and explosions (1) ✓

1.2.2 To ensure the local exhaust systems operate properly (1) ✓

1.2.3 To eliminate pressure differences at doors (1) ✓

1.2.4 To ensure complete combustion (1) ✓

1.2.5 To conserve energy (1) ✓

1.3. It has been decided by mine management to deepen it 's existing vertical shaft by 500m to establish 4 additional production levels. For sinking the 7.5 m diameter shaft a force exhaust system will be used. A minimum air volume of 20 m^3/s will be required at shaft bottom to ensure a 30-minute re-entry period directly after blast.

1.3.1 What is the maximum distance from the shaft bottom that the exhaust intake can be carried to ensure a 30 minutes' re-entry period? Discount over breaking of the rock in this calculation. Clearly state the assumption you make. **(6)**

Answer

The fan discharge volume = 20 m^3/s

Diameter of the shaft =7.5 m

Number of air change (Assume) =6 (2) ✓✓

Shaft Area = $\frac{\pi D^2}{4}=\frac{\pi 7.5^2}{4}$= 44.17 say 44.2$m^2$ (1) ✓

The total of air to be replaced by the fan in 30 minute is

Volume of air replaced =Q×re-entry period$_{(seconds)}$=20× (30×60) = 36 000 m^3(1) ✓

The maximum distance between the force discharge and the exhaust intake must be determined, the shaft area has been determined as 44.2 m^2 and the air volume to be replaced as 36 000 m^3. The distance applicable to these vales must now be determined and will therefore represent the maximum distance between the discharge and exhaust intake column.

Length $=\frac{Volume\ of\ air}{Area}\ \frac{36\ 000}{44.2}$ *= 814.47 say 814.5 m(this is for one air change)(1) ✓*

For 6 air change $=\frac{Total\ length_{one\ air\ change}}{Number\ of\ air\ changes}=\frac{814.5}{6}$ *=135.75say 136m(this is for six air change) (1) ✓*

1.3.2 Once you have determined the maximum distance, do a check to see whether 20 m^3/s would be adequate to ensure a safe re-entry period of 30 minutes. **(4)**

(b) Check the answer obtained in (a) above, maximum volume to be cleared with one air change:

Volume= Area ×Length=44.2×136 =6 011.2 m^3 (1) ✓

Total volume to be replaced in the 30 minutes' re-entry period:

=6011.2×6=36 0672.2 m^3 (1) ✓

Total air volume required:

Q $=\frac{Volme\ of\ air\ to\ be\ displaced}{Time_{\ seconds}}=\frac{36\ 067.2}{30\times60}$ *=20.03 say 20m^3/s (1) ✓*

The Distance of 136 m is correct (1) ✓

QUESTION 2 (45 Points)

Your mine group proposes to start a new mine in the Free state area. The following are some of the planning parameters for the mine:

- Tonnage broken 220 000 tons per month
- Average depth below surface 2145m
- Reject wet –bulb temperature 30.5˚C maximum
- Dip of reef 15˚C
- Stoping width 1.5m
- Type of mining Longwall
- Expected VRT (O.F.S) To be calculated

Draw up a report on the various factors that directly concern the occupational Environment (Hygiene) Department in the planning for the mine. Some of the more pertinent factors are given below, and it is suggested that you use these as heading in your report.

- Total face length required to mine the 220 000 tons
- Calculation of the shallowest and deepest working depth
- Air quantity to be circulated
- Optimum shaft sizes (up and down cast)
- Fan requirements (main and diesel motor fans)
- Refrigeration capacity

Your report should follow the normal format and should be brief, but without the omission of important facts.
The following assumptions should be made

- Reject dry-bulb temperature 31.5˚C
- Base your calculation on 220 000 tons/month from 4 longwalls
- Density of the rock is 2700kg/m^3
- Stope face advance rate is 6m per month
- Assume air density is 1.2kg/m^3
- Heat pick in stope face is 2.2kW per metre face length

Answer

1. *Total length required to mine 220 000 tons to be determined*

Face length $=\frac{Total\ tons\ mined\ per\ month}{Face\ advance \times Density\ of\ rock \times Stope\ width}$

$= \frac{220\ 00}{6 \times 2.7 \times 1.5}$ *= 9 053.49 say 9053m 9053 (1)* ✓

2.To get 9053 m you need 4 longwalls on strike at a length each determined as follow

Longwall back length$= \frac{9053}{4}$ *=2 263.25 say 2 263m (1)* ✓

3.The various mining depth related to this problem must now be determined, given that the average mining depth is 2145m, the vertical distance between the start and end of each longwall as follows:

Vertical distance =back length×sin15˚=2263×sin15˚=585.7 say 586m (1) ✓

Depth of the shallowest and deepest workings can now be determined:

Shallowest workings $=2145 - \frac{1}{2} \times 586 = 1852$ *m (1)* ✓

Deepest workings $=2145 + \frac{1}{2} \times 586 = 2438$ *m (1)* ✓

*4.The air quantity that needs to be recirculated can now be determined, let's assume an air quantity factor of 3.5*m^3/s *per kilo ton mine per month. (2)* ✓✓

Air required $= \frac{Ton\ mined \times Air\ quantity\ usage\ factor}{1000} = \frac{220\ 00 \times 3.5}{1000}$ *= 770* m^3/s *(1)* ✓

The downcast velocity in a downcast shaft can vary between 10 and 15 m/s, but in practice 10.5 m/s seems to most suitable (1) ✓

Shaft area $=\frac{Air\ quantity\ required}{Air\ velocity} = \frac{770}{10.5}$ =73.3 m^2 (1) ✓

Shaft area $=\frac{\pi D^2}{4}$

Diameter of shaft$=\sqrt{\frac{4\times Shaft\ area}{\pi}} = \sqrt{\frac{4\times 73.3}{\pi}}$ =9.66 say 9.7 m (1) ✓

The sub-shaft quantities can now be determined (assume 2 sub-shaft) assume air densities remain constant. (1) ✓

Air required by sub-shaft$=\frac{Air\ quantity\ required}{2} = \frac{770}{2}$ =385 m^3/s . (1) ✓

The downcast sub –shaft detail can now be determined:

Downcast sub-shaft area$=\frac{Air\ required\ by\ sub-shaft}{Air\ velocity}=\frac{385}{10.5}$=36.66 say 36.7 m^2

Downcast sub-shaft area $=\frac{\pi D^2}{4}$

Diameter downcast sub-shaft$=\sqrt{\frac{4\times downcast\ sub-shaft\ area}{\pi}}=\sqrt{\frac{4\times 36.7}{\pi}}$ =6.8m (1) ✓

The up –cast velocity in up-cast shaft should not be less than 12m/s; let's assume piratical velocity of 17.5m/s. (1) ✓

Up-cast shaft area $=\frac{Air\ quantity\ required}{Air\ velocity} =\frac{770}{17.5}$ =44.0m^2 (1) ✓

Up-cast shaft area $=\frac{\pi D^2}{4}$

Diameter up-cast shaf $=\sqrt{\frac{4\times up-cast\ subshaft\ area}{\pi}} = \sqrt{\frac{4\times 44.0}{\pi}}$=7.48 say 7.5m (1) ✓

5.The fan requirements must now be determined, by calculating the pressure drops in the down cast shafts, the sub-shaft and the upcast-shaft:

- Pressure drop down cast shaft $=\frac{KCLQ^2}{A^3}\times\frac{W}{1.2}$

$$=\frac{0.025\times 30.5\times 1852\times 770^2}{73.3^3}\times\frac{1.2}{1.2}$$

=2125.9say 2126Pa (2) ✓✓

- Pressure drop 2sub-shaft(parallel)$=\frac{KCLQ^2}{A^3}\times\frac{W}{1.2}$

$$=\frac{0.025\times 21.4\times 586\times 385^2}{36.7^3}\times\frac{1.2}{1.2}$$

=940.1say 940Pa (2) ✓✓

- Pressure drop in the up-cast shaft$=\frac{KCLQ^2}{A^3}\times\frac{W}{1.2}$

$$=\frac{0.004\times 23.6\times 1852\times 770^2}{44.0^3}\times\frac{1.2}{1.2}$$

= 1216.8 say 1217Pa (2) ✓✓

Total Shaft pressure losses=2126 +940+ 1217 =4283 Pa (1) ✓
Let assume that the pressure loss in working is 50% of the lost in the shaft (1) ✓
Pressure loss in workings =0.5×4283=2141.5 say 2142 Pa (1) ✓
Total shaft pressure loss=4283+2142=6425Pa (1) ✓
Therefore install three fans at the top of the up-cast shaft, with the following duty 257m^3/s(770/3) @6425Pa (1) ✓
6.Using Atkinson's formula P=RQ^2, determine the total resistance for the shaft:
The resistance R for the shaft $=\frac{P}{Q^2}=\frac{6425}{257^2}$ *=0.0972Ns^2/m^8 (1)* ✓
Assume an emergency quantity of 200 m^3/s : P
P=RQ^2= 0.0972×200^2= 3 888Pa or 3.9kPa (1) ✓
The emergency fan should be able to handle 200 m^3/s at 3.9kPa (1) ✓
7.The refrigeration capacity should now be determined and the VRT must first be determined
VRT= 20 +(14.6×depth(km)) =20 +(14.6×2,450) =55.77 say 55.8˚C (1) ✓
The heat load in the stope faces=9053×2.2=19 916.6 say 19 917kW (1) ✓
Let assume the heat load due to machine, fissure water etc, minus net cooling by compressed air and auto decompression can be taken as ½(haft) of the Kw per metre face length, therefore9958.5 say 9959Kw (19 917/2) (1) ✓
Total heat load in stope is therefore=19917+9959=29 876 kW (1) ✓

All other heat loads such as hoist haulage etc add 25% of the total heat load (1) ✓
Total heat load is therefore =29 876+ 0.25×29876=37 345kW (1) ✓

- *Refrigeration to be supplied in the form of chilled water has to determined assume 1 m^3/s of air represents equals 22Kw of refrigeration (cooling done by the air) then as follows:*

Cooling supplied by 770m^3/s air =770×22kW=16 940kW (1) ✓

- *The additional cooling required can be determined as follows:*

Additional cooling required =37345 – 16940=20 405kW (1) ✓
7.Base your service water consumption on 2.5tons of water per ton of rock mined (1) ✓
Service water requirement is as follows:

Service water$=\dfrac{tons\ mined \times water\ factor \times 1000_{litres/ton}}{days\ in\ month \times hours\ per\ day \times 3600}$

$=\dfrac{220000 \times 2.5 \times 1000}{26 \times 24 \times 3600}$

=244.8 say 245 litres/second (1) ✓

The cooling supplied the service water can be determined assuming a Δt of 10˚C for a drop in temperature of the water. (1) ✓

Cooling supplied by service water =mcΔt=245×4.187×10=10 258kW (1) ✓

- *The cooling that has to be supplied through additional cooling, ie bulk air cooling of the air*

Bulk air cooling needed =20405 -10258=10 147kW (1) ✓

The total refrigeration needed can now be determined, assume a plant positional efficiency of 75% (1) ✓

The total amount of refrigeration needed$=\dfrac{Bulk\ air\ cooling + Service\ water\ cooling}{Positional\ efficiency}$

$=\dfrac{10147+10258}{0.75}$

=27 206.6say 27207kW or 27.2MW (1) ✓

QUESTION 3 (20 Points)

A downcast shaft is 1 250 meters deep. The air quantity at the mean shaft density is 300m^3/s. The pressure loss is 1.97kPa and the coefficient of friction K=0.02Ns^2/m^4.
The overall efficiency of the fan system is 75% and the cost of power is R1000/year/kW.
It is proposed to increase the air quantity to 400m^3/s and consideration is being given to streamlining the shaft buntons.
Two types of streamlining are available:
Type A, which will reduce the coefficient K to 0.013Ns^2/m^4 and will cost an amount of R700 00 for the whole shaft.
Type B, which will reduce the coefficient K to 0.0102Ns^2/m^4 and will cost an amount of R1 000 000 for whole shaft.

If the life of the shaft is 20years and the present value of RI per annum at 12% over 20years is R7.47, which would be the best course of action?

3.1 Scheme(a) to leave the shaft as it is
3.2 Scheme(b), to install “Type A” streamlining
3.3 Scheme(b), to install “Type B” streamlining

Note: the fan can be adapted to any of the three conditions without additional cost, other than power cost.

Motivate your answer.

Answer

3.1 Scheme(a) ***(9)***

Pressure required to pass 300m^3/s through shaft =1970Pa

From the equation P=RQ^2 it is obvious that P is directly proportional to Q^2, which means that:

$$\frac{P_2}{P_1} = \frac{Q_2^2}{Q_1^2}$$

$$P_2 = P_1 \times \frac{Q_2^2}{Q_1^2} = 1970 \times \frac{400^2}{300^2} = 3\,502\text{Pa} \quad (3) \ ✓✓✓$$

New pressure to pass 400 m^3/s through the shaft is 3502Pa

Air power$=\frac{pQ}{1000}=\frac{3502\times400}{1000}$ *=1400.8 say 1400kW (2)* ✓✓

The inlet power to the fan motor must now be determined, given the fan overall system efficiency as 75%:

Inlet power to the fan motor$=\frac{Air\ power}{Efficieny - fan}= \frac{1400}{0.75}$ *=1867 kW (2)* ✓✓

Cost input power per year= R(1867×1000)= R 1 867 000 (1) ✓

PV of power costs =(1867000×7.47)= R13 946 490 (1) ✓

There is no capital cost involve in scheme (a)

3.2 Scheme (b) – TYPE A ***(4)***

Assuming that the efficiency of the fan system remains constant, PV of power cost scheme be will vary directly as the K –factor.

PV of power cost =Power cost $_{scheme\ a} \times \frac{K_a}{K_{original}}$

$$= 13\,946\,490 \times \frac{0.013}{0.02} = R9\,065\,219 \ (3) \ ✓✓✓$$

Capital cost =R 700 000

Total owning cost=R (9 065219 + 700 000) = R 9 765 219 (1) ✓

3.3 Scheme (B) – TYPE B ***(7)***

Assuming that the efficiency of the fan system remains constant, the PV of power cost for scheme c will also vary directly as the k –factor:

PV power costs =Power cost$_{scheme\ a} \times \frac{K_b}{K_{Original}}$

$=13\ 946\ 490 \times \frac{0.0102}{0.02}$

=R 7 112 710 (3) ✓✓✓

Capital cost =R1000 000 (1) ✓

Total owning cost=R (7 112 710+1000 000) =R8 112 710 (1) ✓

Scheme (c) would be the best course action (2) ✓✓

QUESTION 4 (15 Points)

Elaborate on one (1) of the following relevant articles (Journal 74 – number 4 – October /December 2021):

"Hardline performance ducting friction factor"

Answer

- *Introduction (1) ✓*
- *Instrumentation(3) ✓✓✓*
- *The duct testing instrument(3) ✓✓✓*
- *Testing methodology(3) ✓✓✓*
- *Test resul(3) ✓✓✓*
- *Coclusion(2) ✓✓*

OR

Mine ventilation in a post Covid-19 world:
"Remotely controling underground ventilation devices to realise ventilation on demand"

Answer

- *Introduction (0.5) ✓*
- *Research background and context (2) ✓✓*
- *Problem statement (2) ✓✓*
- *What is ventilation on demand(VOD)? (2) ✓✓*
- *Why consider remote control and management of ventilation system (2) ✓✓*
- *How does a remote control system work? (2) ✓✓*
- *Static, finding and analysis (2) ✓✓*
- *Practical scenario (one is enough) (2) ✓✓*
- *Conclusion (0.5) ✓*

Hardline performance ducting friction factor

S. Ambrosio, VortexOHS Systems cc, Director / Consultant, South Africa
Peer Review by D. Marais, Prysm Ventilation Services Pty (Ltd), Director / Consultant, South Africa

ABSTRACT

During the course of a ventilation professionals work, it is often required to determine the distance that a fan and its duct can supply an adequate amount of ventilation to the working face. To do this accurately, the professional will need to understand the performance characteristics of the fan and the ducting to be used. To determine the characteristics of the duct, use is typically made of the well-known Atkinson's Formula. One of the vital parameters in this formula is the Friction Factor. This factor has numerous sources but most of the friction factors in common use have become dated (and in some cases irrelevant) with the advent of new technology and equipment. It is therefore critical in the modern era to properly assess the Friction Factor of any new products that become available on the market. This article deals with a Friction Factor Test conducted on a new semi-rigid polymer ducting called HardLine Performance Ducting. There is emphasis on the testing methodology which aims to be practical in nature and the calculation of results.

1. INTRODUCTION

ABC Ventilation Systems South Africa (Pty) Ltd is a well-known manufacturer and supplier of ventilation fans, flexible ventilation ducting and other ventilation appliances to the mining industry in South Africa and Africa. Through the parent company, ABC Canada Technology Group Ltd, such services are offered on the global market. VortexOHS Systems cc were commissioned to conduct tests on their new range of the "HardLine Performance Ducting". Specifically, such tests needed to determine the metric Friction Factor expressed in Ns^2/m. of these ducts. The tests conducted essentially made use of the manipulation of Atkinson's Formula to determine the friction factor of the ducting manufactured. All tests described in this document were conducted at ABC Ventilation Systems South Africa (Pty) Ltd premises in Johannesburg, South Africa.

2. INSTRUMENTATION

The instrumentation used during the test process consisted of the following:

- An Airflow PVM620 Digital Manometer
- A Davis Vane Anemometer
- A Dwyer Pitot Tube
- A Greisinger GPB 3300 Electronic Barometer
- An AMS Haden Whirling Hygrometer
- A Measuring Tape

All instruments were appropriately calibrated and checked prior to use. By means of the above, air quantities, temperatures, pressures, and the psychrometric properties of air (density and massflow) were determined.

3. THE DUCT TESTING APPARATUS

Use was made of a duct testing apparatus shown in Diagram 1.

In essence, a Ø572mm HardLine Performance Ducting ventilation column in which the tests were conducted (30m in length) was installed, at floor level, within a workshop facility.

It should be noted that the workshop facility was specifically selected to negate atmospheric environmental conditions from interfering with the test (e.g., wind and heat).

As can be seen in picture 1 the ducting was installed next to a brick wall.

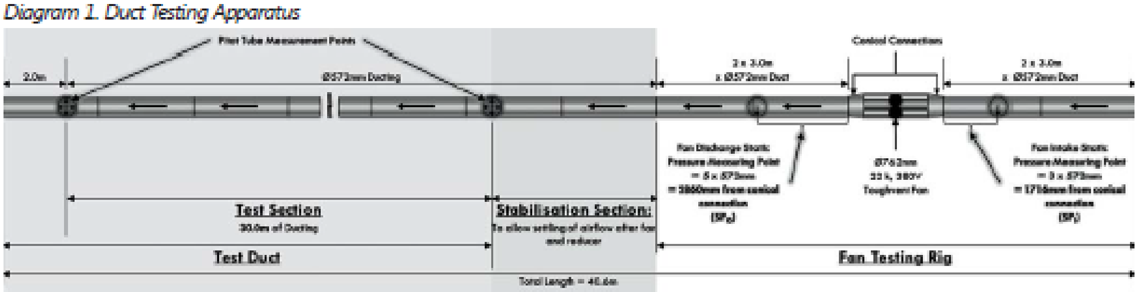
Low pressure fans above the wall insure an elevated steady cross-airflow over the duct. The effects of this airflow are negligible.

This column was connected to a Ø762mm, 22kW Fan equipped with conical connections to accommodate the Ø572mm duct.

The Duct Testing Facility consists of 3 main components:

- The Testing Rig
- The Stabilisation Section
- The Test Section

Diagram 1. Duct Testing Apparatus



Original paper presented at the second 2021 MVSSA Virtual Conference

Picture 1. Longitudinal View of the Testing Apparatus (from Fan Side)

3.1 HardLine Performance Ducting Material and Assembly

The ducting is manufactured using the manufacturers proprietary and industry-leading RigiFLEX-FR™ polymer.

Due to its semi-rigid nature, HardLine can be used for positive or negative pressure systems. There are two variants:

- The HardLine Performance Ducting – high visibility safety yellow-green colour.
- The HardLine Performance Anti-Static – black colour.

Both duct types feature flame retardant properties. It is equipped with a single quick-to-install coupling system that is shared across all configurations. For shipping purposes, HardLine is compressed as shown in Picture 2.

Picture 2. HardLine shipping container packaging

The ducting is assembled using fusion-welding technology for high-strength. The process ensures sizes remain accurate and reliable from specification to installation.

Picture 3. Assembled HardLine duct

Picture 4. HardLine re-enforcement ring

As can be seen in picture 5, the innovative coupling mechanism is simple yet effective.

Picture 5. HardLine Coupling Mechanism (over a re-enforcement ring)

The polymer material features a smooth gloss finish. The surface feels almost "oily" and "slippery", similar to polished motor vehicle paint.

Picture 6. View of Polymer Material

Due to its material and semi-rigid nature, the ducting can with-stand reasonable manipulation without damage. This can be visibly seen in Figure 7.

Picture 7. Demonstration of Duct Strength

3.2 The Test Fan

For the purposes of the test, use was made of a Ø762mm, 22kW, 380V Toughvent Fan as shown in Picture 8.

Picture 8. The Toughvent Fan

To conduct different tests with different statics pressures within the duct, the fan was equipped with a Variable Speed Drive (VSD).

Picture 9. Variable Speed Drive Control

3.3 The Test Section

A 30m section was selected within the Test Duct (referred to as the Test Section). On either side of the Test Section (i.e. 2 testing points), holes were drilled at 90° increments in the duct to allow for velocity pressure measurements (refer to Points A and B as shown in Diagram 2) with a pitot tube. This was done to determine whether flow in the duct is laminar or turbulent (Reynolds Number) and to accurately determine the velocity within the duct at these points.

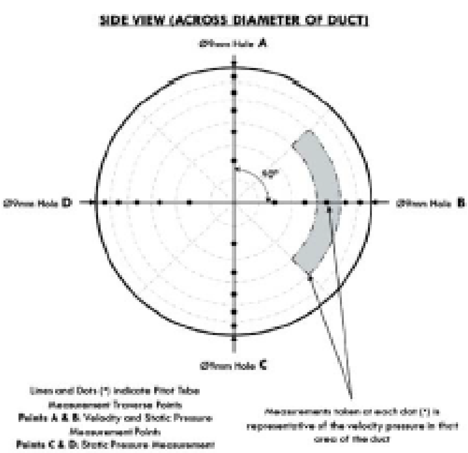


Diagram 2. Velocity and Static Pressure Measurement Points

The various measuring points that were to be used on the Pitot Tube were determined by means of the following formula:

$$RN = d\sqrt{\frac{2n-1}{4N}}$$

Where,

n = the n^{th} reading from the centre

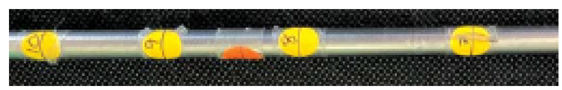
Rn = radius of the reading (mm)

d = duct diameter (mm)

N = number of readings across a diameter

These measurement points (distance from the edge of the duct) are summarised as shown here. Each point is representative of the velocity pressure in that area of the duct.

These points are then marked off on the pitot tube as shown in Picture 10.



Picture 10. Example of marked-off measurement points on pitot tube

Picture 11. Example of measuring with the pitot tube

In addition to the above, static pressure measurements were taken on either side of the test section at Points[1] A, B, C and D to determine the actual static pressure drop over the section. Given that the distance and the dimensions of the duct was known, by means of manipulation of Atkinson's Formula the duct's Friction Factor was determined.

4. TESTING METHODOLOGY

4.1 Tests Conducted

A total of four tests were conducted as follows:

- Test 1: The fan was run at 12.5Hz (25% of capacity)
- Test 2: The fan was run at 25Hz (50% of capacity)
- Test 3: The fan was run at 37.5Hz (75% of capacity)
- Test 4: The fan was run at 50Hz (100% of capacity)

Table 2: Pitot Tube Measurement Positions

Duct Diameter	Ø or d	mm	572	762	1016	1200
Position from Outside	Pos	Factor	mm	mm	mm	mm
Edge of Duct	1	0.026	14.9	19.8	26.4	31.2
	2	0.082	46.9	62.5	83.3	98.4
	3	0.146	83.5	111.3	148.3	175.2
	4	0.226	129.3	172.2	229.6	271.2
	5	0.342	195.6	260.6	347.5	410.4
	6	0.658	376.4	501.4	668.5	789.6
	7	0.774	442.7	589.8	786.4	928.8
	8	0.854	488.5	650.7	867.7	1024.8
	9	0.918	525.1	699.5	932.7	1101.6
	10	0.974	557.1	742.2	989.6	1168.8

4.2 Determination of the Psychrometric Properties of the Airflow

In each test, the following information was measured and calculated:

- The Quantity, Temperature and Barometric Pressure of air entering the duct.
- The Quantity, Temperature and Barometric Pressure of air leaving the duct.
- By means of psychrometric calculation, the Density and Massflow of the air at the intake and discharge of the duct were determined.

4.3 Determination of the Fan Operating Static Pressure

In each test, the operating fan static pressure was determining as follows:

- The static pressure on the inlet side (SPI) of the fan was measured (3 x duct diameter from fan).
- The static pressure on the outlet side (SPO) of the fan was measured (5 x duct diameter from fan).

  - Refer to Diagram 1 for these locations.

- The Fan Operating Static Pressure (SPFan) was calculated as follows:

  - $SP_{Fan} = SP_O - SP_I$

4.4 Determination of the Velocity Pressure and Air Velocity

Velocity pressure measurements were taken along the full cross section of the duct on either side of the Duct Testing Section (see 3.3). The Reynolds Number was determined by means of the following formula:

$$Re = \frac{wVD}{m}$$

Where,

Re = Reynolds number (dimensionless)

w = density (kg/m³)

V = velocity (m/s)

D = diameter (m)

µ = dynamic viscosity (Ns/m²)

1. *It is well understood that theoretically Points A, B, C and D should have the same static pressure. However, given the turbulence in the duct, each of the points would return slightly different values during measurement. In the interests of accuracy, the average of these four points has been used as the representative Static Pressure.*

In addition, the true velocity within the duct was determined by means of the following formula:

$$Vp = \frac{V^2 w}{2}$$

Where,

VP = velocity pressure (Pa)

V = air velocity (m/s)

w = air density (kg/m³)

4.5 Determination of the Static Pressure Loss

Static pressure measurements were taken on either side of the Duct Testing Section. The difference between these two values was deemed indicative of the pressure loss within the section.

4.6 Friction Factor Determination

It is well understood that the pressure loss within an airway is a function of the resistance and the amount of airflow within that airway as shown in this simplified version of Atkinson's Formula [see reference (Patterson 1999)]:

$$P=RQ^2$$

Therefore, the resistance of the duct can be determined as follows:

$$R = \frac{P}{Q^2}$$

Where,

P = pressure loss (Pa)

R = resistance (Ns^2/m.)

Q = air quantity (m^3/s)

The resistance is a function of the dimensions (diameter, circumference, and length), the friction factor and the density of the duct. It is determined as follows:

$$R = \frac{KCL}{A^3} \; x \; \frac{w}{1.2}$$

Where,

K = friction factor (Ns^2/m.)

C = circumference (m)

L = length (m)

A = area (m^2)

w = air density (kg/m^3)

These formulae combined determine the pressure loss within a system as shown in this expanded version of Atkinson's Formula:

$$P = \frac{KCLQ^2}{A^3} \; x \; \frac{w}{1.2}$$

Therefore, given that the dimensions of the duct (diameter, length, etc.) are known, that the air quantity has been

Table 3: Summary of Friction Factor Test Results

Test	Fan Speed	Ave Quantity in Test Section (m3/s)	Static Pressure Pressure Loss	Min Reynolds No	Airflow Status	Friction Factor (K) in Ns2/m
Test 1	Fan @ 12.5 Hz (745 rpm)	3.24	62.3	351869	Turbulent	0.00223
Test 2	Fan @ 25 Hz (1490 rpm)	4.42	105.6	482829	Turbulent	0.00206
Test 3	Fan @ 37.5 Hz (2235 rpm)	6.72	229.6	728376	Turbulent	0.00195
Test 4	Fan @ 50 Hz (2980 rpm)	8.90	391.2	964229	Turbulent	0.00190
Average						0.00203

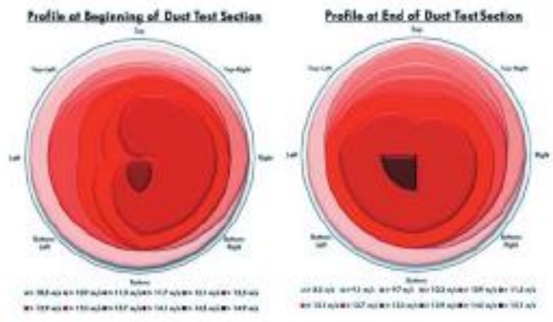
Table 5: Friction Factor Comparisons

Duct Type	Friction Factor (K) in Ns2/m.	Improvement	Source
ABC Hardline Performance Ducting	0.00203	-	This Study
6 Swage Std. Galv. Duct	0.00364	-44%	MVS Databook
8 Swage Std. Galv. Duct	0.00409	-50%	MVS Databook
Fibreglass Vent. Duct	0.00237	-14%	MVS Databook

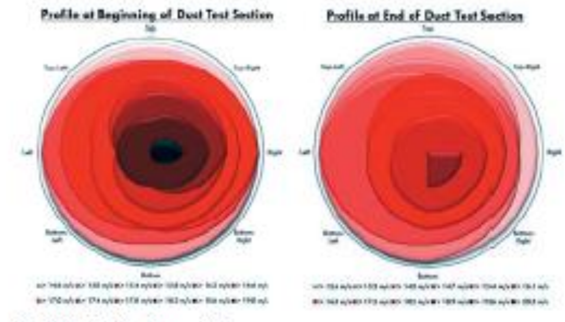
Table 6: Equivalent Resistance of the HardLine Performance Duct (1.0m length)

Duct Ø (mm)	380	572	762	1016	1200	1400
Friction Factor (K) in Ns^2/m.	0.00203	0.00203	0.00203	0.00203	0.00203	0.00203
Circumference (C) in m	1.194	1.797	2.394	3.192	3.770	4.398
Length (L) in m	1.0	1.0	1.0	1.0	1.0	1.0
Area (A) in m^2	0.113	0.257	0.456	0.811	1.131	1.539
Density (w) in kg/m^3	1.200	1.200	1.200	1.200	1.200	1.200
Resistance (R) Ns^2/m.	1.6613	0.2150	0.0512	0.0122	0.0053	0.0024

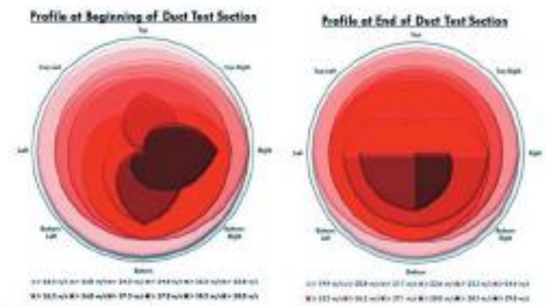
Table 4: Test Velocity Profiles



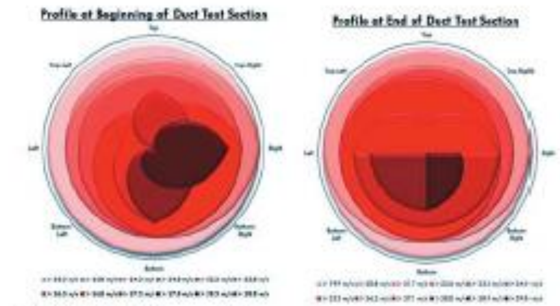
1. 12.5Hz (25% of capacity)



2. 25Hz (50% of capacity)



3. 37.5Hz (75% of capacity)



4. 50Hz (100% of capacity)

determined (from the air velocity) and that the psychrometric properties if the air within the duct have been determined, the Friction Factor of the duct was calculated by means of the following manipulation of Atkinson's Formula:

$$K = \frac{PA^3}{CLQ^2} \ x \ \frac{1.2}{w}$$

5. TEST RESULTS

5.1 Summary of Results

Table 3 shows a summary of measurements taken and the determination of the Friction Factor in each test.

From the tests, the Mean Friction Factor for the HardLine Performance Duct was determined to be 0.00203 Ns^2/m.

5.2 Turbulence within Duct

As shown in Table 3[2], Reynolds numbers indicate that turbulent conditions are prevalent within the duct in all tests conducted. This was anticipated as previous research [see reference (Meyer 1990)] has shown similar findings on duct tests.

Table 4 shows the air velocity profile on either side of the Test Section within the duct during each test.

2. Note that as readings are only taken in the vertical and horizontal axis, values in the diagonal orientation as shown in the carts are inferred (interpolated).

5.3 Comparison with Industry Accepted Friction Factors

Table 5 shows a comparison of the HardLine Performance Duct against accepted friction factors for commonly used ducts within the South African Mining Industry (Meyer 1990) (Patterson 1999).

The results are self-explanatory. A significant reduction in friction is evident.

5.4 Equivalent Resistance of the HardLine Performance Duct

Table 6 shows the calculated Equivalent Resistance for a 1.0m length of the HardLine Performance Duct for various duct sizes.

6. CONCLUSION

Based on the measurement outcomes as determined, it is therefore concluded that the nominal friction factor for the HardLine Performance Duct is 0.00203 Ns^2/m. This value compares very favourably when evaluated against other, commonly used ducting within industry.

7. REFERENCES

1) Meyer, CF. 1990. "Determining the Friction Losses of Underground Ventilation Ducting." (Mine Ventilation Society of South Africa) October.

2) Patterson, A. 1999. MVS Databook. Mine Ventilation Society of South Africa.

Mine Ventilation in a post-Covid-19 world:

Remotely controlling underground ventilation devices to realise ventilation on demand

F.S. Bergh, Howden Africa

ABSTRACT:

The COVID-19 pandemic has certainly shocked the world and made everyone rethink, rework and reimagine the workplace of tomorrow.

Mining is one of most the vulnerable industries due to the large numbers of people it employees. Furthermore, the congested areas such as cages, change houses, transport etc. make it challenging to adhere to social distancing protocols. Added to this, the absence of key personnel from work due to pandemic begs the following question: *How will mines be able to supply qualitative and quantitative airflow to the underground workings continually, and in an economically sustainable manner?*

The 21st century engineer will have to work smarter to manage the changing environment and employ technological tools to aide him in his quest for zero harm.

This paper will aim to outline one such innovation: The concept of remotely, and autonomously, supplying ventilation. A concept also referred to as Ventilation-on-Demand.

1. INTRODUCTION

COVID-19 has changed the way we perform our daily tasks. Despite all the challenges and heartache, it is also an opportunity to embrace new technology, which will reduce operational cost and improve safety.

COVID-19 is defined as "illness caused by a novel coronavirus now called severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) which was first identified amid an outbreak of respiratory illness cases in Wuhan City, Hubei Province, China." (Cennimo, 2020)

The COVID-19 pandemic has certainly shocked the world and made everyone rethink, rework and reimagine the workplace of tomorrow. Mining is one of most the vulnerable industries due to the following reasons:

- Mines are labour intensive
- Employees conduct work in confined spaces
- Large groups of persons gather in congested areas such as cages, change houses, buses etc.

The pandemic came at a time when the industry is grappling with a number of challenges. Two of them being:

Original paper presented at the second 2021 MVSSA Virtual Conference

a) supplying adequate fresh air as operations are expanding laterally, as well as vertically, away from shaft complexes and

b) Reliable supply of electricity and associated rising cost.

Added to this, the absence of key personnel from work due to pandemic begs the following question:

How will mines be able to supply qualitative and quantitative airflow to the underground workings continually, and in an economically sustainable manner?

Over ventilating mines i.e. "Set and forget "can be one approach. The challenge is that most large mines are well established from a ventilation network point of view i.e., established fan infrastructure, establish return airway networks, working places and ventilation commitments. This creates a challenge in that the system can only handle what it was designed to and cannot accommodate the additional quantities required.

The brute force principal of ventilating a mine also comes at the expense of energy, rendering it uneconomical and non-environmentally friendly.

The 21st century engineer will have to work smarter to manage the changing environment and employ technological tools to aide him in his quest for zero harm.

This paper will aim to outline one such innovation: The concept of remotely, and autonomously, supplying ventilation. A concept also referred to as Ventilation-on-Demand.

2. RESEARCH BACKGROUND AND CONTEXT

The dynamic environment, and the dependence on human intervention, makes it challenging to supply ventilation to areas where persons are required to travel and/ or work. Resultantly, a deterioration of workplace conditions is a constant threat. This is truer now than ever. With skilled and experienced personnel working from home, the risk of mismanagement of the ventilation system is a constant threat.

This deterioration can have disastrous health and safety impacts. It is therefore critically important that Mine Ventilation professionals empower themselves with the available tools to ensure workplaces remain safe, and risk free to the health of employees.

Mines need to become innovative and utilise their available infrastructure to distribute air in a more optimised and autonomous fashion.

This approach will minimise the dependency on human intervention. A significant step towards managing hazards and risks whilst working from home.

3. PROBLEM STATEMENT

This paper aims to answer the following question: how will mines handle the significant changes to the work environment concerning management of their ventilation networks?

The 21st century engineer will have to work smarter to manage the changing environment and employ technological tools to aide him/ her in the quest for zero harm.

This paper will aim to outline one such innovation: The concept of supplying ventilationon-demand.

4. WHAT IS VENTILATION ON DEMAND (VOD)?

Ventilation-on-Demand (VOD) is a system capable of real-time adjustments to mine ventilation equipment to meet underground atmospheric quality requirements for personnel and equipment based on status and location.

Through active monitoring and equipment modulation, VOD systems are able to reduce the amount of "wasted air" supplied to mine workings, thereby reducing overall operational costs.

VOD is an optimisation system that allow the user to control ventilation devices remotely, and autonomously in any of the following ways:

- Remotely stopping and starting fans and / or adjusting their speed
- Schedule events i.e. maintenance periods and have fans and regulators adjust accordingly to deliver the desired quantity
- Automaticallyadjusting fans and regulators based on feedback received from environmental instrumentation underground
- Deliver ventilation to areas of the mine where machinery and/ or personnel are present

5. WHY CONSIDER REMOTE CONTROL AND MANAGEMENT OF A VENTILATION SYSTEM?

The world and workplace of tomorrow looks different. More and more employees are working from home and mining certainly will follow suit.

Managing a ventilation system remotely will empower mine ventilation engineers to carry out their legal duties even if being on-site is not possible.

Underground mines need to remain ventilated and environmental parameters maintained to ensure safe, healthy and sustainable production of resources that form such an integral part of the South African economy.

Furthermore, as mines operate on multiple shifts the risk exists that conditions can deteriorate during periods where subject matter experts are not present e.g., exposure to pollutants and/ or a fire or influx of gas during a night shift that could endanger the lives of hundreds of persons.

A control system will assist by logging all changes to the ventilation system, complete with alerts based on varying levels of severity. This function will also fulfill the legal requirement of an early warning system. In addition to this, a control system allows mitigation of sub-standard conditions in real time.

6. HOW DOES A REMOTE-CONTROL SYSTEM WORK?

The positions of men and machines, along with flow and gas sensor readings are communicated to a control system. Events are scheduled and set points created for desired airflow quantities and velocities, temperatures, percentage gases in general atmosphere etc.

The software would then compute the air demand and determine the necessary fan and regulator set points required to achieve these environmental parameters or ventilation standards.

Hardware such as Programmable Logics Controllers (PLCs) or remote Inputs and Outputs (I/Os) enable the remote control of equipment such as fan starters, Variable Frequency Drives (VFDs) or actuators.

7. STATISTICS, FINDINGS AND ANALYSIS

Ventilation-on-Demand (VOD) is a system capable of real-time adjustments to mine ventilation equipment to meet underground atmospheric quality requirements for personnel and equipment based on status and location.

Through active monitoring and equipment modulation, VOD systems are able to reduce the amount of "wasted air" supplied to mine workings, thereby reducing overall operational costs.

A VOD system will utilise VOD software as part of the following control strategies for a mine:

- Adjustment of primary fans with a Variable Speed Drive (VSD)
  - On a fixed schedule
  - To maintain adequate airflows within the mine
  - As vehicles are operating within the mine (to reduce "wasted" fresh air)
- Adjustment of secondary fans with an ON/OFF starter
  - On a fixed schedule
  - As vehicles or personnel enter headings
  - To maintain environmental standards in these headings
- Adjustment of regulators
  - On a fixed schedule
  - To meet vehicle's airflow demands within different primary vent zones
  - To maintain an adequate level of gases, airborne pollutants or temperature
- With these controls, the implementation of a VOD system can:
  - Monitor and control air quality within regulatory limits

- Schedule events for reduced flows during shift-change and breaks
- Production maximisation through available air
- Reduce ventilation in zones where no production is occurring
- Reduce ventilation in operation services that do not require ventilation at 100% continuously
- Reduce ventilation rates in zones where air is not required 100% of the time and where the ventilation exceeds the requirements
- CAPEX and OPEX
- Energy consumption optimization and energy savings
- Post blast ventilation management to minimise blast clearing times.

8. PRACTICAL SCENARIOS

The following examples will aim to highlight the practical application of the system and will showcase how the system operates to supplement existing controls to create a workplace which is safe and healthy. To view sensor data in real time, whilst logging changes and notifying officials of sub-standards via email, sms, alarms and notifications in itself is very powerful – to measure is to know, but in addition to the above point, the system allows the user to implement controls in real-time that will safeguard worker health.

Limiting the time of exposure to airborne pollutants, preventing a buildup of gas in a heading or re-directing noxious gases as a result of a fire are practical examples of how a ventilation on demand solution will aid the operation's existing controls in creating an environment that will go a long way to achieving "ZERO HARM.

8.1 Scenario 1:

Description: Fire in the back-bye causing smoke and noxious gases travelling to the section.

Apart from the existing controls the mine has in place, a VOD system can supplement the existing controls in the following fashion:

- Install and connect the system to a fire door that is strategically placed. Once the intake sensor detects CO in excess of 30ppm the system opens a fire door and intake air is redirected to buy the miners time to reach a place of safety.

8.2 Scenario 2:

Description: Personnel / machinery entering old areas of the mine to conduct inspections or work.

Apart from the existing controls the mine has in place, a VOD system can supplement the existing controls in the following fashion:

- Use a VOD system to schedule events when personnel are entering old workings and abandoned areas to ensure these are adequately ventilated.
- Level 4 – VOD – can be employed to automatically ventilate this area whilst level 2 – scheduling – serves as a back-up.

8.3 Scenario 3:

Description: Production sections inadequately ventilated due to changes in the out bye areas of the mine.

Apart from the existing controls the mine has in place, a VOD system can supplement the existing controls in the following fashion:

- Use a VOD system as an early warning system to notify officials and employees of insufficient airflow in their production sections through alarms and notifications.
- Use a VOD system to ensure minimum set points are maintained in production sections by manipulating regulators.
- Use a VOD system and sensors to manage airflow in the back bye areas of the mine – workshops, refuelling bays, abandoned areas, tractor doors etc.

  This to ensure sufficient airflow is supplied to these, when necessary, but that human error does not lead to excessive leakages / ventilation commitments in the back bye that might have a negative impact on the production sections i.e. high-risk fire and explosion areas.

8.4 Scenario 4:

Description: Increase in men and machinery in an area leading to the requirement for additional ventilation to dilute gases, DPM, airborne pollutants etc.

Apart from the existing controls the mine has in place, a VOD system can supplement the existing controls in the following fashion:

- Use a VOD system to adjust the airflow in this specific area to ensure adequately quantities are supplied that meets the minimum fresh air requirements based on the amount of men and machinery in an area. This can be achieved through level 2 or 4.

8.5 Worked example 5:

Description: Build-up of flammable gas/ airborne pollutants in a heading.

Apart from the existing controls the mine has in place, a VOD system can supplement the existing controls in the following fashion:

- Install a VOD system and a sensor in the return of each heading. Once gas is detected, the regulator is opened, and the section cleared of gas.
- Fans installed in headings as a back – up to scoop brattice or a fan with ducting installed in the return and designed to exhaust gases from each heading.

VentSim control to function as an early warning system notifying officials on surface as well as start fans and clear headings of gas build up.

- The above can certainly be true for airborne pollutants i.e. workers exposed to excessive concentrations of coal dust. A dust sensor installed in the active headings (CM and roof bolter) that immediately supplies larger quantities to these headings when high dust readings are encountered. By doing so, preventing illness / adverse health effects due to dust exposure.

9. CONCLUSION

The aim of this paper was to provide interested stakeholders with information regarding VOD solutions.

This, to ensure mines empower themselves to benefit from the technological advancements that will enable a sustainable future for our industry.

Real time monitoring of environmental parameters is crucial and something that is being employed extensively within the mining industry.

A VOD solution will enable employers to also act and mitigate exposure to airborne pollutants in real time.

Based on the information contained in this paper, it is evident that VOD solutions are advantageous. Mines need to consider utilising these technologies to improve workplace conditions.

10. ACKNOWLEDGEMENTS

The author wishes to thank Mr. Mothusi Mochubele and Howden for their contributions to this paper.