SAFETY IN MINES RESEARCH ADVISORY COMMITTEE

SIMRAC

Revised (2)
DRAFT

Final Project Report

Title: REDUCE EXPLOSION RISKS AND IMPROVE SAFETY AND HEALTH CONDITIONS BY BETTER VENTILATION PRACTICES IN MECHANICAL MINER HEADINGS

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Project No: COL 205
Date: APRIL 1999

Executive Summary

Project COL205 has concentrated on improving ventilation conditions in the face area where mechanical miners are executing bord-and-pillar developments. In the process, a number of issues were investigated and each output concentrated on various aspects of ventilating the heading effectively.

The first investigation concentrated on the effective use of jet flow fans and the factors that influence the behaviour of the air inside the heading when these fans are used. Use was made of both CFD modelling and underground tests to get to know more about the use of jet fans. It became evident that the interior design and performance of the fan determine the angle at which the air enters the heading, which in turn determines the penetration distance, which in turn determines the airflow pattern inside the heading.

The use of controlled recirculation to ventilate a bord-and-pillar heading was also investigated. A thorough literature search was conducted on the methods used and the rationale behind the concept of the reuse of air as an effective means of ventilating a heading. The information that was gathered provided a better understanding of and insight into the definition of recirculation of air and also the advantages and disadvantages of using such a method. The final conclusion was that South African conditions and mining methods do not allow the introduction of controlled recirculation of air as an effective means of ventilating mechanical mining bord-and-pillar headings.

An important aspect of face ventilation that was investigated was the use of air-moving systems on the mechanical miners. The output was divided into two parts, namely continuous miners and roadheaders, but the objectives were similar in the sense that a combination of venturi air-movers, water sprays and on-board scrubbers was found to be the most favourable solution to ventilating the immediate face area. The physical difference between the two machine types would necessarily mean that the actual configuration and number of water sprays or venturi air-movers that should be used would differ. It is important, however, to ensure that the complete ventilation system used in the heading is balanced to be able to address both methane and dust contamination in the face area.

The last issue that was addressed was to develop a method that could be used to quantitatively measure or monitor the effectiveness with which an applied ventilation

system can control methane liberated during the cutting process. The most common of these methods is the calculation of the face ventilation effectiveness (FVE) index. This index works well for static or near-static ventilation flow patterns.

An approach in which the methane levels are monitored at the cutting face and in the last through road was modified to be able to apply the method in an active section. This entailed the monitoring of methane levels at the cutting drum and the rear of the mechanical miner. This was done to try and overcome the delay between peak levels recorded at the face and the rear of the heading, as well as to simplify the logistics of the monitoring procedure. On implementation of the modified FVE method, various anomalies were identified which rendered this specific application of the method unsuitable for general application. As it is important to be able to assess the effectiveness with which methane is controlled, a method more suitable for South African conditions was developed. This method requires that the methane levels be recorded at the drum of an active mechanical miner over a period of time. The methane safety index (MSI) is then calculated from these data, taking into account the actual methane levels and the rate of methane accumulation in a heading. The index gives a single number for a section, which is easy to interpret and can be used to compare the effectiveness of ventilation systems directly. Initial implementation of the method has been successful.

Col205 initially started in 1994 with a series of Computational Fluid Dynamics (CFD) simulations on different ventilation systems. As a result of the findings of the original COL205, this revised project was initiated and approved. This report is a summary of the findings of the five individual projects within COL205 which were reported in detail in the following documents:

⇒ Report on the airflow characteristics of jet fans using Computational Fluid Dynamics (CFD) simulations. *CSIR, Miningtek,* **June 1996**.

⇒ Literature review: The use of controlled recirculation of mine air inside a bord-and-pillar heading. *CSIR, Miningtek,* **March 1997**.

⇒ Summary of information gathered from literature on the use of sprayfan systems and similar air-moving devices on continuous miners. *CSIR, Miningtek,* **March 1997.**

⇒ Investigation into optimizing the use of air-moving systems on continuous miners. *CSIR, Miningtek,* **July 1997.**

⇒ Optimizing the current use of air-moving systems on roadheaders in South African collieries. *CSIR, Miningtek,* **October 1997.**

An Executive Summary containing the more important findings and recommendations of the whole project (apart from MSI development) is provided at the end of this report.

List of abbreviations, symbols and terms

Abbreviations

ASJ	"Aero Safe Jet"
CFD	Computational Fluid Dynamics
CM	Continuous Miner
FVE	Face Ventilation Effectiveness
FVM	Face Ventilation Measurement
LEL	Lower Explosive Limit
MSI	Methane Safety Index
SIMRAC	Safety in Mines Research Advisory Committee
USBM	United States Bureau of Mines

Symbols

kW	kilowatts
m^3/s	cubic metres per second
m	metres
m/s	metres per second
m^2	square metres
$m^3/s/m^2$	cubic metres per second per square metre
L/m	litres per minute
mg/m^3	milligrams per cubic metre
s	seconds

Acknowledgments

The authors would like to thank the following people, organizations and companies for their assistance and co-operation in the execution and completion of this project:

⇒ The personnel and management of CSIR Miningtek for their assistance and for making the necessary resources available for this project.

⇒ SIMRAC for making this project possible.

⇒ The management and personnel of INGWE, AMCOAL and SASOL for their assistance in making available test sites and personnel to complete the underground investigations.

⇒ FLOSEP, a Division of AEC, for the CFD simulations and the evaluation of the results.

⇒ Tamroc Voest Alpine for supplying technical data and general information.

⇒ Various fan manufacturers for supplying technical data on jet fans and for making fans available for underground evaluations.

⇒ Colliery Dust Control Services for supplying technical data on spray nozzles and venturi air-movers.

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1 Introduction

The SIMRAC project COL205 was initiated at the beginning of 1996 and was planned to continue for two years until the end of 1997. The main objective of this project was to improve ventilation conditions in bord-and-pillar headings and in particular where mechanical miners were in use. By improving these ventilation conditions, safer and healthier working conditions for the underground workers would also be guaranteed.

A number of issues were identified for investigation and this was to be completed by the end of the two-year period. The results were to be distributed to the industry which would take note of the recommendations and implement them if needed. The issues to be investigated included the use of jet flow fans, further improvements to on-board air-moving systems on a continuous miner and on a roadheader, more detailed information on the use of controlled air recirculation inside a bord-and-pillar heading, and finally an effective means of evaluating the ventilation systems used in bord-and-pillar headings.

These issues have all been investigated and the results have been reported in detail in individual interim project reports distributed to the SIMRAC committees and the industry. This final report will therefore not discuss the detailed findings of each individual investigation, but will instead provide only a summary of the conclusions and recommendations reached in each case, with reference to the individual reports that have been compiled and published.

2 Report on Outputs

2.1 Effective use of air jet fans (Meyer, 1996)

Jet fans have been used extensively in most coal mines to ventilate bord-and-pillar headings mined with mechanical miners. They are popular because they can be used without the aid of ventilation ducting, they are easy to install and can be used basically when standing on the floor or suspended from the roof. These fans are available in a number of sizes and capacities, depending on the user's specifications and needs.

When a jet fan is used, a great deal of turbulence is created inside the heading, which is excellent for methane control but sometimes has a negative effect on dust concentrations. When a jet fan is used to ventilate a bord-and-pillar heading, it causes different airflow

patterns within the face area, which are often counterproductive when used in conjunction with other on-board ventilation systems.

In order to use jet fans more effectively, it necessary to understand the behaviour of the airflow inside a heading when these fans are used, and to know why a jet fan in particular creates these different airflow patterns.

2.1.1 Different airflow patterns

During various underground tests and investigations, two main airflow patterns were observed inside the headings when the jet fans were used.

The first is called the "U" shape flow pattern, which means that the fresh air penetrates the heading on the intake side and, after flushing the face, flows out of the heading on the return side. Figure 2.1.1(a) shows the position of the jet fan in the heading and the resulting airflow pattern.

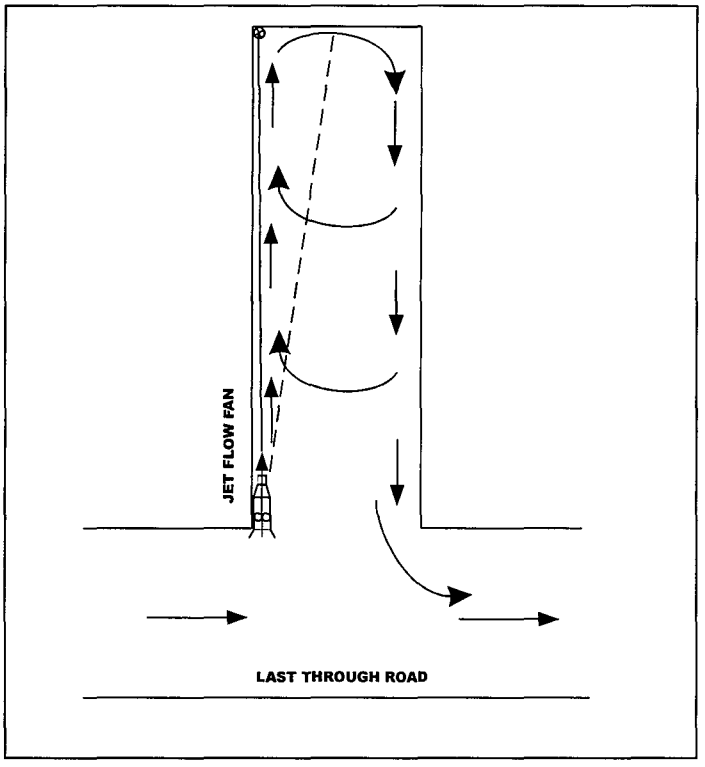


Figure 2.1.1(a) Sketch demonstrating the "U" shape airflow pattern

The second pattern is called the "figure of eight" airflow pattern. Here the fresh air enters the face of the heading from the return-air side before swirling across the face in the

opposite direction and leaving the heading on the return-air side. Figure 2.1.1(b) shows how the air changes direction to form the so-called "figure of eight".

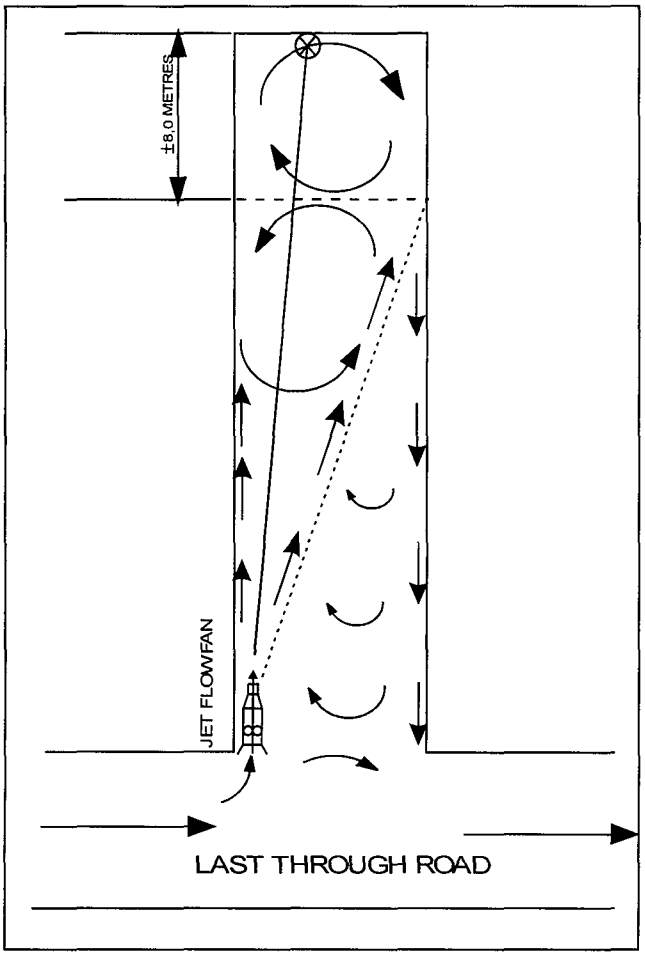


Figure 2.1.1(b) Sketch demonstrating the "figure of eight" airflow pattern

Through CFD simulations and underground measurements, it was established that it is preferable to have a "U" shape airflow pattern inside the face area for optimum dust and methane control. It was established that fans from different fan manufacturers create different airflow patterns and also differ with regard to the maximum reach of the airflow and the fan performance for the same kW rating.

To establish the reasons for these differences in behaviour and performance, seven fans were tested and evaluated using, in essence, Computational Fluid Dynamics (CFD) and verifying some of the results by means of underground tests. The CFD simulations were used to compare the different fan designs and their effect on the airflow behaviour as the air leaves the fan outlet. It was found that the airflow pattern inside the heading depends largely on the characteristics of the air as it leaves the fan nozzle.

The fans that were evaluated ranged from 4,0 kW to 11,0 kW capacity. Detailed engineering information on the fans was obtained from the various fan manufacturers to ensure that the CFD results would be reliable and comparable. The details of the CFD results are given in the interim project report on jet fans (Meyer, 1996).

The conclusions and recommendations arising from this investigation are summarized below.

2.1.2 Discussion

Before the fans are compared and the results discussed, it is important to explain some of the terms that will be used.

- The impeller blades of the fans cause the air to spin inside the nozzle before leaving the nozzle outlet. The spin velocity (V_θ) differs from fan to fan due to the difference in impeller blade design, the rotation speed of the impeller blades and the internal diameter of the fan and nozzle.

- The air leaves the fan nozzle at a specific angle which is determined by the relationship between the spin velocity (V_θ) of the air and the forward velocity (V_Z) of the air. This angle actually determines the penetration distance of the air.

- This relationship between the spin velocity and the forward velocity of the air is called the swirl number (S_g) and is determined by the following equation:

$$S_g = V_{\theta\,(max)} / V_{z\,(max)}$$

From the CFD results and the various underground investigations that were performed, it became evident that the use of a jet flow fan is much more complex than was first imagined. It was proved that whenever there is an engineering or design change to the inside of a jet fan, the airflow behaviour outside of the fan changes.

Important aspects such as the swirl number, the direction of spin of the air and the angle at which the air leaves the fan nozzle were not previously recognized but were found to determine the performance of the fan.

Each fan tested proved to have a different swirl number, volume flow, nozzle area and spin velocity, which in essence means that each fan will have a different angle at which the air leaves the nozzle, which will then result in different air-penetration distances.

To best explain the difference between the various fans tested, the CFD results and fan characteristics are shown in Table 2.1.2. Note that two of the fans have a negative spin velocity. This means that the air spins in the opposite direction to the rotation direction of the impeller blades. The air in all the other fans spins in the same direction as the impeller blades.

Table 2.1.2

Comparison of fan characteristics

Fan #	Power rating (kW)	Volume flow (m^3/s)	Swirl number	Penetr. Dist. (m)	V_θ-max. (m/s)	V_Z-max. (m/s)	Nozzle area (m^2)
#1	11,0	4,7	0,14	41,0	6,04	42,0	0,114
#2	4,0	2,0	0,1	37,0	2,63	25,5	0,081
#3	7,5	3,5	0,12	36,5	5,29	44,4	0,081
#4	5,5	2,0	0,51	27,2	-23,08	44,7	0,048
#5	7,5	2,3	0,25	27,2	-18,87	73,6	0,033
#6	5,5	1,3	0,8	27,0	23,56	29,3	0,049
#7	11,0	4,7	0,17	43,7	5,33	30,9	0,156

As a result of these differences in fan characteristics, it can be expected that each fan will generate a different airflow pattern inside a heading. The airflow patterns that are most likely to occur when these fans are used are listed below:

- Fan #1 = "U" shape
- Fan #2 = "U" shape
- Fan #3 = "U" shape
- Fan #4 = "figure of eight'
- Fan #5 = "figure of eight"
- Fan #6 = "figure of eight"
- Fan #7 = "figure of eight"

If these and other results were used to draw up a list of specifications that could be used when a fan is ordered or as criteria when a fan is inspected for effective performance, the specifications should be as follows:

- The impeller blades should turn clockwise.

- There should be a sufficient number of guide vanes to cope with most of the spin inside the fan and ensure even flow through the fan nozzle outlet. A high spin velocity encourages re-entrainment of air outside the fan, which in turn adversely affects the penetration distance of the air, which in turn influences the type of airflow pattern created inside the heading.

- The nozzle should be long enough to cancel out any negative spin that may occur inside it.

- The design of the cone inside the fan is important to minimize the zones where negative flows occur.

- The nozzle diameter should be large enough to maintain a forward velocity of below 30 m/s to assist in keeping the swirl number below 0,2.

2.1.3 Recommendations and concluding remarks

The purpose of this investigation was not to state whether or not a jet fan should be used to ventilate a bord-and-pillar heading, but rather to make the industry aware that there are important variables that influence the behaviour of the airflow when jet fans are used and why this is so.

It was proved that the fan manufacturers need to investigate and test the designs and performances of their fans more thoroughly and more realistically.

To use a jet fan inside a mechanical heading, a number of rules should be followed to ensure that the correct airflow patterns and the best conditions prevail:

- The jet fan should always be installed in the upstream position.

- The air from the scrubber outlet should be directly in line with the air from the jet fan nozzle.

- The jet fan and the on-board scrubber should be installed on opposite sides of the heading.

- The fan inlet should be in a position where it will not recirculate the air.

- The nozzle outlet should point directly into the heading to create a "U" shape airflow pattern.

- It is advisable to use on-board air-moving systems together with the jet fan to assist in ventilating the face area.

- The jet fan can be used either on the floor or against the roof, depending on the particular mining conditions.

- It is advisable to position the jet fan not closer than 10 m from the face to minimize the dispersal of airborne dust created during the cutting process.

2.2 Use of controlled air recirculation (Meyer, 1997a)

The main objective of this investigation was to do a literature study of the means used locally and internationally to ventilate a bord-and-pillar heading by controlled recirculation. The reuse of air inside a bord-and-pillar heading is prohibited by law and for this reason it was decided first to do the literature study and a feasibility study on whether such a ventilation system would be effective, before an attempt was made to test the concept inside a heading.

From the literature study it was evident that there is little or no recorded information on the use of such systems within South African collieries, except on the reuse of air within a ventilation district. This is obviously because this practice is prohibited.

All the information gathered concerned international mines. Working through the information created a better understanding of the concept behind air recirculation and what is meant by the term "controlled air recirculation". It appears that in order for such a system to work effectively, the complete ventilation strategy currently being used in South African collieries would have to be changed from on-board systems back to conventional

force-exhaust systems. Figure 2.2 shows a typical layout of a controlled ventilation system as used in some of the international collieries. For these ventilation methods to work effectively and safely, strict control must be exercised over variables such as air quantities and ventilation duct distances. Considering the amount of dust and the methane volumes that are likely inside the headings with the high production rates in South African collieries, it would be extremely difficult to control the environment inside the face area with regard to uncontrolled turbulence and the recirculation zones that are frequently created.

For this reason it was found that it would not be economically viable to use such a system. From a health and safety point of view as well, it would be difficult to control all the variables that would influence the effectiveness of such a system. However, it is of great interest to study the material given in the official report on this part of the COL205 project. This report contains the basic definitions and explains in detail the theories behind the concept of controlling the recirculation of air. It is shown that under the required controlled conditions, such a system does not create an accumulation of methane and dust, as long as the supply of fresh air is kept within the required limits.

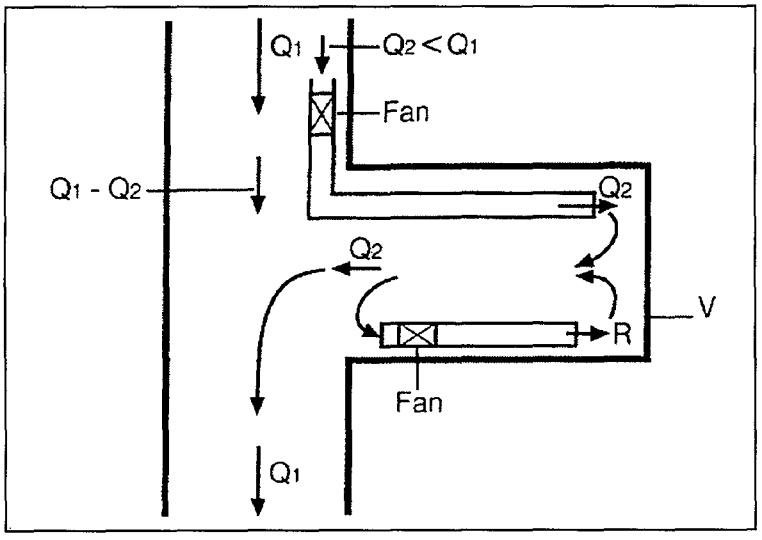


Figure 2.2 Typical layout of a controlled air recirculation system used in a heading

2.2.1 Recommendations and concluding remarks

The following are some of the more important remarks from the literature with regard to the use of controlled air recirculation:

- The quantity of the intake air used should be designed for the original amount of methane make.
- For face air velocities below 0,4 m/s, the amount of dust make does not greatly increase with the air velocity. When the air velocities exceed 4,0 m/s, the amount of dust made can be expected to increase proportional to the air velocity.
- Controlled air recirculation results in an increase in the airflow rate, reducing the risk of methane ignitions by better mixing.
- With controlled air recirculation in headings, the dust clouds are confined to the face area and the ventilating air is continuously moving forward.
- Controlled recirculation in advance headings can also result in a reduction in noise levels and less congestion of equipment, because the number of fans can be limited without limiting the increase of available air.
- Controlled recirculation can contribute to significant power and cost savings because more air is available without having to introduce additional or larger fans.
- The force-exhaust overlap system proved to be the best system as it addresses the issues of both methane and dust.

Considering the conditions in South African collieries, the following statements can be made:

- Information from the literature has shown that controlled air recirculation will not cause the build-up of harmful gases or dust. It will rather improve the dilution and/or removal of these substances, providing the methane-release rate remains the same and that there is a constant supply of fresh air.
- Information from the literature has also shown the importance of proper ventilation planning, of knowing the methane content of the coal and of knowing the release rates in the areas that are being mined. Air quantities and allowable dust and methane concentrations can be calculated at the various positions using the equations given in the original report. If these aspects are known, then it is possible to calculate the amount of air recirculation that can be allowed for ventilating the headings.
- The test results from the literature cannot be applied to South African conditions, for the following reasons:
    - The tests in the literature were done in headings on either the intake or return side of a longwall face. No specific reference is made to dust distribution or dilution with regard to mechanical miner headings.

- The conditions in the overseas mines were different from those in South African mines and the ventilation systems and air quantities used were also different.
- None of the systems that was tested included the use of on-board scrubbers, sprayfan systems, jet fans, etc., which are most commonly used in South Africa.
- The different equations and relationships given in the original report are, however, very valuable and by studying them, a better understanding can be gained of the mechanics of air recirculation and the importance of keeping it under control.
- The type of recirculation that is currently allowed in South African collieries around the scrubber systems is difficult to control and to quantify, because of various factors such as three-dimensional airflow patterns, turbulence, re-entrainment of air, more than one ventilation system in operation, different heading conditions, etc. The ventilation systems used in South African collieries, and the resulting airflow patterns, are much more complex than those described in the overseas literature studied.
- Because of the factors mentioned above, CFD is currently the most effective method known to determine what portion of air present inside a heading can be regarded as recirculated air and what percentage as fresh air. The use of conventional air-measuring techniques has shown that because of the complexity of the airflow, more advanced techniques will have to be used to determine the amount of air recirculation. It will therefore be very difficult to control and use the technique of controlled air recirculation as a means of ventilating a bord-and-pillar heading as is done in the international mines.
- To use controlled air recirculation in South African collieries in the way it is used in overseas mines, force-exhaust systems would have to be reintroduced without the use of on-board scrubbers and sprayfan systems, which complicate the airflow patterns in the face area.

2.3 On-board air-moving systems on continuous miners

(Meyer, 1997c)

Ventilating the face of a mechanical miner heading becomes more complex as further knowledge is gained on the behaviour of airflow, dust and methane and what should be done to control these substances more effectively. To create a safe and healthy environment in the face area, it is important to ensure that sufficient fresh air reaches the face at the point of cutting and that this fresh air is controlled effectively.

The main objective of this part of the project was to establish a ventilation system that could be used as an effective basic air-moving system on a continuous miner (CM) and, by means of a few minor adjustments, could be adopted by any colliery that uses continuous miners for bord-and-pillar development.

This investigation was done in two parts. First an extensive literature study was done to learn more about the concept of using water sprays and other air-moving devices on a continuous miner. A number of basic guidelines and recommendations were found from both international and local mines on the installation and use of these systems, based on individual research that had been conducted. This formed the subject of a separate report (Meyer 1997b).

Secondly, systems currently in use on the machines were evaluated by means of underground surveys and CFD simulations. These findings, together with those of the literature study, were used to draw up some guidelines on the basic system that should be installed on the machine and what modifications should be made to suit individual requirements and needs.

Previous research has indicated that certain factors affect the influence of air in combating dust and methane inside a bord-and-pillar heading. Some of these factors are:

- last through road air velocities

- position of the CM in relation to the position of the auxiliary ventilation system

- position of the on-board scrubber and the auxiliary force ventilation system relative to the airflow direction in the last through road

- position of the cutting drum

- position of the machine within a cutting cycle

- balance between the force and exhaust air quantities inside the heading

- type of ventilation used, etc.

Because the airflow inside a heading behaves in a three-dimensional manner, it is important to realize that dust and methane behave differently from each other under the same circumstances. It must therefore be decided whether the ventilation system should be aimed at controlling the dust or at controlling the methane.

What is effective for methane will not necessarily be effective for dust and vice versa. The ultimate aim would be to have a system that could address both contaminants, which means one that would balance the quantities of the force and exhaust air.

Although most of the systems investigated gave more than sufficient air movement in the face area, difficulties were experienced in getting sufficient fresh air to reach the area underneath the cutting drum for the purpose of methane dilution. Because dust control or methane is very often the more important motivation for installing a ventilation system, care should be taken to limit the amount of turbulence created in the face to prevent the dust from blowing past the scrubber intake and thereby reducing the capture efficiency of the scrubber intake.

The main objective of this section of the project was to establish a system that would be able to address both these contaminants with the aid of on-board air-moving devices. Using CFD simulations and underground validation tests, three main systems were evaluated, i.e. those that had proved to be the most effective ones used in the industry. These systems were:

- System 1: Venturi sprays in combination with the scrubber and the normal water spray system on the cutting head.

- System 2: A combination of the directional spray-fan system and the venturi air-movers together with the scrubber.

- System 3: A directional spray-fan system together with the on-board scrubber.

2.3.1 Discussion of results

The three systems were evaluated quite extensively through the use of CFD and underground measurements. Although not without their shortcomings, the results proved that, with minor adjustments, it is possible to create a sufficient fresh air supply and positive air movement in the face area to control both methane and dust.

The ventilation systems can be divided into two main categories, namely the use of a directional spray-fan system, venturi air-movers or a combination of both, together with the use of on-board scrubbers. For these systems to act effectively as on-board air-movers, it is important that they be used in balance with the other ventilation systems in the heading, having regard to the air-moving capabilities of the system as a whole.

To achieve the best ventilation of a heading for the existing methane and dust problems, a few basic rules and guidelines must be adhered to:

- First of all, the positions of all the relevant ventilation systems used inside the heading and the direction of the airflow inside the last through road are important. When the air flows from right to left past the heading in the last through road, the on-board scrubber must be situated on the left-hand side of the machine and vice versa.

- The force ventilation system, if one is used, must be installed on the intake air side of the heading, on the opposite side to the scrubber position.

- With this configuration in place, the air should theoretically flow across the face to the scrubber inlet. For this to be effective, the air from the force duct or the ductless fan should not interfere directly with the air stream from the scrubber outlet. If it does interfere, air recirculation will be increased and the supply of fresh air to the face area will be reduced.

- The cutting sequences of the machine during production are important. With the air flowing from right to left past the heading, the first sump or first cut of the heading should always be on the right-hand or intake-air side of the heading, with the shearing on the left. This way the scrubber is always against the left sidewall and better contains the dust in the face, which enables greater capture efficiency. The converse is applicable to left-hand machines.

- The air quantities of force-exhaust systems should always be in balance to ensure that they deal most effectively with both methane and dust. If the scrubber/exhaust quantity is much higher than the force quantity, the air velocity at the face will be slow and therefore the fresh air supply will be slow. This is good for dust control because the dust is contained and the scrubber is allowed to capture the dust. It is not, however, the answer to methane control. Turbulence, high air velocities and a good fresh air supply are needed to remove and dilute methane. It is therefore very important to find the right balance between these two ventilation strategies.

The use of air-moving devices on the cutting machines provides a practical solution to improving air movement at the face. Given larger scrubber air quantities, the force air quantities can be kept in compliance with the 0,2 $m^3/s/m^2$ required and the scrubber will then recirculate more than 50 %. The answer is to assist the force ventilation system with directional sprays or venturi air-movers.

It must be remembered that air-moving devices do not supply fresh air to the face, but merely move the air from one side of the face to the other. Fresh air must therefore be supplied to the point where these devices take over. For best results, it is necessary to achieve a balance between the total quantities of force air and exhaust air.

From all the tests, the combination of venturi air-movers, an on-board scrubber and a directional spray-fan system proved to be the best option, with a few water sprays added under the boom to assist in moving the air in this area. Figure 2.3.1 shows a suggested system that would best address both methane and dust concentrations in the face area. In the sketch a force ventilation duct is shown as the force system for supplying fresh air, but any approved force ventilation system can be used for this purpose. The important factor is to deliver fresh air to the point where the air-moving systems can take over.

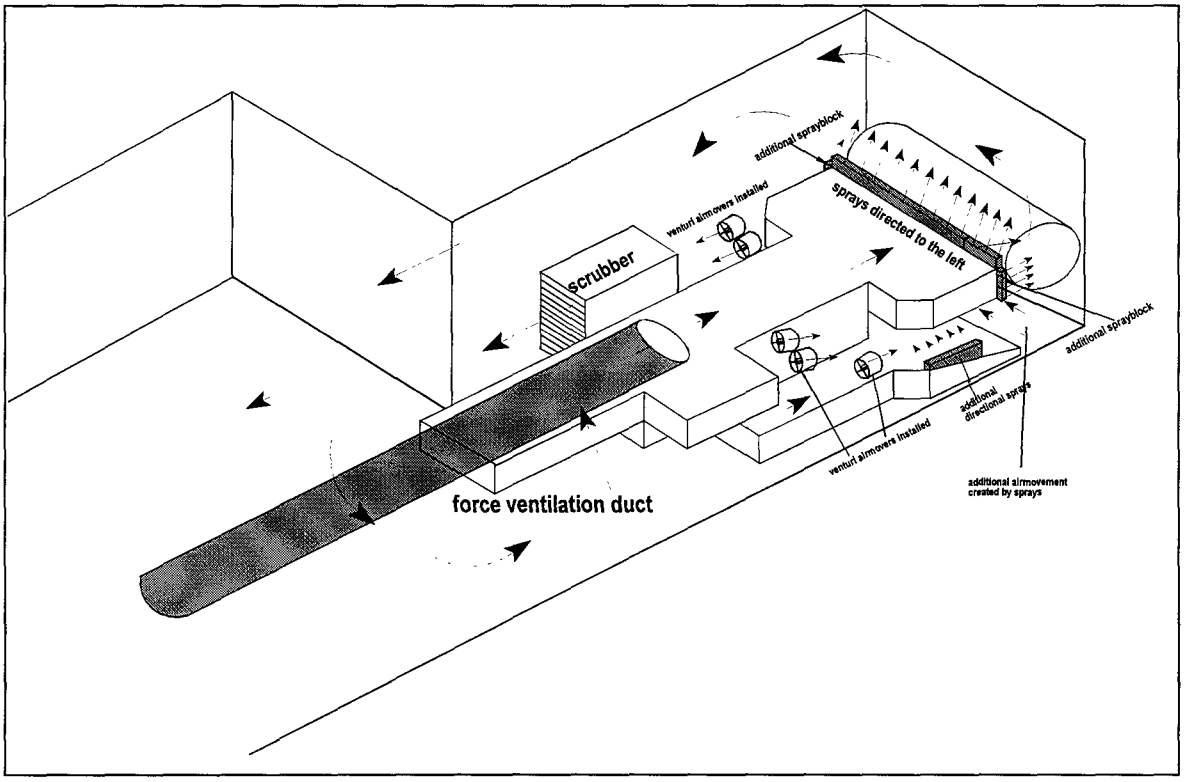


Figure 2.3.1 Suggested installation for best methane and dust control in the face using air-moving systems

The total number of venturis and water sprays used will be critical in that the amount of energy created in the face must be controlled. The type of nozzles used and the direction of the water flow will determine the number of spray-blocks or venturi air-movers that should be used.

Each mine will have to design and install the system that best suits its specific situation, depending on the amount of air needed in the face and the water pressure available for the air-moving systems. The system as described should only be used as a basic design from which alternative designs can be generated. Table 2.3.1 shows the types of nozzle that are generally used, together with the expected airflow rates from these nozzles when in operation. The nozzle suggested for use in the directional sprays is the D2 Hollow-cone nozzle and for the venturi air-movers, the D3 Full-cone nozzle is suggested. Depending on the system installed on the machine, these flow rates can be used to determine the type and number of nozzles needed for effective ventilation of the face area.

Table 2.3.1:

Comparison between the flow rates of the nozzles

Water pressures (Pa)	*Nozzle types*							
	D2 Hollow-cone		**D3 Hollow-cone**		**D3 full-cone**		**D4 Full-cone**	
	Air (m^3/s)	**Water *(ℓ/min)**	**Air (m^3/s)**	**Water *(ℓ/min)**	**Air (m^3/s)**	**Water *(ℓ/min)**	**Air (m^3/s)**	**Water *(ℓ/min)**
2 000	0,239	1,40	0,265	2,30	0,477	3,40	0,238	4,90
3 000	0,318	1,70	0,434	2,80	0,682	3,90	0,682	6,10
4 000	0,477	2,00	0,597	3,20	0,796	4,40	0,796	7,10
5 000	0,531	2,19	0,796	3,70	0,954	4,70	0,955	7,90
6 000	0,597	2,40	0,955	3,90	0,955	5,00	1,194	8,60

* (litres per minute)

Depending on the scrubber air quantity and the water pressure available, the number of water sprays and/or venturi air-movers can be increased at the suggested positions if dust control and methane control present a problem. The total amount of energy moved by these systems, together with the force duct, should not be greater than the exhaust/scrubber quantity. If the force ventilation energy is greater than the scrubber quantity, two ventilation systems tend to form inside the face area. This prevents the fresh air from reaching the face and, especially, under the drum, which results in the methane being trapped without being diluted.

The system as suggested should be effective in controlling both methane and dust, with different nozzle configurations used to suit individual airflow needs.

2.3.2 Recommendations and concluding remarks

From the literature study and the tests as described in the original reports, it is clear that the use of air-moving systems on continuous miners is important to ensure the effective supply of fresh air onto the face of a heading. Obviously there are a few factors that influence the performance of any ventilation system, such as the specific mining layout, the type of ventilation system used, the air quantities delivered into the heading and the position of the machine with regard to the ventilation system used.

From the literature study that was conducted, the following important aspects can be highlighted:

- Normal sprayfan systems will only ventilate a heading that is developed between 6 m and 10 m from the last through road. Headings that are any deeper will need the assistance of an additional ventilation system.
- When the normal sprayfan system is combined with an on-board scrubber, it is possible to ventilate headings up to distances of 20 m from the last through road.
- The power that should be used by the sprayfan system to move the air is determined by the amount of methane that is generated at the face during the cutting process, in that more air is needed in the face for higher methane concentrations.
- An effective sprayfan system can move as much as 300 times the amount of fresh air that enters a heading.
- The important area in which the sprayfan action must be concentrated is underneath the boom since most of the dust is made below the boom with the downward shearing action of the drum. It is also true that methane tends to accumulate under the boom because there is usually relatively little air movement in this region.
- The water sprays that are normally installed on top of the boom are effective only within the first 300 mm. These sprays should therefore be designed and installed to achieve "low reach" and there should be no overspray.
- The most common angles at which the water sprays are used in the sprayfan systems seem to be 30° to the side and between 10° and 20° over the cutting drum. This enables effective pick lubrication, wetting of the face and movement of air across the face.

From the literature study as well as the actual tests that were carried out, the conclusion was reached that on-board scrubbers have become an important part of the way in which continuous miner headings are ventilated and that they can no longer be seen only as the dust-suppression system on the machine. The on-board scrubber, as it is used today, has become one of the main suppliers of fresh air to a heading. It is also used to deal with the dust that is made during the cutting process. These scrubbers have become capable of delivering larger and larger air quantities to cope with the large amounts of dust created. Unfortunately, the additional ventilation systems used to ventilate the headings have not been upgraded to deal with the higher air quantities enforced by the scrubbers.

To ensure that there is sufficient airflow at the face, the coal mining industry has moved to the use of on-board air-moving systems to assist the auxiliary force and exhaust ventilation systems in ventilating the face area. These systems include the use of sprayfan systems and venturi air-movers or a combination of both. For these systems to act effectively in their role as air-movers, it is important that they be used in balance with the rest of the ventilation systems in the heading with regard to air-moving capabilities.

To ventilate a heading to deal best with the existing methane and dust problems, a few basic rules and guidelines must be adhered to:

- The positions of all relevant ventilation systems used inside the heading and the air flowing inside the last through road are important. When the air direction is from right to left past the heading, the on-board scrubber should be situated on the left-hand side of the machine and vice versa.
- The force ventilation system, if used, must be installed on the intake side of the heading, which is the side opposite to the scrubber.
- With this configuration in place, the air should theoretically flow across the face to the scrubber inlet. For this to be effective, the air stream from the force duct or ductless fan should not interfere directly with the air stream from the scrubber outlet. If it does interfere, the air recirculation will be enhanced and the fresh air supply to the face area will be reduced.
- Cutting sequences are also important. With the air flowing from right to left past the heading, for example, the first web being cut should be on the right-hand or intake side of the heading and shear off on the left. This way the scrubber is always against the sidewall and the dust is contained more effectively. The converse is applicable to left-hand machines.
- Air quantities in the face area that are created by the individual ventilation systems should be kept in balance to control both dust and methane.

It is important to remember that these on-board systems (excluding the scrubber) do not supply fresh air but are merely air-moving devices. The auxiliary force ventilation system that is used supplies the fresh air to the point where the air-movers take over and deliver and move it to the face area.

The effective reach distance of the air from the force system is approximately 20 m from the outlet position, provided the air quantity complies with the required 0,2 $m^3/s/m^2$ of face

area. This means that the whole strategy of ventilating a continuous miner heading, or split, must be formulated on the basis of these guidelines.

2.4 On-board air-moving systems on roadheaders

(Meyer, 1997d)

As with the study on continuous miners, the main objective was to find the best face ventilation system to use when a roadheader is cutting a bord-and-pillar heading. Because of the difference in the cutting methods between a continuous miner and a roadheader, a different approach has to be taken in designing a face ventilation system for a roadheader. When the area around the cutting head is investigated, it becomes evident that the options are rather limited.

With the amount of open area around the cutting head needed to accommodate its movement, the problem of moving air in the face is more complex. The cutting sequence also differs from that of a continuous miner. This means that ventilating a heading where a roadheader is cutting is easier than where a continuous miner is operating, in that the number of systems that can be used is limited. The same principles and reasons for moving the air and supplying fresh air to the face apply as were discussed in the previous section. The same information on the water sprays applies and it will therefore not be repeated.

The investigation into air-moving systems on roadheaders commenced with a study of what is currently used in the industry and what options there are for improving these systems. It was found that the industry uses a basic system, mainly the standard system that is normally supplied by the manufacturers with the machine. It was also learned that the industry and the manufacturers were co-operating on a few special projects in which improved ventilation systems were being tested and evaluated. These systems, together with the standard system, were evaluated in this part of the project and the results will be discussed individually.

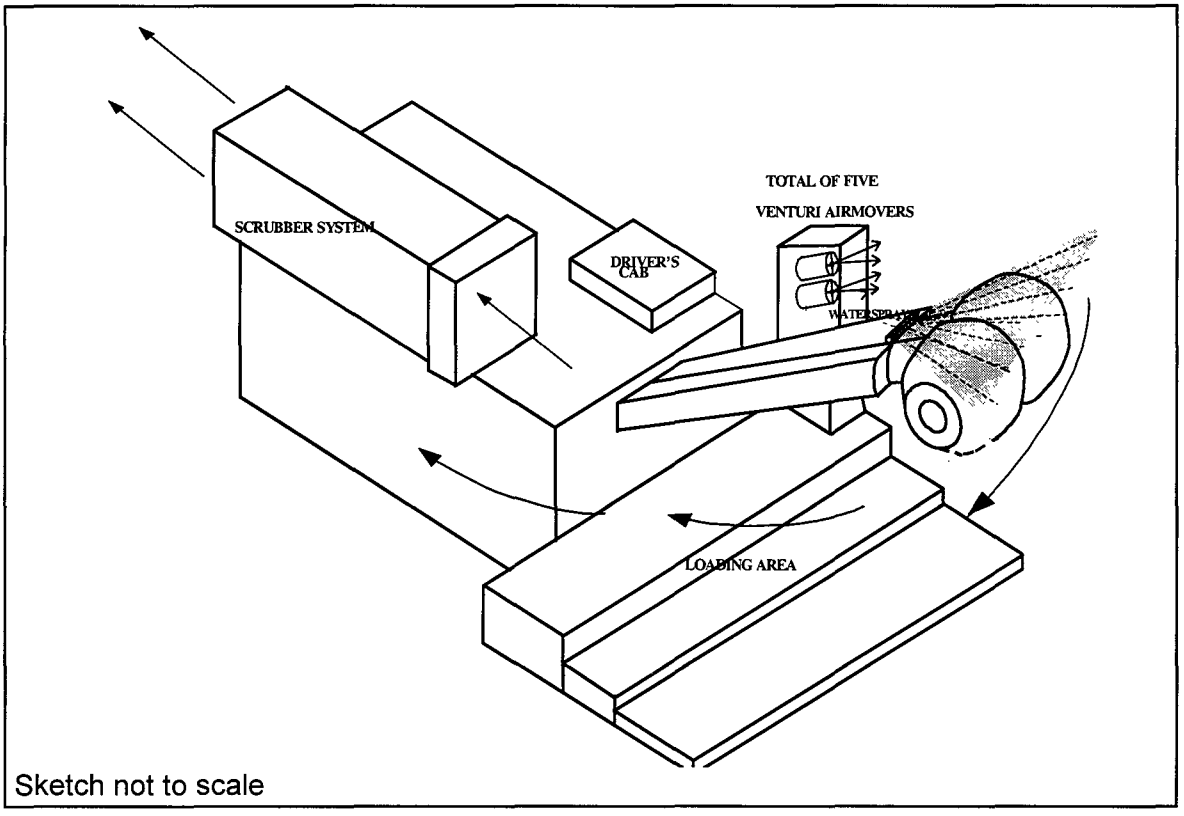
2.4.1 System 1: Standard ventilation system

The standard ventilation system that is usually fitted on any roadheader consists of a "wet head" system on the cutting drum, a set of water sprays around the cutting head and a set of venturi air-movers situated on the left side of the boom. These air-movers allow air

movement sideways across the face towards the scrubber inlet. The scrubber used is normally designed to handle an air quantity of between 8 m^3/s and 10 m^3/s, determined according to the face area.

Figure 2.4.1 shows the basic layout of the standard system that is fitted on the machine when supplied to the customer.

Although this standard ventilation system is designed to address the airflow and contaminants at the face, the desired effect is often not achieved. Visual observations during underground tests and investigations indicated that most of the dust in the dust clouds moves past the scrubber intake. A practical explanation for this is that the balance between the airflow at the face and the capacity of the scrubber is incorrect. This can be rectified by increasing the scrubber capacity to a volume that is similar to or greater than the total air movement created by the forcing systems.



Sketch not to scale

Figure 2.4.1 Schematic layout of a standard ventilation system as fitted on a roadheader

With regard to the control of methane at the face, CFD simulations and visual observations underground showed that the standard configuration of the venturi air-

movers on the left side of the machine does not create sufficient air movement in the area below the cutting drum to dilute the methane adequately.

Once these shortcomings had been identified, it was found necessary to investigate the possibility of improving these standard systems in order to establish safer and healthier conditions at the face during the cutting process.

2.4.2 System 2: High-capacity on-board scrubber

The on-board scrubber system that is usually supplied with a roadheader machine will deliver an average air volume of between 5 m^3/s and 10 m^3/s, depending on the individual needs of the customer. Normally this would be enough, but when the seam height of the area being mined is increased (>4 m), it is necessary to increase the amount of air flowing in and out of the face area to comply with the required 0,2 $m^3/s/m^2$ of face area. This is, however, not the only motivation for increasing the scrubber air volume. As mentioned in the previous discussion, it is often necessary to increase the scrubber volume to achieve a balance between the force and exhaust air in the face area. This allows better control of the dust cloud created during the cutting process.

The air volume of the scrubber under discussion was increased from 10 m^3/s to 15 m^3/s in an attempt to improve the airflow and dust conditions in the face area. Together with this increased air volume, additional water sprays were installed to spray onto the cutting head in order to reduce the amount of dust liberated. Figure 2.4.2(a) shows a sketch of the roadheader with the larger scrubber and the additional water sprays.

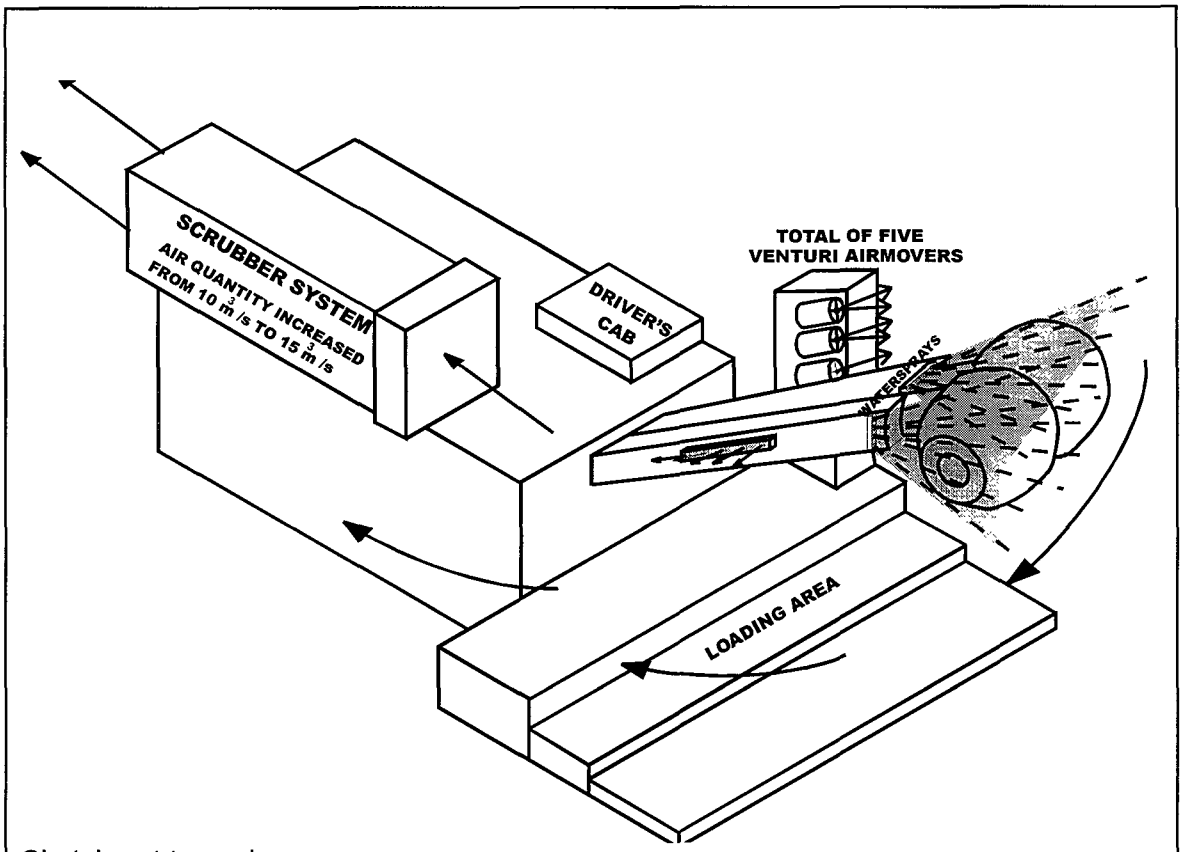


Figure 2.4.2(a): Schematic layout of the roadheader with a larger scrubber and additional water sprays on the cutting head

The immediate effect of this combination was impressive and the dust cloud did not move past the scrubber intake for the first few minutes after cutting commenced. The high air volume of this scrubber effectively addressed the dust cloud above the cutting head.

As cutting continued, however, a problem did occur lower down and underneath the cutting drum; indications were that sufficient sideways air movement was still lacking in this region despite the installation of the additional water sprays. After the first few minutes of cutting, dust rollback occurred and the lower dust cloud moved past the scrubber intake position and towards the driver. The increased air volume of the scrubber is effective, but limited to the area immediately around the scrubber inlet position.

To address the lower dust cloud, a short piece of ventilation ducting (± 1,0 m) was connected to the inlet of the scrubber to extend it and taken as close as possible to the swivel position of the cutting boom.
In this way the scrubber intake was taken closer to the dust source and the scrubber capture efficiency was increased (see Figure 2.4.2(b)).

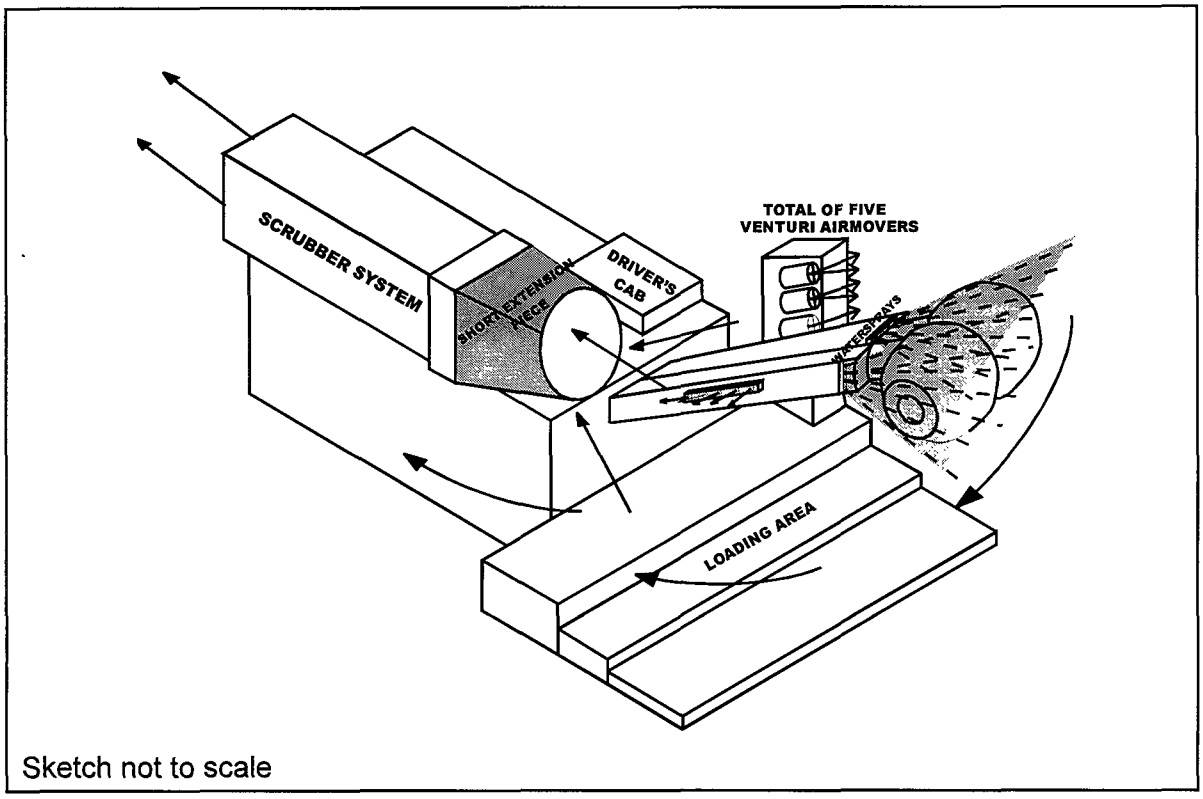


Figure 2.4.2(b): Schematic layout of the ventilation system with the short extension piece connected to the inlet of the scrubber

Dust samples were taken to evaluate the effectiveness of this method and the results showed that the average dust concentrations over an eight-hour shift decreased dramatically. The average dust concentration without the extension piece was 13,99 mg/m^3 while that with the extension piece was 6,33 mg/m^3 .

It is obvious that this alternative has a positive effect on the dust conditions in the face area. Although a number of practical problems were experienced with the use of this ventilation extension piece, the concept behind this option is worth pursuing since in this way dust concentrations can be effectively controlled in the face area. However, with regard to methane control, the problem of insufficient air movement persists in the region underneath the cutting drum. The suggestion is that a small alteration should be made to the venturi configuration on the left side of the machine. One or two additional venturi air-movers could be installed to spray directly sideways under the cutting head, different from the direction of flow of the other venturi air-movers.

These additional venturi air-movers should create sufficient air movement to solve the problem underneath the cutting drum. Because of the large open areas under the cutting

head and the sideways movement of the boom, the amount of additional equipment that could be installed is limited. The suggested inclusion of additional sprays has been discussed with production personnel, however, and should not present a problem. Figure 2.4.2(c) shows the suggested layout with the additional venturi air-movers in position and the expected effect on the airflow patterns.

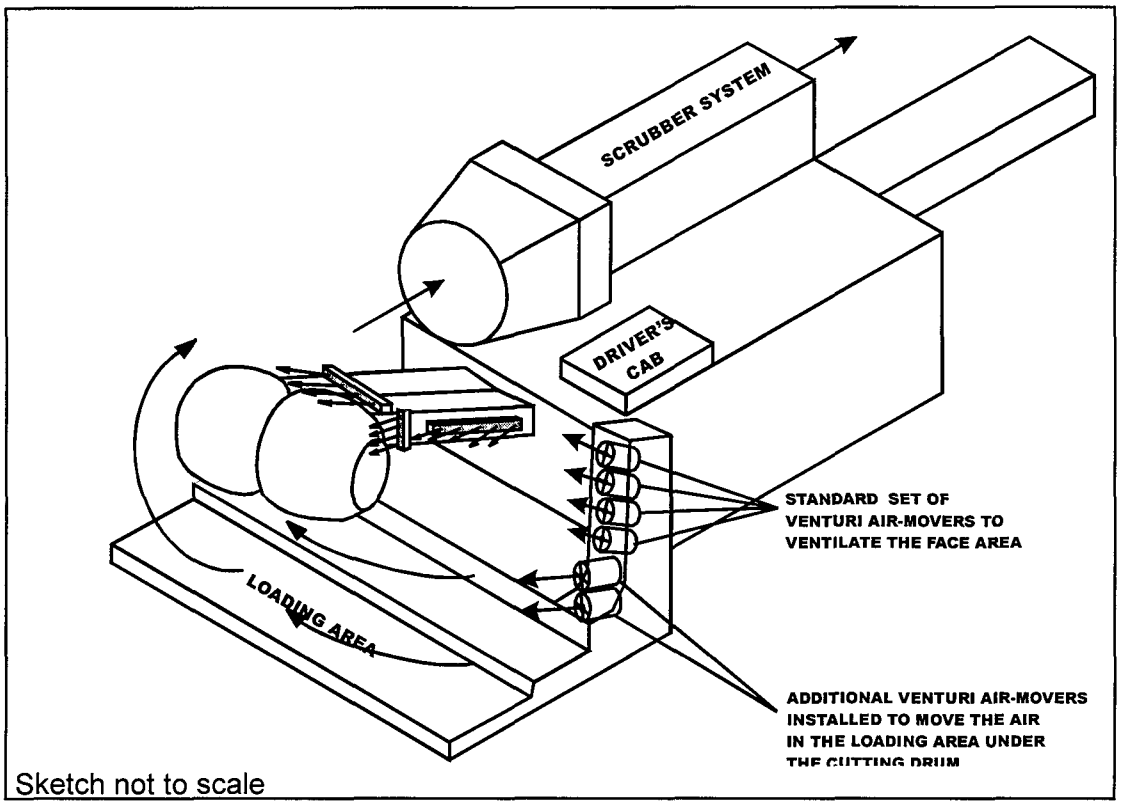


Figure 2.4.2(c): Suggested layout with the additional venturi air-movers and the expected airflow patterns under the cutting head

2.4.3 System 3: Aero Safe Jet system

This system was tested on the initiative of Tamroc Voest Alpine, mainly to address the issue of methane ignitions at the face during the cutting process (also called frictional ignitions). The system introduces water and compressed air at optimized pressure, thus greatly reducing the possibility of a frictional ignition. It also addresses the area under the cutting drum where the coal is loaded and where the airflow is low or non-existent.

This type of ventilation system consists of two "Aero Safe Jet" (ASJ) blocks fitted on either side of the cutting boom, approximately 0,5 m behind the cutting drum. Each ASJ block contains 10 jets (spray nozzles) of which two are directed towards the cutting zone and the remainder towards the loading/storage area. Water under high pressure (120 bar or

12 000 kPa) at 0,8 l/min and compressed air (2,5 bar or 250 kPa) at 8 m^3/min supplied to the ASJ blocks ensure optimal functioning of the system at a water-to-air ratio of 1:10 000. Figure 2.4.3(a) shows a sketch of an ASJ block containing the 10 jet nozzles.

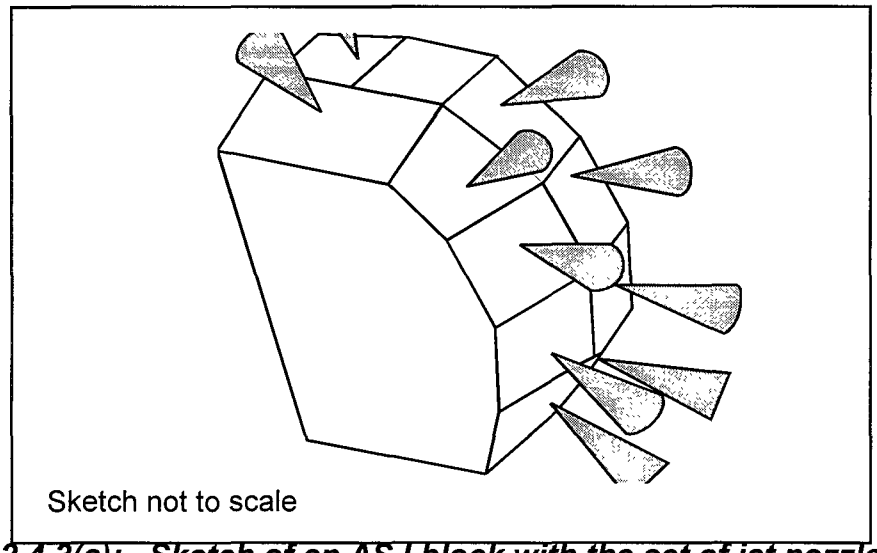


Figure 2.4.3(a): Sketch of an ASJ block with the set of jet nozzles

This system was tested in one of the South African coal mines. The investigation concentrated mainly on the effect of this high-pressure water/air combination on the dust clouds and more specifically on the airborne dust concentrations. Because of the high turbulence caused, the presence of high methane concentrations and the dangers of insufficient methane control were ruled out.

The results discussed below are from the investigations that were conducted underground while the system was installed on a roadheader.

When the system is in operation, a large area around the cutting drum and in the immediate face area is subject to a great deal of turbulence and air movement. The high-pressure water/air mixture creates sufficient airflow to prevent a methane ignition of any kind in the cutting zone.

Figure 2.4.3(b) shows the difference between the areas affected when a conventional set of water sprays is used and when an "Aero Safe Jet" system is used.

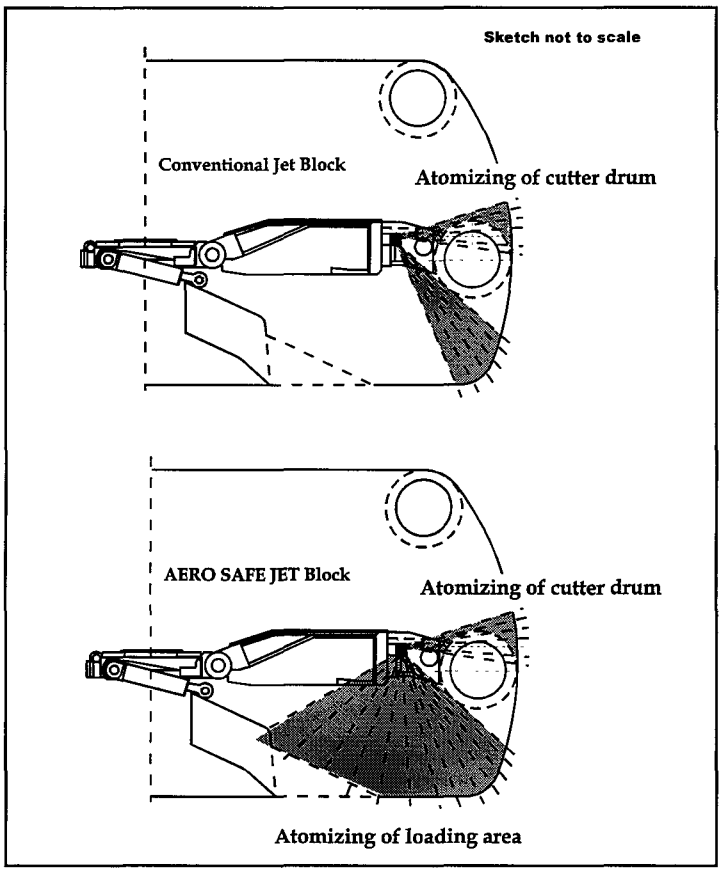


Figure 2.4.3(b) Sketch showing the difference in the water spray pattern when the ASJ block is used

Because of this difference and the large size of the area in the face that is affected, a range of underground tests was performed to determine the airborne dust levels when this system is used. The manufacturers claim that the amount of air that is moved by this system, when in operation, is 1 % of the total scrubber capacity and for this reason there should be no negative effect on the airborne dust count in the vicinity of the machine operator. During the series of tests, the ASJ system was switched on and off under the same conditions to determine its effect on the dust counts.

Briefly, the ASJ system was indeed found to be effective in combating the hazard of methane ignitions at the face. Because of the high turbulence and air movement caused by the air/water mixture that is introduced into the face at extremely high pressures, any methane occurrence is dealt with immediately. The high degree of turbulence, however, causes a problem with dust control in the face area. The dust is blown past the scrubber intake position towards the operator and the return airways.

The principle of balancing force and exhaust quantities in the face area for optimum dust and methane control cannot be applied when using this system. A practical problem with this system is maintaining a water pressure of 12 000 kPa and an air pressure of 250 kPa for the ASJ. It is impossible to supply that type of pressure with the current infrastructure of South African mines. For this reason, a separate compressor was installed on the machine, but it failed on a number of occasions. Space for additional equipment on the machine also poses a problem.

2.4.4 System 4: Air curtains (dust shields)

This system was initiated by one of the coal mines and is currently under investigation by their mining personnel, having been installed on a roadheader machine. It was difficult to arrange access to this particular mine to perform objective and individual tests on the system. For some reason, the mine is reluctant to allow any visitors to inspect the system in operation and, after a number of attempts, no further efforts were made. Reports from Voest Alpine and unofficially from mine personnel were that the air curtains, as they were installed, effectively prevented fresh air from entering the face area where cutting was taking place.

The only air that penetrated this sealed area was that pulled in by the on-board scrubber. From the point of view of dust control, the system should be effective as all the dust is captured in front of the scrubber intake position. This increases the capturing efficiency of the scrubber and removes the dust from the operator's position. The main area of concern with regard to the lack of sufficient airflow would be the lower region below the cutting drum where it is important to create additional airflow to prevent any methane build-up.

Although no information was forthcoming from the actual test site, it was possible to obtain from a roadheader manufacturer information on tests that had been performed on similar systems and the findings thereof.

The investigations were mainly done using CFD simulations. Apart from the other configurations that were tested, specific attention was given to the use of shields or ventilation brattices, also called "air curtains", on the sides and top of the machine in the vicinity of the scrubber intake position. Two scenarios were tested in which the capacity of

the scrubber was altered, and the dust concentrations were monitored and compared with those that occur when the standard ventilation layout is used.

On the machine that was used, the AM80 model, the driver's cab position is parallel to (in line with) the intake position of the scrubber system. This means that the driver is not completely isolated from any dust that is created at the face. Although the shields are supposed to enable the scrubber to be more effective in controlling the dust, the dust does tend to roll back towards the driver's position. The amount of dust that reaches the driver's position depends on the scrubber air quantity and the effect on the enclosed face area.

Figure 2.4.4 shows a sketch of the roadheader and the position of the shields as they were simulated and evaluated.

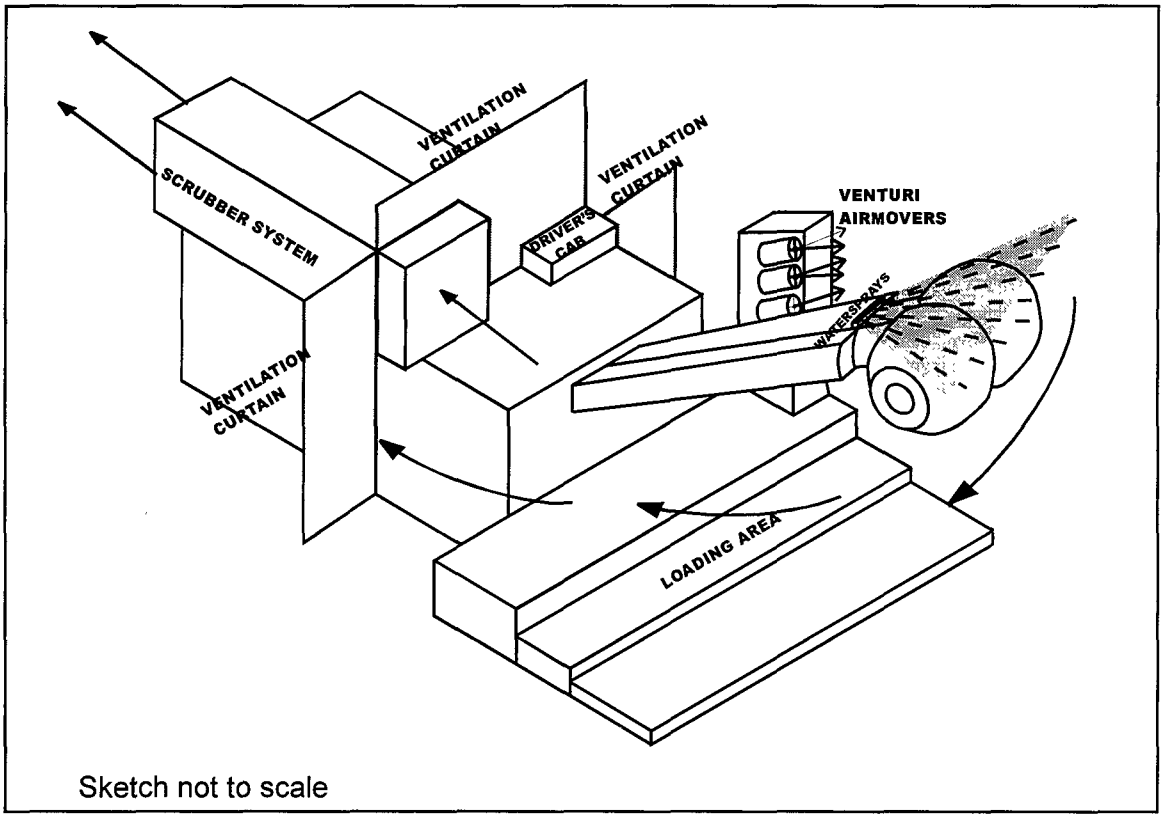


Figure 2.4.4: Sketch showing the positions of the shields on the machine as they were evaluated

A summary of the results of the investigations and some comments on the effectiveness of the ventilation systems are given in Table 2.4.4.

Table 2.4.4

AM80 CFD simulation results - Evaluation and assessment

Case	Machine layout		Scrubber system			Dust at operator	Comments
	Type	Description	Air quantity	Intake	Outlet	Dust conc.	
1	Refer. Case	CDCS scrubber venturi air-movers	8,0 m^3/s	5 m/s 0° hor.	12,9 m/s 15° out.	9 mg/m^3	- dust over operator - dust cloud close to operator
2	Standard system	Similar to case1 but ENGART and not CDCS	11 m^3/s	6,8 m/s 0° hor.	17,7 m/s 15° out.	15 mg/m^3	Comparison with case 1: + more fresh air over operator - dust cloud close to operator - dust passing scrubber
3	Air curtain (A)	Shields installed on top and at sides	11,0 m^3/s	6,8 m/s 0° hor.	17,7 m/s 15° out.	9 mg/m^3	Comparison with case 2: - fresh air over operator disturbed because of short-cutting behind shields - dust cloud closer to operator
4	Air curtain (A1)	Similar to case 3 but with lower outlet quantity	9,2 m^3/s	5,7 m/s 0° hor.	9,5 m/s 15° out.	15 mg/m^3	*Comparison difficult, because both velocity and volume were changed - less dust sucked from face because of reduced air velocities

It is clear from the table that with the shields, the dust is contained in front of the scrubber intake, although the operator is still exposed to the dust cloud from the face.

When the scrubber volume is increased, the dust concentration at the operator's position is reduced, but the dust cloud is still close due to the relative positions of the cab and the

scrubber intake. The position of the shields also causes a problem with the availability of fresh air to the operator. This option would therefore not be recommended.

The initial problem of supplying fresh air to the face for methane-control purposes still exists. Increasing the scrubber quantity will control the dust more effectively at the face, but the air will still short-circuit to the scrubber intake and leave the areas of concern at the footwall unventilated.

2.4.5 Recommendations and concluding remarks

The purpose of this document was to establish what methods were used in South Africa to ventilate the headings when a roadheader is used, with particular reference to the face area. The project was initiated after a study on the use of air-moving systems on continuous miners had been completed and after recommendations had been made on what ventilation configurations to use for effective face ventilation.

Ventilating the face area while a roadheader is cutting is somewhat more complex because of the physical layout of the machine and the nature of the movement of the boom. The number of systems that could be used is rather limited and all possibilities were evaluated and discussed in the body of the report.

Using all the information available and after completing the tests, it is possible to make recommendations on what ventilation system to use and what the configuration of the machine should be. As was the situation with the investigation regarding continuous miners, it is once again difficult to suggest a particular system for any particular mine. Mining conditions and individual needs differ from mine to mine and therefore each mine will have to alter the designs to suit its individual needs.

2.4.6 Summary of previous systems

The investigation concentrated on the air-moving systems installed on roadheaders and the additional mechanisms that could be used to ventilate the face heading when the roadheader is cutting the face. Areas that particularly need to be addressed are those underneath the cutting drum and over the operator.

All three of the improved systems that were investigated had their advantages and disadvantages. The summary below briefly describes each system as it was evaluated, together with the standard system as normally supplied with the machine. Because System 3, with the air curtains, could not be investigated in practice, the information used is based only on previous investigations and the CFD simulations that were conducted by the manufacturer.

STANDARD SYSTEM:

A roadheader is usually fitted with a standard system when delivered to the client except when the client has certain specific requirements with regard to the ventilation system on the machine. The machine is usually fitted with an on-board scrubber capable of delivering between 5 m^3/s and 10 m^3/s. Behind the cutting drum a set of water sprays is installed and on the left of the machine a set of venturi air-movers is installed to assist with moving the air across the face (refer back to Figure 2.4.1).

This system is sufficient in most cases where dust and methane do not present a problem. Once cutting commences and dust clouds are formed at the face, however, the water sprays and the scrubber are not effective in controlling the dust and preventing the dust cloud from reaching the operator. Because of the positions and direction of airflow of the venturi air-movers situated on the left side of the machine, fresh air supply close to the footwall in the loading area presents a problem and in the case of high methane concentrations, methane may accumulate in these areas.

HIGH-CAPACITY ON-BOARD SCRUBBER:

In an attempt to control the dust cloud at the face more effectively, the capacity of the on-board scrubber has been increased from 10 m^3/s to 15 m^3/s. In addition to this, water sprays have been installed on the side of the boom as well as vertically behind the drum (refer back to Figure 2.4.2(a)). This large amount of fresh air flowing into the heading should theoretically solve any ventilation problem that may occur inside the face area with regard to methane and dust. This system is effective, but only during the initial stages of the cutting cycle, after which the dust cloud from the loading area rises and passes the scrubber inlet. Because of the position of the scrubber inlet, 4 to 5 m from the face, only the area immediately around the scrubber inlet is affected.

Another important aspect is the balance between the systems forcing air into the heading and those exhausting air out of the heading. It is important to ensure that the total quantity of air forced into the heading and face area is in balance with the scrubber air quantity.

It is also important to note the direction of the airflow created by air-moving systems such as venturi air-movers.

AERO SAFE JET SYSTEM:

The Aero Safe Jet system is basically a set of water sprays installed behind the cutting drum that eject water and air under high pressure and direct them onto the face (refer back to Figure 2.4.3(b)). The remaining systems on the machine are standard. The main motivation behind the use of this system is that frictional ignitions are prevented because methane cannot accumulate with so much turbulence. In terms of methane control, this system is excellent and, for this reason, no further tests were conducted on the methane-control aspects of this system.

Dust control, however, is a completely different matter. The large amount of turbulence caused results in the dust being blown past the scrubber intake and towards the driver as a result of rollback and recirculation. The measurements that were taken, as described in the body of the report, show clearly the system's negative effect on the dust concentrations during the cutting process.

AIR CURTAINS (DUST SHIELDS):

This system is intended mainly for the control of dust in the face area and will be applicable only to mines in which methane does not present a problem. The shields are installed on the sides and on top of the machine in the vicinity of the scrubber intake and prevent the dust from blowing past the scrubber intake (refer back to Figure 2.4.4). In this way the capturing efficiency of the scrubber is improved and the dust cloud from the face is controlled more effectively.

The results from the CFD investigations show that the operator is still exposed to the dust from the face, regardless of the scrubber air quantity. Fresh air flowing over the operator is reduced and the fresh air supply to the areas under the cutting head and in the loading area is also reduced, which may cause a methane hazard.

With all the information available and keeping in mind the information that was gathered during the continuous miner investigations, it is now possible to make some recommendations on ways to ventilate the face while the roadheader is cutting, using air-moving systems on the machine.

Suggested Ventilation System

Because the options available for additional systems are rather limited, it is suggested that the second improved system, with the higher-capacity scrubber and the extension piece, as described, be introduced as a basic system on roadheaders. In addition, it is suggested that additional venturi air-movers be installed to create airflow in the lower region in the loading area. As also shown and discussed in the main body of the report, Figure 2.4.5 demonstrates this basic layout with the additional venturi air-movers installed on the left side of the machine.

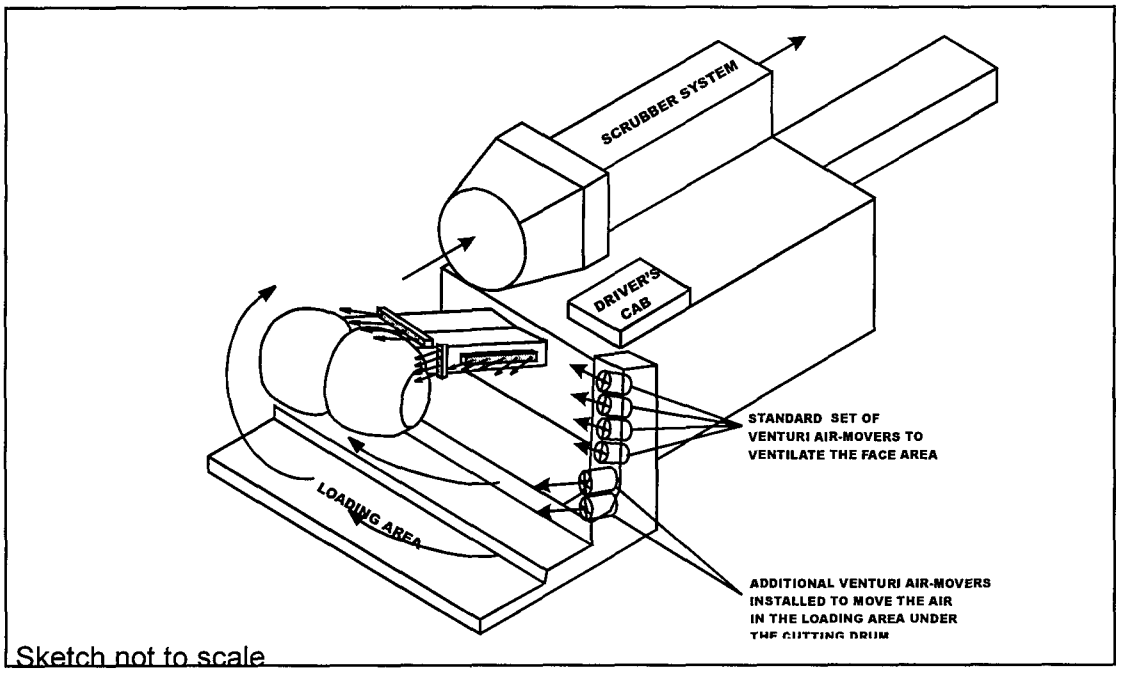


Figure 2.4.5: Basic layout of the suggested ventilation system

It must be emphasized that this is a basic layout that could be followed and is not meant to be in any way prescriptive to the industry. The actual installation positions, the number of water sprays and venturi air-movers needed and the actual capacity of the scrubber would need to be determined by each individual mine according to its needs.

This basic design addresses all the basic concerns such as airflow, methane and dust control. An adequate supply of fresh air is guaranteed by the large scrubber air quantity.

Dust control and improved capturing efficiency are ensured by the extension piece at the inlet of the scrubber. Sufficient methane control is ensured by the installation of the venturi air-movers on the left side of the machine.

To ensure that conditions in the heading and the face area are optimal, care must be taken that the total quantity of air moved by the forcing systems, both in the heading and on the machine, is balanced by the total quantity of air moved by the exhaust systems in the heading and face. It is important to keep the force quantity the same as or slightly lower than the exhaust quantity. In this way, fresh air will always flow over the driver in a forward direction and dust rollback will be kept to a minimum.

2.5 Means of evaluating the effectiveness of ventilation systems in mechanical miner headings

In the preceding sections, the emphasis of project COL205 was on developing a fundamental understanding of various air-moving systems. With this knowledge, the systems can be applied more effectively to improve dust and methane control in bord-and-pillar headings. In practice, mining conditions can vary considerably from colliery to colliery with regard to the mining techniques used and the geology of the coal seam being mined. Variations in cutting sequences, mining equipment used, ventilation techniques, ventilation equipment design, ventilation equipment settings, airflow quantities, seam height, methane content of the coal, pillar centres, bord width, etc. all play a part in the airflow patterns encountered in a specific section. As dust and methane control are closely linked to the airflow patterns, it is clear that there are numerous variables that need to be balanced to achieve the optimum ventilation strategy.

To be able to assess a specific ventilation set-up in a given situation, it is necessary to measure its effectiveness quantitatively. The effectiveness has to be measured in such a way that the value obtained is reliable, easy to interpret and can be universally used to compare the performance of various ventilation set-ups directly.

2.5.1 Current methods

Over the years, various techniques have been proposed and used to quantitatively and independently evaluate ventilation set-ups. One technique for determining the

effectiveness with which a ventilation system controls methane in a heading is to calculate the face ventilation effectiveness (FVE) index. The FVE index is determined by dividing the methane concentration in the return air by the methane liberated in the face region (Kissell *et al.*, 1986). As all the liberated methane must leave the face area, the closer this ratio is to one, the more effective the ventilation set-up.

Apart from this index, various other quantifiable indices for evaluating face ventilation conditions have been proposed, i.e.

- peak face-area methane-liberation rate (FL)
- methane-dilution capacity (MD)
- face ventilation index (FVI) (Haney *et al.*, 1995)

These indices require the quantity of air crossing the face area to be known, making their application difficult in cases where ventilation conditions near the face are awkward to assess and measure, as is the case with active production headings in South African bord-and-pillar sections.

Another method that was also proposed by the USBM was the face ventilation measurement (FVM) which simply measures ventilation conditions at the working face, eliminating the need to measure methane (Vinson *et al.*, 1980). Again, this method is difficult to apply in active sections where the ventilation conditions near the face are dynamic and the environmental conditions unsuitable for airflow-monitoring equipment. Because airflow measurements across the face of a heading are required in order to apply the above methods, the FVE index appears to be the most suitable method for South African conditions.

To establish the suitability of the FVE index for South African conditions, trial tests were conducted. The classic approach in applying the FVE index - that of measuring the methane levels at the cutting face and in the last through road - had to be adjusted for local conditions. The aim was to reduce the time lag between the methane peaks recorded at the face and then at the rear of the heading, which makes analysis difficult.

It was decided to measure the methane levels at the cutting head and the rear of an active mechanical miner. As the aim of the method is to determine how effectively the ventilation system clears the face, this configuration also reduces the effects of recirculation at the rear of the machine. The physical implementation of the method was also simplified by allowing all sensors and equipment to be mounted on the mechanical miner.

Upon examining the results, various problems were identified (Van Zyl *et al.*, 1997). Firstly, the methane levels recorded in the cutting face region consist of a series of peaks and low points as the CM sumps and shears. These variations cause the FVE values to fluctuate in a similar manner. The fluctuating FVE values make it difficult to determine a single FVE value that will accurately describe the effectiveness of the ventilation system for a specific section.

Even when a general trend of FVE values is established, no fixed value can be arrived at. Either a general increase, a general decrease or both can be observed in FVE values over a period of time. If these trends were to be used to depict the ventilation effectiveness, the FVE index could become difficult to interpret and hence difficult to apply.

Apart from this uncertainty about a representative FVE number for a section, various anomalies in FVE numbers occur as a CM advances into a cut. In some instances, the FVE index indicates that the ventilation conditions improved, whereas they were actually deteriorating. After analysis of the conditions in which these anomalies were observed, it was found that they were related to the positions of the sensors on the CM. Altering the sensor positions to cover the whole heading should improve the results. However, in practice this will make the monitoring of methane levels very complex, as time delays and other ventilation phenomena have to be accounted for.

Because of the way in which the FVE index is calculated, a ratio is used to describe the ventilation effectiveness, but use of a ratio means that the actual levels of methane recorded are lost. For example, an FVE index close to one indicates the effective removal of methane from the face, but does not reflect the general methane levels, which may well be above the allowable limits. In such cases, although the ventilation reaches the face, the ventilation system is inadequate to cope with the liberated methane.

Another situation that adversely affects FVE calculations is when low methane levels are

present in a heading. This is due mainly to the inaccuracy of current monitoring equipment at levels below 0,3 % methane by volume. To evaluate the FVE in headings where methane levels are generally lower than 0,3 %, a bag sampling technique was developed (Rider *et al.*, 1997). However, this technique is cumbersome and will give limited data in the dynamic conditions of a heading, reducing the representativeness of the results.

Though widely used, the classic approach to the FVE index cannot cope effectively with the methane-liberation conditions in a dynamic heading. It was therefore decided that the FVE index is unsuitable for use in South African collieries. However, the need for a method to quantitatively assess methane control in active headings still remains.

This led to the development of a method suitable for South African mines, taking into account the dynamic behaviour of methane levels in a heading and the actual levels recorded.

2.5.2 Methane safety index (MSI)

To quantitatively assess the effectiveness with which a ventilation system controls methane in an active heading, an analysis of the methane concentrations in the face area alone should be sufficient (Campbell and Dupree, 1990).

In developing a method that can be applied universally, is simple to interpret, easy to apply and gives reliable information, the shortcomings in the application of other methods had to be addressed. These were identified as being:

- difficulty in deriving a single number representing the whole cutting cycle and its inherently dynamic methane levels
- producing consistent and reliable results
- reflecting the actual methane levels and trends observed
- producing reliable data in areas where low methane levels are recorded.

Using these basic criteria, the methane safety index (MSI) was devised. This index provides a single, universally applicable number with which the effectiveness of a ventilation system can be described. The index both reflects the ability of a particular ventilation system to keep the methane levels below acceptable limits in an active heading, and gives a quantitative indication of how well or badly it is achieving this. The process of deriving the MSI is illustrated in Figure 2.5.1.

The first step towards deriving the MSI is to find a way in which a section can be divided into zones or stages for which the ventilation conditions and machine movements are relatively constant, i.e. predictable. If this can be done sensibly, the huge amount of dynamic data available in a section can be reduced to more manageable proportions.

The development of a section is not a matter of cutting at random into the coal face. Normally, it is a carefully orchestrated sequence of cuts, which is repeated periodically to allow the section to advance into a coal seam.

If we look at the series of cuts in a production section from a ventilation and methane-liberation point of view, we find that firstly, for each of these cuts the ventilation conditions at the start of the cut, during the course of the cut and at the end of the cut should be approximately the same. This is due to the initial heading geometry, and the changes due to cutting associated with each cut, being fairly constant. Also, during a cut the only major machine-travel movements should be those of the shuttle cars, ensuring minimal disturbance of airflow patterns during production. Secondly, the cutting process itself is the main contributor to methane-liberation in a section. From this it follows that by dividing the section into a set of zones corresponding to the cutting sequence of a section, a finite set of repeated and distinct ventilation scenarios will be obtained for which the methane behaviour should be fairly constant. This is the first step in obtaining an MSI for a section. For each zone an MSI is calculated, and the maximum value obtained is used as the MSI for the section. This will allow the colliery to determine whether the section is safe during all phases in the production cycle. By using a zone approach, the colliery can easily determine during which cuts there are likely to be problems with methane and can hence pinpoint problem areas and take appropriate action.

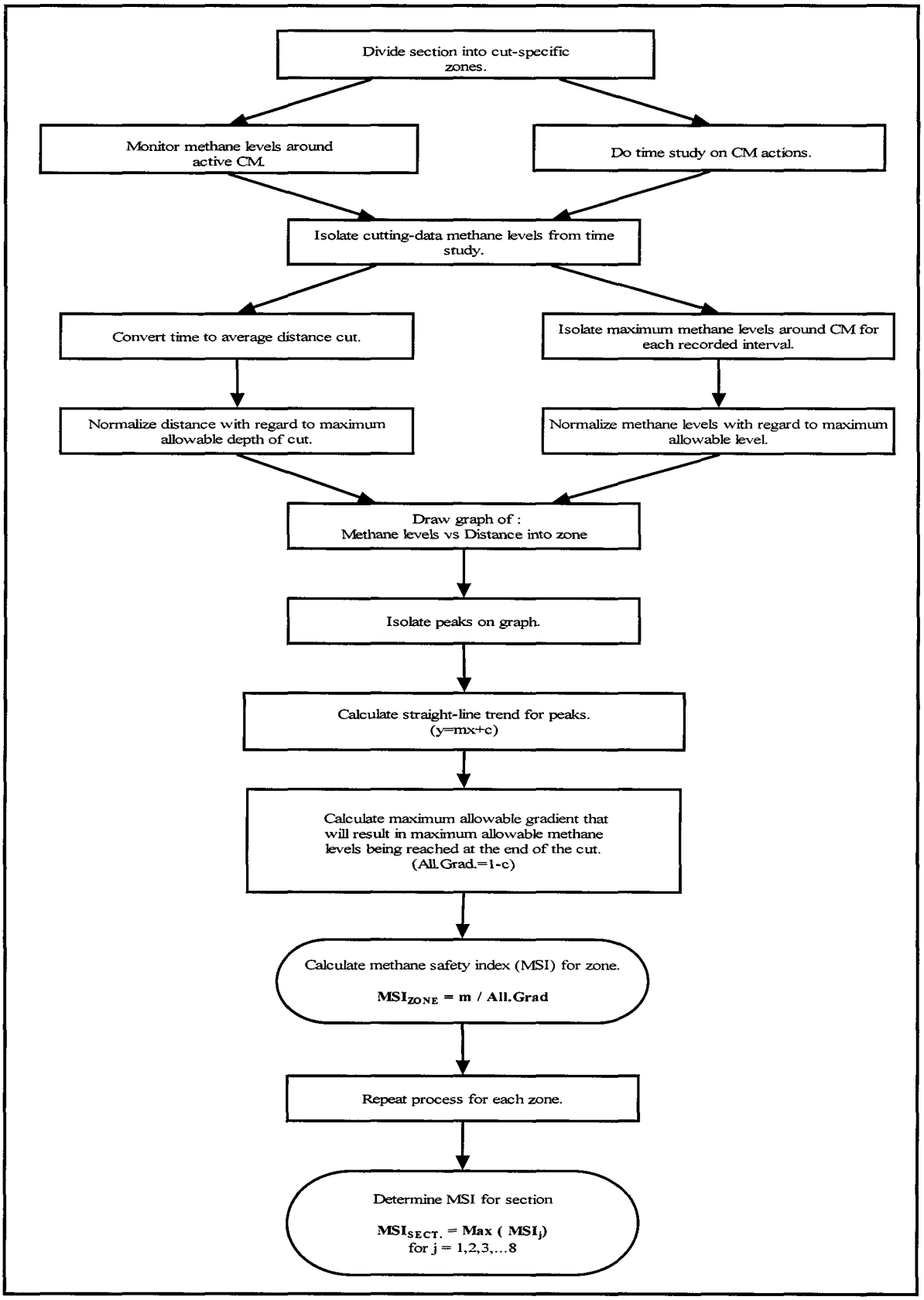


Figure 2.5.1 Methodology for determining the methane safety index (MSI)

Once the zones have been identified, the methane levels around the mechanical miner for each zone have to be monitored. Monitoring of methane levels is done continuously as the mechanical miner advances into the zone. The levels are recorded at four positions on the mechanical miner, i.e. on both sides of the cutting drum and on both sides at the rear of the machine. The four monitoring positions will ensure that all possible maximum levels recorded around the CM will be detected. The methane levels are digitally recorded every 10 s during the cut. These data are then downloaded onto a PC for analysis. As only the methane levels during the cutting process are of interest, a time study of machine movements is done to enable the cutting-only data to be isolated from the recorded data. This is the data set used to determine the MSI.

To determine the worst-case scenario, the maximum methane levels recorded around the mechanical miner are isolated. This results in a single-line graph depicting the maximum methane levels recorded around the CM for a zone.

To be able to relate the methane levels recorded to the position of the mechanical miner in the heading, the time data are converted to "distance into the cut". Dividing the total distance cut by the time required to do this will yield an "average advance rate" during the cut, which, if multiplied by a time interval, will give an approximation of the distance advanced into the heading at that time.

The recorded methane levels and distance cut into the heading are now normalized to allow the data to be used universally. Both values are normalized to a value of one. The methane levels are normalized with regard to the maximum allowable limits for the section (usually to 1,4 % by volume), and the distance with regard to the stipulated maximum depth of the specific cut (currently 12 m maximum). A graph is then generated of normalized methane levels vs normalized distance into the cut.

From this graph it can be seen that the methane levels follow a series of peaks and low points. Again, as we are interested in the worst-case scenario, the peak values are isolated on the graph. A peak value is defined as one that has values lower than itself for the preceding and following time intervals. A straight-line trend is then fitted through the isolated peak methane values.

The trend line will be described by an equation of the form:

$$y = mx + c$$

where:

y = normalized methane level

m = gradient of peak methane values

x = normalized distance into the cut

c = theoretical initial maximum methane level at the start of the cut.

The theoretical initial maximum methane level at the start of the cut (c) is then used to calculate the theoretical "allowable gradient" which will result in the maximum allowable methane levels being reached at the end of the zone. As the methane levels and distance cut are normalized to one, this is simply done by subtracting c from one, i.e. "allowable gradient" = 1 - c.

The MSI is now calculated by dividing the actual methane gradient (m) by the theoretical allowable gradient:

$$MSI = \frac{\text{Actual methane gradient}}{\text{Theoretical allowable gradient}}$$

This whole process is completed quickly and efficiently with a spreadsheet program in approximately ten minutes. The MSI for each zone is now calculated and the maximum of these values used to represent the section.

Because the methane levels and distance cut are normalized, the index can be universally applied. This implies that there are fixed MSI ranges to which a specific meaning can be coupled. The MSI ranges are as follows:

MSI $\leq$ 0

MSI values in this range indicate that the ventilation is improving as the CM advances into the zone. If this is the case, it is always advisable to check the data and the equipment, as this is an unlikely but possible scenario.

0 < MSI $\leq$ 1

In this range, the ventilation is coping with the methane load and is still within the legal limits at the end of the cut. The closer the values are to zero, the better the ventilation conditions with regard to methane control. As the value approaches one, it is advisable to

check the ventilation conditions as the margin for coping with unforeseen events or circumstances reduces.

$1 \leq$ MSI < 3,5

In this range, the ventilation set-up is not coping with the methane load during the cutting cycle. Above one, the peak methane levels are not within the legal limits and at some stage during the cutting of the zone they will exceed the cut-off limit. A value of 3,5 indicates that the peak methane levels are entering the lower explosive limit (LEL) of methane in air of 5 % by volume. In this case, action needs to be taken urgently to improve the ventilation conditions in the active heading.

MSI $\geq$ 3,5

In this range, operations must be stopped immediately as the CM will operate in an explosive atmosphere at some time during the cut into the specific zone.

2.5.3 Concluding remarks

The MSI has been applied in practice and has yielded very good results. It has been used successfully to compare various ventilation set-ups by returning a single number that accurately reflects the data trends observed. Another helpful feature of the index is that it is an absolute index, meaning that if the MSI exceeds one, the allowable legal limits will most likely be exceeded during the course of the cutting process. All this is possible because the method takes into account the actual methane levels recorded and the trends observed, allowing the index to be both absolute and comparative.

As we are comparing the actual methane trends with the maximum allowable trends, the MSI can be used in sections where low methane levels are recorded, i.e. below 0,3 % methane. The results can be relied on, as errors in low-level methane monitoring will not adversely affect the MSI reliability, because the index relates the absolute values to the allowable levels. This means that if low methane levels are recorded, which are well below the allowable limits, an MSI of well below one will be obtained.

By monitoring only the methane levels around the machine, the data acquisition is simplified as a central recording unit is placed on the mechanical miner and linked to the sensors. The need for external measurements, such as last through road methane levels, is eliminated. This also helps with data processing and analysis as all data are

downloaded in a single operation onto a single spreadsheet. All calculations can be done by means of the spreadsheet program within approximately ten minutes.

As a section is divided into multiple zones, each having its own MSI value, it is easy to identify the problem area if an undesirable MSI value is returned. This will assist in addressing possible shortcomings in the ventilation system.

Overall, initial tests indicate that the MSI is well suited for use in the dynamic conditions of a production section.

3 Summary of findings and recommendations

3.1 Effective use of airjet fans

The purpose of this investigation was not to state whether or not a jet fan should be used to ventilate a bord-and-pillar heading, but rather to make the industry aware that there are important variables that influence the behaviour of the airflow when jet fans are used and why this is so.

To use a jet fan inside a mechanical heading, a number of rules should be followed to ensure that the correct airflow patterns and the best conditions prevail:

- The jet fan should always be installed in the upstream position.
- The air from the scrubber outlet should be directly in line with the air from the jet fan nozzle.
- The jet fan and the on-board scrubber should be installed on opposite sides of the heading.
- The fan inlet should be in a position where it will not recirculate the air.
- The nozzle outlet should point directly into the heading to create a "U" shape airflow pattern.

- It is advisable to use on-board air-moving systems together with the jet fan to assist in ventilating the face area.

- The jet fan can be used either on the floor or against the roof, depending on the particular mining conditions.

- It is advisable to position the jet fan not closer than 15 m from the face to minimize the dispersal of airborne dust created during the cutting process.

3.2 Use of controlled air recirculation

The following are some of the more important facts that were learned from this project in terms of ventilating a heading by means of controlled air recirculation:

- The quantity of the intake air used should be designed for the original amount of methane make.

- For face air velocities below 0,4 m/s, the amount of dust make does not greatly increase with the air velocity. When the air velocity exceeds 4,0 m/s, the amount of dust made can be expected to increase in proportion to the air velocity.

- Controlled air recirculation results in an increase in the airflow rate, reducing the risk of methane ignitions by better mixing.

- With controlled air recirculation in headings, the dust clouds are confined to the face area and the ventilating air moves forward continuously.

- Controlled recirculation in advance headings can also result in a reduction of noise levels and less congestion of equipment, because the number of fans can be limited without limiting the increase in available air.

- Controlled recirculation can contribute to significant power and cost savings because more air is available without the introduction of additional or larger fans.

- The force/exhaust overlap system proved to be the best system as it addresses the issues of both methane and dust.

Considering conditions in South African collieries, the following statements can be made:

- Information from the literature has shown that controlled air recirculation will not cause the build-up of harmful gases or dust. Rather it will improve the dilution and/or removal of these substances, providing that the methane-release rate remains the same and that there is a constant supply of fresh air.

- Information from the literature has also shown the importance of proper ventilation planning, of knowing the methane content of the coal and of knowing the release rates in the areas being mined. Air quantities and allowable dust and methane concentrations can be calculated at the various positions using the equations given in the original report.

3.3 On-board air-moving systems on continuous miners

The following are the more important findings from both the literature study and the actual underground tests with regard to the ventilation of CM headings:

- Normal sprayfan systems will only ventilate a heading that is developed between 6 m and 10 m from the last through road. Headings that are any deeper will need the assistance of an additional ventilation system.

- When the normal sprayfan system is combined with an on-board scrubber, it is possible to ventilate headings up to distances of 20 m from the last through road.

- The power that should be used by the sprayfan system to move the air is determined by the amount of methane generated at the face during the cutting process, in that more air is needed in the face for higher methane concentrations.

- An effective sprayfan system can move as much as 300 times the amount of fresh air that enters a heading.

- The important area in which the sprayfan action must be concentrated is underneath the boom since most of the dust is made below the boom with the downward shearing

action of the drum. It is also true that methane tends to accumulate under the boom because there is usually relatively little air movement in this region.

- The water sprays that are normally installed on top of the boom are effective only within the first 300 mm. These sprays should therefore be designed and installed to achieve "low reach" and no overspray.

- The most common angles at which the water sprays are used in the spray-fan systems seem to be 30° to the side and between 10° and 20° over the cutting drum. This enables effective pick lubrication, wetting of the face and movement of air across the face.

From the literature study as well as the actual tests that were carried out, the conclusion was reached that on-board scrubbers have become an important part of the way in which continuous miner headings are ventilated and that they can no longer be seen only as the dust-suppression system on the machine. The on-board scrubber, as it is used today, has become one of the main suppliers of fresh air into a heading. It is also used to deal with the dust that is made during the cutting process. These scrubbers have become capable of delivering larger and larger air quantities to cope with the large amounts of dust created. Unfortunately, the additional ventilation systems used to ventilate the headings have not been upgraded to deal with the higher air quantities enforced by the scrubbers.

To ensure that there is sufficient airflow at the face, the coal mining industry has moved to the use of on-board air-moving systems to assist the auxiliary force and exhaust ventilation systems in ventilating the face area. These systems include the use of sprayfan systems and venturi air-movers or a combination of both. For these systems to act effectively in their role as air-movers, it is important that they be used in balance with the rest of the ventilation systems in the heading with regard to air-moving capabilities.

To ventilate a heading to deal best with the existing methane and dust problems, a few basic rules and guidelines must be adhered to:

- The positions of all relevant ventilation systems used inside the heading and the air flowing inside the last through road are important. When the air direction is from right to left past the heading, the on-board scrubber should be situated on the left-hand side of the machine and vice versa.

- The force ventilation system, if in use, must be installed on the intake side of the heading, which is side opposite to the scrubber.
- With this configuration in place, the air should theoretically flow across the face to the scrubber inlet. For this to be effective, the air stream from the force duct or ductless fan should not interfere directly with the air stream from the scrubber outlet. If it does interfere, the air recirculation will be enhanced and the fresh air supply to the face area will be reduced.
- Cutting sequences are also important. With the air flowing from right to left past the heading, for example, the first web being cut should be on the right-hand or intake side of the heading and shear off on the left. This way the scrubber is always against the sidewall and the dust is contained more effectively. The converse is applicable to left-hand machines.
- Air quantities in the face area that are created by the individual ventilation systems should be kept in balance to control both dust and methane.

It is important to remember that these on-board systems (excluding the scrubber) are not fresh air suppliers but merely air-moving devices. The auxiliary force ventilation system that is used supplies the fresh air to the point where the air-movers take over and deliver and move it to the face area.

The effective reach distance of the air from the force system is approximately 20 m from the outlet position, provided the air quantity complies with the required 0,2 $m^3/s/m^2$ of face area. This means that the whole strategy of ventilating a continuous miner heading, or split, must be formulated on the basis of these guidelines.

Following the underground trials, a basic installation on a continuous miner was identified that could best deal with methane and dust control. This was shown in sub-section 2.3.1 and Figure 2.3.1.

3.4 On-board air-moving systems on roadheaders

The best way to summarize the results from this part of the project is by means of a table showing the CFD simulation results, by summarizing the findings on the individual systems that were tested and discussing the suggested ventilation system that arose from the project.

Summary of previous systems

The investigation concentrated on the air-moving systems installed on roadheaders and the additional mechanisms that could be used to ventilate the face heading when the roadheader is cutting the face. Areas that particularly need to be addressed are those underneath the cutting drum and over the operator.

All three of the improved systems that were investigated had their advantages and disadvantages. The summary below briefly describes each system as it was evaluated, together with the standard system as normally supplied with the machine. Because System 3, with the air curtains, could not be investigated in practice, the information used is based only on previous investigations and the CFD simulations that were conducted by the manufacturer.

STANDARD SYSTEM:

A roadheader is usually fitted with a standard system when delivered to the client except when the client has certain specific requirements with regard to the ventilation system on the machine. The machine is usually fitted with an on-board scrubber capable of delivering between 5 m^3/s and 10 m^3/s. Behind the cutting drum a set of water sprays is installed and on the left of the machine a set of venturi air-movers is installed to assist with moving the air across the face (refer back to Figure 2.4.1).

This system is sufficient in most cases where dust and methane do not present a problem. Once cutting commences and dust clouds are formed at the face, however, the water sprays and the scrubber are not effective in controlling the dust and preventing the dust cloud from reaching the operator. Because of the positions and direction of airflow of the venturi air-movers situated on the left side of the machine, fresh air supply close to the footwall in the loading area presents a problem and in the case of high methane concentrations, methane may accumulate in these areas.

HIGH-CAPACITY ON-BOARD SCRUBBER:

In an attempt to control the dust cloud at the face more effectively, the capacity of the on-board scrubber has been increased from 10 m^3/s to 15 m^3/s. In addition to this, water sprays have been installed on the side of the boom as well as vertically behind the drum (refer back to Figure 2.4.2(a)). This large amount of fresh air flowing into the heading

should theoretically solve any ventilation problem that may occur inside the face area with regard to methane and dust. This system is effective, but only during the initial stages of the cutting cycle, after which the dust cloud from the loading area rises and passes the scrubber inlet. Because of the position of the scrubber inlet, 4 to 5 m from the face, only the area immediately around the scrubber inlet is affected.

Another important aspect is the balance between the systems forcing air into the heading and those exhausting air out of the heading. It is important to ensure that the total quantity of air forced into the heading and face area is in balance with the scrubber air quantity.

It is also important to note the direction of airflow created by the air-moving systems such as venturi air-movers.

AERO SAFE JET SYSTEM:

The Aero Safe Jet system is basically a set of water sprays installed behind the cutting drum that eject water and air under high pressure and direct them onto the face (refer back to Figure 2.4.3(b)). The remaining systems on the machine are standard. The main motivation behind the use of this system is that frictional ignitions are prevented because methane cannot accumulate with this much turbulence. In terms of methane control, this system is excellent and, for this reason, no further tests were conducted on the methane-control aspects of this system.

Dust control is, however, a completely different matter. The large amount of turbulence caused results in the dust being blown past the scrubber intake and towards the driver as a result of rollback and recirculation. The measurements that were taken, as described in the body of the report, show clearly the system's negative effect on the dust concentrations during the cutting process.

AIR CURTAINS (DUST SHIELDS):

This system is intended mainly for the control of dust in the face area and will be applicable only to mines where methane does not present a problem. The shields are installed on the sides and on top of the machine in the vicinity of the scrubber intake and prevent the dust from blowing past the scrubber intake (refer back to Figure 2.4.4). In this way the capturing efficiency of the scrubber is improved and the dust cloud from the face is controlled more effectively.

The results from the CFD investigations show that the operator is still exposed to the dust from the face, regardless of the scrubber air quantity. Fresh air flowing over the operator is reduced and the fresh air supply to the areas under the cutting head and in the loading area is also reduced, which may cause a methane hazard.

With all the information available and keeping in mind the information that was gathered during the continuous miner investigations, it is now possible to make some recommendations on ways to ventilate the face while the roadheader is cutting, using air-moving systems on the machine.

SUGGESTED VENTILATION SYSTEM

Because the options available for additional systems are rather limited, it is suggested that the second improved system, with the higher-capacity scrubber and the extension piece, as described, be introduced as a basic system on roadheaders. In addition, it is suggested that additional venturi air-movers be installed to create airflow in the lower region in the loading area. As shown and discussed in the main body of the report, Figure 2.4.5 demonstrates this basic layout with the additional venturi air-movers installed on the left side of the machine.

4 References

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