COALTECH

PREVENTING CUTTING HEAD METHANE EMISSIONS ON CONTINUOUS MINERS. PHASE 5.

FINAL REPORT

By

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April 2020

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Task 2.9.6

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April, 2020

CONTRACT REPORT

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SUMMARY

Extensive use was made of CFD simulations, supported by underground measurements, to evaluate numerous Continuous Miner (CM) heading ventilation systems and operations. These included straights and splits, single and double scrubbers, straight and side scrubber discharges, jet fans, scoop brattices and force columns, with and without shuttle cars.

Methane emissions were included from the face, cut and falling coal, coal on the gathering arms and the chain conveyor, and coal on the shuttle car.

Ventilation flows were generally represented as coloured flow lines or contours on the CFD outputs, with methane as coloured contours. These clearly showed the ventilation flow patterns and areas of poor ventilation flow, with potential for, or with higher methane concentrations.

Limitations of the previous COL518 research could be demonstrated with CFD, in particular the effects of drum rotation, falling coal, and the complexities of ventilation flow in splits. None of these could be included in the COL518 physical test at Kloppersbos.

Relying on COL 518 may be not be sufficient as the guide for in-heading ventilation design for any configurations that are more complex or where material design changes, such as scrubber systems, have occurred.

Mines and manufacturers relying on COL 518 as the sole means of designing heading and on-board ventilation systems should therefore take cognizance of these limitations. They should therefore exercise due care and diligence as required in terms of the Mine Health and Safety Act to ensure that in-heading ventilation, health and safety conditions are, in fact, within acceptable limits when such changes are affected.

ACKNOWLEDGEMENTS

We would like to acknowledge the significant contributions made to this project by our colleague Mr. CF Meyer who sadly passed away in 2018.

CONTENTS

FIGURES

1 BACKGROUND

This project was initiated following a number of methane ignitions in South African coal mines. The question being asked was “why should these ignitions still occur when so much is known about how to ventilate mines in order to adequately dilute methane and also how to manage ignition risks”?

Since all the reported ignitions occurred while a heading was being excavated by a Continuous Miner (CM) it would have been easy to focus on a single aspect e.g. frictional ignitions or water sprays or human behaviour. However, this project looked at the problem in a holistic way, guided by the involvement of personnel from coal mining companies and equipment manufacturers. Early meetings and workshops identified 10 key areas, each requiring additional research or a review of previous research. Risk assessments were also undertaken to identify the principal potential contributors to methane ignitions

As the project evolved, with ongoing research, the objectives became to quantify ventilation flows and methane accumulations around continuous miners and advise on the applicability of COL518 to the present mining operations.

This involved extensive use of Computational Fluid Dynamics (CFD) to model heading ventilation, and to compare the results to underground measurements for verification, and with the COL518 test tunnel results.

2 REVIEW: COL 518, JANUARY 1999: MECHANICAL MINER ENVIRONMENTAL CONTROL, EVALUATION OF ENVIRONMENTAL AND DUST CONTROL SYSTEMS IN A VENTILATION SIMULATION TUNNEL

2.1 Summary of COL 518 objectives, fundamental elements comprising the spray fan system, scrubber size and configuration and heading ventilation methods.

The primary objective of Project COL 518 was “to control the environment to ensure that dust and methane levels were within regulating requirements”. To this end, CSIR-Miningtek were assigned to test and evaluate ventilation systems to ensure compliance with the new dust standard (<5mg/m^3) and the existing methane standard (<1% by volume, methane to air mixture).

The project was conducted in two phases, the first on surface at the newly built ventilation tunnel at the Kloppersbos Research Centre and the second phase being the underground evaluation of the proposed systems.

The report, entitled “Mechanical Miner Environmental Control: Evaluation of Ventilation and Dust Control Systems in a Ventilation Simulation Tunnel” was published in 1999 and the systems proposed therein have subsequently been adopted as the fundamental design standard for controlling dust and methane in continuous miner headings.

In summary, these systems are one of the following heading ventilation systems:

- A forcing ventilation system consisting of a ventilation duct fitted with an in-line auxiliary fan (ducted systems);
- A forcing ventilation system consisting of a jet fan so positioned at the inlet of the mechanical miner heading as to induce flow from the last through road into the heading;
- A forcing ventilation system consisting of a scoop brattice so positioned at the inlet of the mechanical miner heading as to induce air flow from the last through road into the heading.

In conjunction with these systems, an additional system consisting of an on-board mobile exhaust system, consisting of an on-board scrubber system fitted with a fan discharging in a direction linear to the direction of mining was utilised to act as an "exhausting" system to assist with conveying the foul air from the face area back towards the last through road.

Elements within the project which received specific attention were:

- A new spray nozzle design incorporating 1.6mm inlet and 2.0mm outlet apertures;
- The "Kloppersbos" directional spray fan system (specifically the spray configuration);
- Air movers over the flight conveyor;
- Extended scrubber intake, with inlet cone fitted, and
- The introduction of a physical air curtain

During the project, combinations of these systems were tested with particular focus on the volumes of air being conveyed into the heading, recirculated within the heading and, finally, discharged from the heading.

In all configurations tested, the scrubber was on, whilst the scrubber inlet (draw point) was moved closer or further from the face zone in order to determine the effect of the draw point on the air flow surrounding the continuous miner and within the production (cutter) zone of the face. The effect of a deflector plate at the scrubber outlet was also evaluated.

In addition to the systems described above, a further set of mechanical air movers consisting of directional water sprays which were mounted on the continuous miner in various positions on and around the cutter boom, as well as directional air movers mounted above the coal conveyor and discharging towards the face were utilised to enhance the flow patterns around the machine and inside the cutting zone.

This system is colloquially identified as the "spray fan system".

Once the configurations, air intake and discharge positions of the auxiliary ventilation systems, air flow rates, water flow rates and pressures and mounting positions were refined, the systems were then fitted to an active continuous miner and tested and further refined under real-life conditions.

These designs, especially with reference to the on-board systems constituting of the combination of the linearly or diagonally upward discharging scrubber system and the machine mounted spray fan and air mover system, were thereafter universally adopted as the basis for future on-board dust suppression designs for continuous mining machines.

Subsequently, on-mine changes have occurred where these systems (especially the on-board scrubber size and discharge configuration) have been arbitrarily modified to accommodate changes to the continuous miners, to attempt to improve scrubber efficiencies and to attempt to improve air flow conditions within headings. In the latter case, an example is the adoption of sideway discharging scrubbers, where the scrubber discharge is angled towards the sidewall to reduce the discomfort of high air speeds and entrained dust which impacted the machine operators seated on these machines and, especially, the shuttle car operators.

In addition, the scrubber throughput was arbitrarily increased in the expectation that it would be more effective in scrubbing dust, without due cognizance being taken of the effect on air flow patterns around the CM and its effect on the spray fan system. In many cases, especially during subsequent assessments and CFD modelling, it was established that the additional energy thus imparted to the airflow and the altered air flow patterns in some cases completely overwhelm the spray fan induced air flow pattern around the cutter head and boom.

Since the original work was conducted at Kloppersbos, the use of on-board machine operators has also been almost completely terminated and these machines are now remotely operated by operators positioned on foot, diagonally positioned behind these machines. The scrubber discharge directions have, however, in most cases not been modified back to the original diagonally upward and more linear discharge directions as the space behind these scrubbers is now often utilised for other on-board control systems.

Many of the hybridised systems therefore now do not support the original “clean flow pattern” design as originally developed at Kloppersbos.

2.2 Discussion of COL 518 research methodology, limitations, advantages and disadvantages.

In conducting the work at Kloppersbos, the assessment procedures essentially relied on practical, physical observations and empirical measurements.

These processes have the benefit of verifiable data acquisition such as flow directions and, to some extent, velocities.

Gross flow rates and patterns were identified around the machine and scrubber system and these can, to some extent, be quantified w.r.t. air velocities, dust and moisture content. Included in these evaluations were the discharge positions and directions of the jet fan system and the ducted systems, respectively.

A good understanding of the effect of spray nozzle type and size and, hence, water pressure/flow rates and patterns was developed during the Kloppersbos trials which proved invaluable in the subsequent spray fan system design.

However, the manual assessment processes utilised to evaluate air flow directions and patterns do not necessarily identify all of the flow patterns, areas of accumulation of contaminants or the nuances and effects of other dynamic processes, such as the rotation of the cutter drum, falling coal and the effect of the picks and pick boxes on the aerodynamic forces thus induced, especially in inaccessible places such as below the cutter drum. The very presence of observers in areas where people are not normally present may also influence the outcomes. Other dynamic forces, such as the impact of the movement of coal along the flight conveyor and the movement of the gathering arms are also not necessarily incorporated into the practical observations.

All the Kloppersbos tests were conducted with the cutter boom in the horizontal position in the middle of the face (boom horizontal). The effects of the boom and drum assembly when lowered, which proved to be the highest risk configuration from a methane accumulation perspective in subsequent research, was therefore not specifically addressed.

Subsequent experience also was that the use of the physical air curtain did not find much on-mine support due to practical issues associated with the installation and maintenance of this equipment. The benefits deriving from this system during the Kloppersbos and subsequent trials were therefore not necessarily carried into practice.

Finally, two specific aspects that were not considered at Kloppersbos were the effect of the shuttle car on the airflow and also the impact on airflow patterns when cutting splits left and right from the advancing roadway.

2.3 Summary of COL 518 findings and recommendations

In essence, the following findings were made and conclusions drawn:

- The Kloppersbos simulation tunnel proved invaluable in developing and evaluating dust control systems and their components;
-

The following main developments resulted from these studies:

- New spray nozzle;
- Directional spray system
- Physical air curtain, and
- Changes to the scrubber inlet and outlet.
-

Recommendations were developed for:

- New spray nozzle type and dimensions;
- Kloppersbos directional spray system;
- Air movers fitted over flight conveyor;
- Scrubber intake extended with inlet cone fitted,
- Physical air curtain introduced.

3 REVIEW : COALTECH RESEARCH PROJECT, PREVENTION OF METHANE IGNITIONS IN CONTINUOUS MINER HEADINGS, FINAL COALTECH REPORT, DECEMBER 2015[(2)]

3.1 Summary of Project objectives

This project was initiated in March 2012 following a number of methane ignitions in South African coal mines. The question being asked in 2012 was "why should these ignitions still occur when so much is known about how to ventilate mines in order to adequately dilute methane and also how to manage ignition risks"?

Since all the reported ignitions occurred while a heading was being excavated by a Continuous Miner (CM) it would have been easy to focus on a single aspect e.g. frictional ignitions or water sprays or human behaviour. However, this project looked at the problem in a holistic way, guided by the involvement of personnel from coal mining companies and equipment manufacturers. Early meetings and workshops identified 10 key areas, each requiring additional research or a review of previous research. Risk assessments were also undertaken to identify the principal potential contributors to methane ignitions.

Key Areas:

1) **Website and Database:** A website and database was established (cmsafety.org.za) for the purpose of preserving all past, present and future research and development information for the all interested parties as well as for future generations. Access to this website and database is also possible through the Coaltech website (coaltech.co.za). This website is updated on a continuous basis and presents the latest research documents and reports emanating from this project.
2) **Human Behaviour:** This task looked at competency, training, attitudes and leadership styles, focusing mainly on the "soft" issues with respect to human decision-making. An important deliverable from this Task was a template that was developed based on industry best practice. This template can be used by the

end-user to evaluate the performance levels of workers. It is an Excel based program that can also be downloaded from the website and used.

3) **<u>Virtual Reality Training Modules:</u>** Presenting underground heading ventilation, methane and airflow dynamics using animation developed DVD's. The training videos first describes a hypothetical scenario as an introduction where a number of substandard ventilation and methane conditions are shown in an underground workplace, followed by a methane explosion which left one person dead and another seriously injured in hospital. This introduction DVD sets the scene for the following four training videos. The themes that were used for the four DVD's included:
   - Module 1: Rules of ignition
   - Module 2: Fundamentals of Ventilation
   - Module 3: Last Through Road Ventilation
   - Module 4: Heading Ventilation Systems.

4) **<u>Evaluate Heading Ventilation Systems using Computational Fluid Dynamics:</u>** The use of numerical modelling to evaluate the methane dilution effectiveness and capabilities of the CM heading ventilation systems that are mostly used by the industry. The focus was placed on low and high seam airflow patterns and methane dilution capabilities. A CFD software program called FloEFD was used and developed to simulate and evaluate different ventilation systems combined with various scrubber and on-board system configurations. The validity of the CFD simulation results were proven through a number underground in-situ measurements. The use of CFD to evaluate ventilation systems proved to be very valuable and a credible way of testing new and old concepts. Important learnings from this Task includes:
   - It is important to deliver the fresh air directly to the face area to ensure maximum methane dilution and control. From all the

ventilation systems identified, the ventilation ducting connected to an auxiliary fan proved to be the most effective to use.

- The air quantities of the ventilation systems and on-board systems need to operate in balance with each other to enable sufficient fresh air availability into the high risk area. Fresh air delivery quantities are to be maintained within 60%-70% of the scrubber volume.
- Scrubber recirculation values below 50% and even below 40% proved to be critical to ensure optimum methane control conditions. A practical method was devised that can be used to quantify the scrubber recirculation values.

5) **Continuous Methane Monitoring:** Through the use of CFD and underground test work it was possible to develop an improved understanding of the importance of on-board methane monitoring systems and what aspects need to be considered during the installation and use of these systems. It was also important to evaluate the effectiveness of installing methane sensors traditionally on the left front side of the cutter head. Some of the significant learnings from this Task includes:

- Methane acts and moves with the prevailing airflow patterns inside the heading;
- Methane accumulates underneath the cutter head during the shearing down action of the cutter drum.
- Additional sensor needs to be placed under the cutter head to monitor the methane under the cutter drum.
- Effective real-time data recording proved to be very important and helpful.

6) **Management, plotting and sealing of Horizontal boreholes:** This Task took an in-depth look into the roles of horizontal boreholes, considering the unexpected inrush of methane during accidental intersections of these boreholes and the possible sealing of these boreholes. Important Task findings include:

- The importance of sealing horizontal boreholes effectively and adequately was again emphasized.
- Also it was stressed that any and all boreholes should be plotted and logged accurately to minimise the risk of the accidental intersection of these boreholes and experiencing the sudden inrush of methane into the workings.
- The Task results provide some guidance on effective borehole sealing procedures and materials to use.

7) **Coal Explosibility, Spontaneous Combustion and Methane Characteristics:** The purpose of this Task was to evaluate various international methodologies for quantifying the methane, spontaneous combustion and explosibility characteristics of Coal. These methods were compared against International Best Practice and guidance are presented on methodologies to consider. Important findings include:-

- The importance of knowing these values for ventilation planning was again realised.
- The methods that are currently applied in South Africa still compares very well against International methods and are still acceptable to use to the industry.

8) **OEM Training Effectiveness:** The contents of OEM training material was evaluated with respect to the mandate of this project. (i.e. Prevention of Methane Ignitions). The focus was to establish whether the information contained inside the manuals could empower the operator in understanding the basic fundamentals of methane control and prevent methane ignitions from occurring. The Task findings include:-

- Very few training manuals addressed the aspects of methane and safety. There is a general lack of sufficient information that will prepare the operator to ensure that methane concentrations are minimised and methane ignitions are prevented.
- From the information provided, a guidance document and a template could be developed against which the effectiveness of

training material and the transfer of information to the end user can be evaluated with respect to the basic requirements of methane ignition prevention.

9) **<u>Airflow and Flammable Gas Measuring Instrumentation:</u>** The main purpose of Task 4 was to:
   - Investigate and evaluate current Ventilation Flow recording and reporting instrumentation, technologies and methodologies,
   - Investigate and evaluate current portable flammable Gas Detection Instrumentation (GDI), technologies and methodologies used in the South African coal mining industry, and
   - Source and evaluate any possible future instrumentation developments and make recommendations to the industry.

The findings from these investigations were to be expected and nothing new was discovered. The results are presented in the main body of that report.

10) **<u>Frictional Ignitions:</u>** This output did not form part of the original proposal and was added afterwards as an individual project. The purpose of this research was to establish the status of information and knowledge on the role of the CM cutting picks and also what contributing factors could be present inside the coal seam, such as pyrite, quartz, etc. The role of friction in the "heat" leg of the ignition triangle cannot be underestimated and therefore, the results from this mini-project were also discussed.

11) **<u>Risk Management Model and Change Management Protocol on Evaluating Underground Heading Ventilation Systems with the focus on Methane Ignition Prevention:</u>** These are the final outputs of this project, in that all of the research results are incorporated into a Risk Management Model, in conjunction with a Change Management Protocol in which all of the significant research results are also incorporated. The Change Management Protocol is intended to assist the Ventilation Manager to control

and manage any official and unofficial changes that are that made to any part of a ventilation system or on-board system.

3.2 Risk Assessment Inputs

The risk assessments determine the frequency of sampling required and in particular the conditions that will indicate when an additional sample is required. The risk assessment should include but not necessarily be limited to:

- Hazards:
  - o Ignition of gas;
  - o Ignition of coal dust;
  - o Spontaneous fire;
  - o Type of test required i.e. methane, Kex, Spon Com;
  - o Gas emission rates and contents;
  - o Dust explosibility index;
  - o Wits-EHAC Index and Crossing Point Temperature (Spon Com Tests).
- Current knowledge:
  - o Previous test data;
  - o Variation of results for individual mines over time;
  - o Total number of samples tested and on the database;
  - o Conditions for the mine compared to conditions in neighboring mines, coalfield and SA;
  - o Reports filing and retrieval system;
  - o Access to reports;
  - o Distribution of relevant information.
- Geological:
  - o Narrowing or widening of the coal seam mining height;
  - o The occurrence of sandstones and pyrites;
  - o Roof and floor geology;
  - o Other intrusions;
  - o Partings;
  - o Faults & Slips;
  - o Changes to coal seam e.g. from Gus to Dundas;
  - o Coal seam properties required i.e. CV, proximate analysis.
  - Operational:
    - o Moving to a new area of the mine;
    - o Presence of horizontal and/or vertical drills or drill holes;
    - o Changes to mining operations, e.g. from drill and blast to continuous miner;
    - o Changes to mining direction i.e. a 90 degree turn which affects the methane transport in the coal;
    - o Changes to continuous miner set up, e.g. on board monitoring, scrubber, pick configurations, drum speed, etc.;
    - o Coal transport time while in intake air for the section;
    - o Coal storage. Monitoring:
    - o Fixed gas monitors;
    - o Hand held gas monitors;
    - o Gas testing procedures;

        - Alarm levels and action indicators;
        - Information use at control room.
- Ventilation:
    - Changes to ventilation, or to ventilation systems;
    - Ventilation break down;
    - Scrubber fans;
    - Spray systems;
    - Force system;
    - Exhaust or return system
    - Human factors:
        - Competence of sample testing agency;
        - Competence of sampling staff if self-sampling;
        - Changes to personnel in the section;
        - Training and awareness;
        - Change management.

3.3 Discussion of Salient Aspects Derived from the Coaltech Research Project as these apply to Airflow and Airborne Contaminant Management in Continuous Miner Headings

3.3.1 *First Period of Underground Testing – Two Methane Sensors Installed*

The first aspect discussed here which is relevant to this report deals with the distribution of the methane “cloud” around the cutter head. When working from the premise that respirable dust will behave in a somewhat similar way to the methane, the distribution of the “hybrid” cloud can then be modelled and visualised. For the first round of underground testing under the Coaltech project to verify that actual readings and the CFD projected readings correspond to a reasonable extent, a Continuous Miner was equipped with two methane sensors, positioned on the left front and right front respectively (refer to Figures 1 & 2). These sensors were linked to a data-logging system that enabled the project team to subsequently evaluate the recorded maximum and minimum methane concentrations for the two cutting boom positions (boom-up and boom-down).

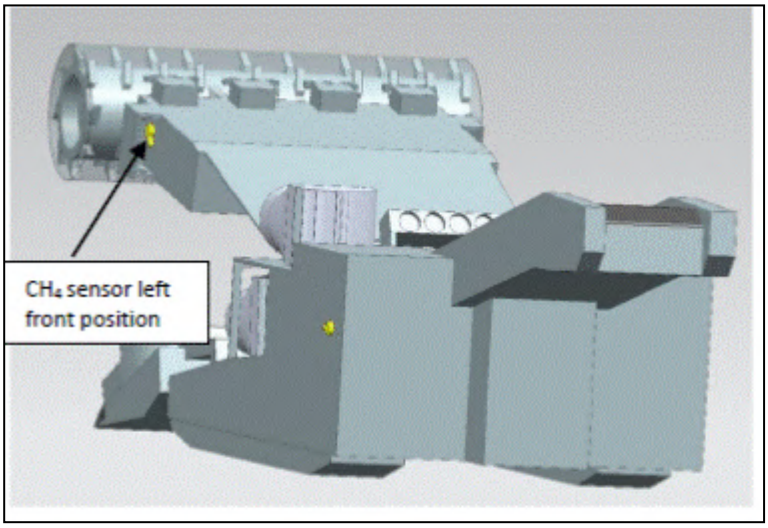

Figure 1 Left-rear view, Cutter Head UP, Methane Sensor Positions

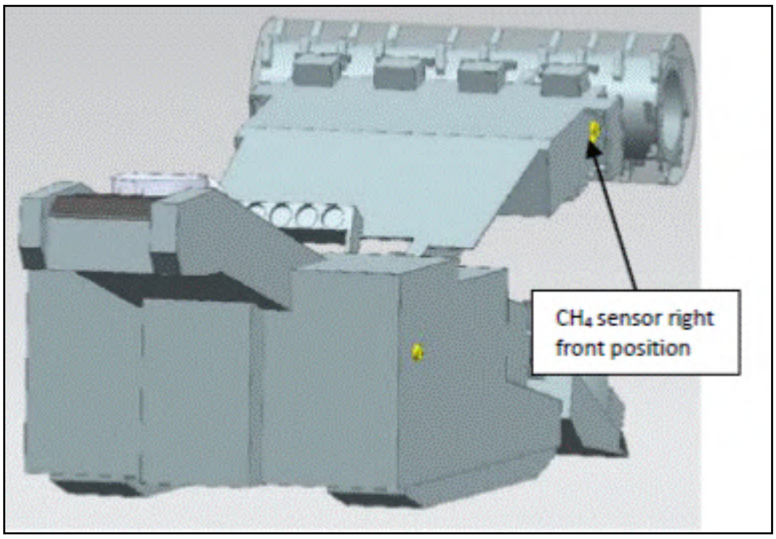

Figure 2 Right-rear view, Cutter Head UP, Methane Sensor Positions

Normal section development was conducted out and the headings were developed to varying distances from the Last Through Road (LTR). The average LTR air velocity were measured as 1.30 m/s.

The CM was fitted with a single, large scrubber unit with a linear outlet specifically designed for this particular type of CM. The inlet of the scrubber had been extended as far forward as practically possible. Figure 3 below demonstrates the modified scrubber design and configuration of the CM and scrubber (modification reflected in green and red).The CM was fitted with the standard COL 518 water spray fan system. For all practical purposes, this design conformed closely with the original COL 518 directives.

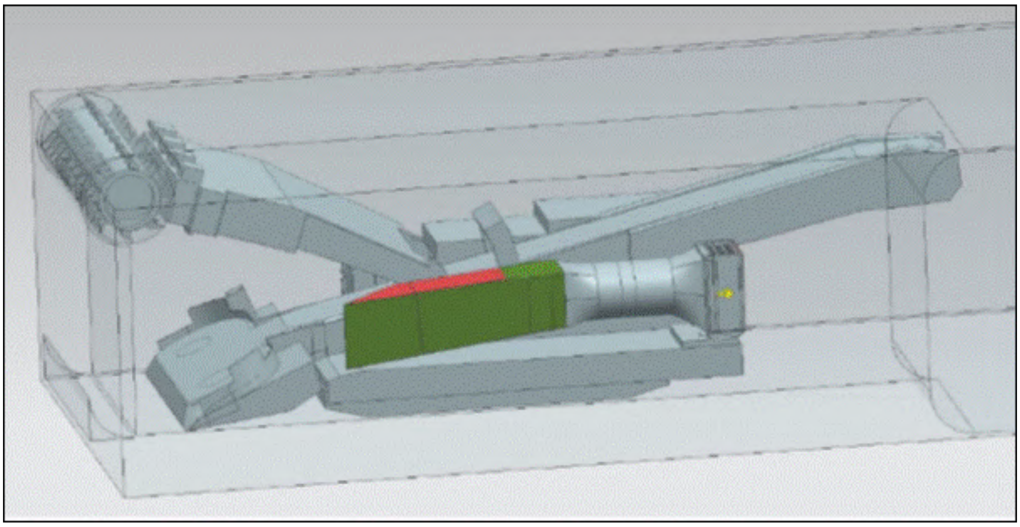

Figure 3 On-board scrubber configuration on the Continuous Miner

A 7.5 kW free-standing jet fan, mounted on a skid, was used to deliver fresh air into the production headings. Figure 4 below demonstrates the design of the jet fan used.

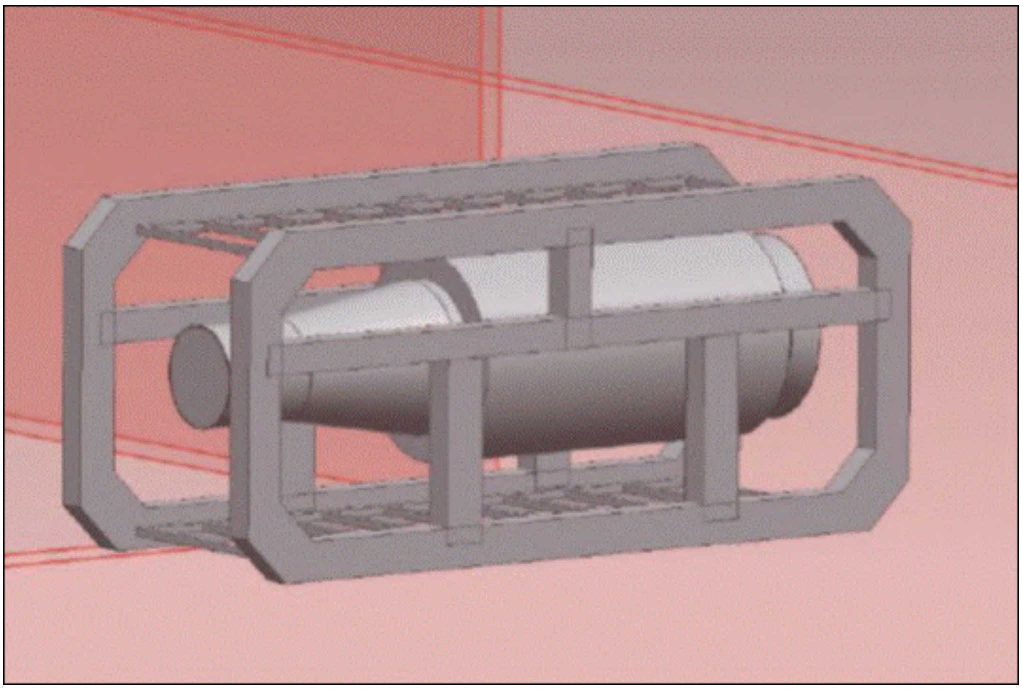

Figure 4 Design of the 7.5 Kw Jet Fan placed on a skid

The applicable heading dimensions and ventilation data were as follows:

- Face area = 26.8 m^2;

- On-board scrubber delivery quantity = 10.8 m^3/s;
- Water sprays used = COL 518 spray fan system;
- Jet fan position = at the entrance of the heading in the upstream position;
- Jet fan delivery quantity (with calculated entrainment) = 8.21 m^3/s;
- Jet fan delivery quantity (without calculated entrainment) = 4.10 m^3/s;
- Expected methane release rates from the cut coal and the broken coal = 1 050 l/min.

The underground trials were conducted over full production shifts during which time the methane data and all other relevant data was recorded and stored.

3.3.2 *CFD Simulation Results - First Underground Test Period*

The purpose of representing the underground test scenarios by means of CFD simulations was two-fold. Firstly the validity and relative accuracy of CFD simulation results could again be verified and demonstrated as being sufficiently accurate to be used in future modelling. Secondly, much more detail on underground ventilation system airflow patterns and methane behaviour can be obtained through the use of CFD.

The simulations were performed with the cutter head sumping in at the top of the face and with the cutter head shearing down towards the bottom. From the underground tests, the cutting scenario that presented the highest readings on the two methane sensors were then modelled as accurately as possible.

The focus was to obtain simulated values and results that would resemble the methane results that were obtained during the underground trials.

It is again emphasised that on the CFD model, methane was released from the full face area and from the broken coal that accumulates underneath the cutter head. It should be remembered that the methane is always released from the coal seam at a concentration of 100%. Thus the concentration levels that are displayed in the “methane cloud” have been diluted from 100% to the relevant concentrations as shown and recorded.

To illustrate the typical presence of the methane in the face area after the steady state solution for the specific heading and ventilation configuration, the methane iso-surfaces are shown for the “head-up” and “head down” positions below in Figures 5 and 6.

What is represented in these figures is the distribution of the methane in the face area with the prevailing ventilation and scrubber installations. Steady state CFD solutions present the conditions inside the model when the simulation is solved and all requested goals as identified on the model have been satisfied. The methane “cloud” as shown is what therefore can be expected in this area with the ventilation conditions and boundary conditions as specified.

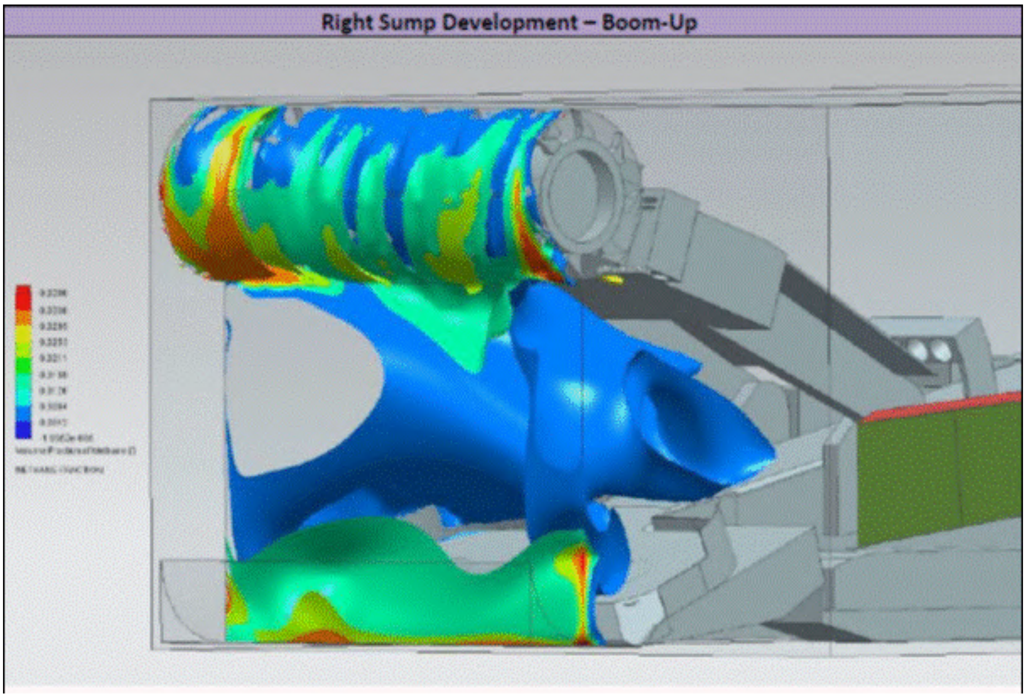

Figure 5 Methane contours for the head-up configuration

As shown in Figure 5 above, methane concentrations of more than 3% can be expected around the cutting head and at the bottom of the face (refer to the legend on the left of the sketch). Considering that the methane are released at 100%, indications are that the dilution rate of the ventilation system is fairly effective and the methane concentrations are maintained below the 5% explosive limit. But the methane can still burn at 2% which means that there are still high risk areas around the cutting drum.

These images are useful to recognise that methane is not confined to specific areas around the cutting head, but will be distributed through the full face area, depending on the airflow pattern that exists at any given time. CFD simulation results are only indicative of what can be expected, but cannot capture the dynamics of the real life situations in the production heading. Based on what is reflected in the simulations outputs, more advanced underground observations can be executed to ensure effective methane monitoring. This was then also done in the Coaltech project to further validate results.

In Figure 6 below the cutter head is moved to the bottom of the face and the methane contours plotted. This image shows that the methane is dragged downwards and consequently higher methane concentrations are experienced under the cutting drum. These higher methane concentrations are reflected on the methane sensors and explains why methane ignitions happens when cutting is done in the bottom part of the face.

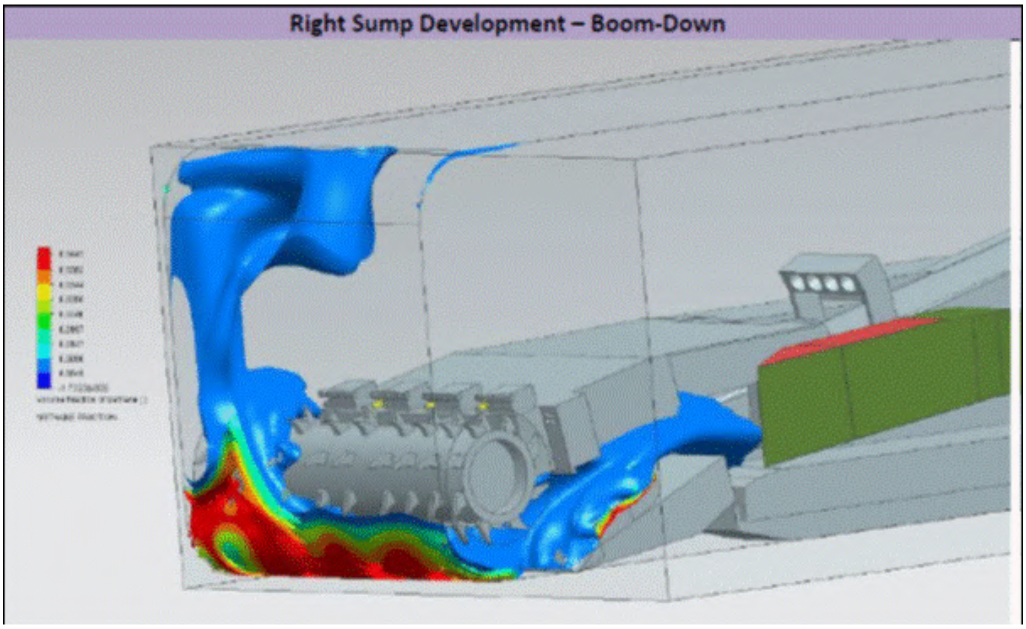

Figure 6 Methane contours for the head-down configuration

3.3.3 *CFD simulation results vs real-time data for all scenarios*

In studying the trend of the modelling and measurement results, both the CFD and the real-time data show that the sensors installed on the left side of the machine record higher methane concentrations than those on the right hand side of the machine. The sensor installed underneath on the left side of the machine records the highest methane for most of the scenarios.

The advantage of having more than one sensor on the machine, was that the flow direction of the air could be monitored, as the methane cloud follows the airflow pattern. Methane concentrations that increase from right to left on the sensors is an indication of the direction of the airflow, being from right to left over the CM head.

Figure 7 shows a methane cloud that accumulates around the cutting head and shows how the air tends to flow from the left of the machine to the right hand side of the machine.

This indicates a high level of air recirculation and is contrary to what the (COL 518) ventilation pattern should be. The airflow should, in fact, be from right to left across the face of the heading towards the scrubber intake position.

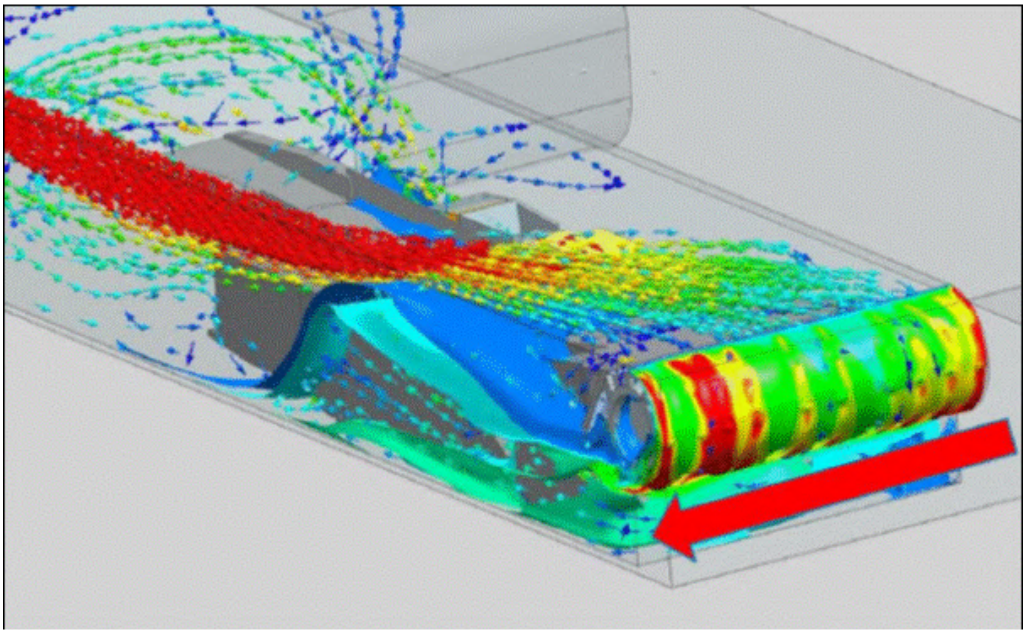

Figure 7 Methane accumulates around the cutter head and to the right side of the machine.

4 EVALUATING CM HEADING VENTILATION USING CFD (COALTECH, MEYER, JULY 2015)

Coal dust explosion evaluation can be done from small scale laboratory tests to large scale or full scale tests.

4.1 Introduction

Heading Ventilation was identified as one of the more important aspects when addressing methane build-up in the coal mining heading and in the Coaltech report the focus was on the results from the research work that was undertaken with specific reference to Heading Ventilation.

A CFD software package called FloEFD was evaluated and identified as suitable software that would fit the needs of this project. Several models were developed over time and verified by means of underground measurements. In this way, useful information was gathered through the series of simulations that were performed.

CFD was used to simulate and evaluate the effectiveness of the three auxiliary ventilation systems primarily used by the industry, combined with two basic scrubber outlet designs and different Continuous Miner (CM) cutting scenarios. The focus was to learn more about the behaviour of methane and how to control the build-up of methane more effectively in the cutting zone while the CM is producing coal.

Throughout the project, a number of important contributing factors were identified that have an effect on the way that headings are ventilated and subsequently the way that methane build-up is controlled and eliminated.

These factors play a major role in ensuring that methane ignitions are prevented during the cutting process.

The high risk area for methane ignitions was identified as being inside the cutting zone and more specifically underneath the cutting head when cutting at the bottom of the face area. It was found that, when these contributing factors are addressed and managed wisely in the heading environment, the cutting zone can be ventilated effectively and economically in the quest to provide a safe and healthy working environment for the workers (bearing in mind that another aspect, namely the dilution and control of respirable dust in the heading also needs to be considered when evaluating ventilation rates and patterns). It is envisaged that the deliverables and outcomes from this project will assist the coal mining industry to be able to deal with the dangers and risks associated with methane ignitions in an effective and mostly economically sound way. The factors contributing to the management and elimination of methane ignitions in the cutting zone are discussed below.

4.2 Factors Influencing Methane Dilution and Control

Optimum Heading Development Distance from the LTR. Throughout the history of South African Coal Mining where Continuous Miners are used to develop a block of coal, the use of auxiliary ventilation together with on-board systems has always been a contentious topic. There normally are differences of opinion between ventilation personnel and production personnel with respect to when the auxiliary ventilation system should be initiated, mostly due to perceived practical constraints.

Historically, research programmes focussed on the effect of LTR airflow on ventilation conditions inside the developed heading. (Meyer, August 1990). Through previous research it was established that air flowing inside the LTR past an empty heading will penetrate to distances varying between 12 and 14 metres into a heading, depending on determining factors such as seam height, LTR velocity, etc. These penetration distances are typically achieved with LTR air velocities ranging between 1.0 and 1.4 m/s. (Note: The Kloppersbos trials conducted for COL 518 indicate an optimum LTR velocity of 1.3m/s).

It must be emphasised that this previous research work did not consider the effect of the presence of a CM inside the heading, nor were the use of on-board scrubbers and directional water sprays considered.

CFD was once again utilised to test this basic concept. However, this time round the CM with all on-board systems were included but without secondary ventilation. The tests were conducted for distances ranging from 12.0 metres, to 18.0 metres and then at 24.0 metres.

The air recirculation values were calculated and the potential methane build-up was modelled to establish the maximum allowable distance for a “scrubber and water sprays only” configuration before any secondary ventilation is introduced.

These simulations were conducted for a twin-curved scrubber configuration as well as for single linear discharge scrubber configuration. Simulations were conducted for high seam (4.5 metre) and low seam (2.0 metre) scenarios and the results proved to be similar for these varying seam heights. In this report a summarized version of only the high seam simulation results and for the single linear discharge scrubber configuration will be shown and discussed. Full details are available in the separate Task Report. (Meyer, July 2015).

4.2.1 *Simulation Results – Single Scrubber with Linear Discharge*

Introducing air through a secondary ventilation system into a production heading at the correct instance is crucial to maintaining a safe and healthy working environment from a methane and airborne dust perspective. Depending on the type of on-board scrubber configuration, these decisions are determined by contributing factors such as airflow patterns, methane emission rates, air recirculation values and amount of fresh air that is delivered to the cutting zone.

Following below is first of all a description of the input values into the CFD model followed by the a summary of the results that were obtained from the CFD simulations for a single scrubber with a linear discharge configuration relative to heading development distances of 12.0 metre, 18.0 metre and 24.0 metre from the LTR.

Figure 8 below shows the CAD model that was used for simulating the single scrubber configuration.

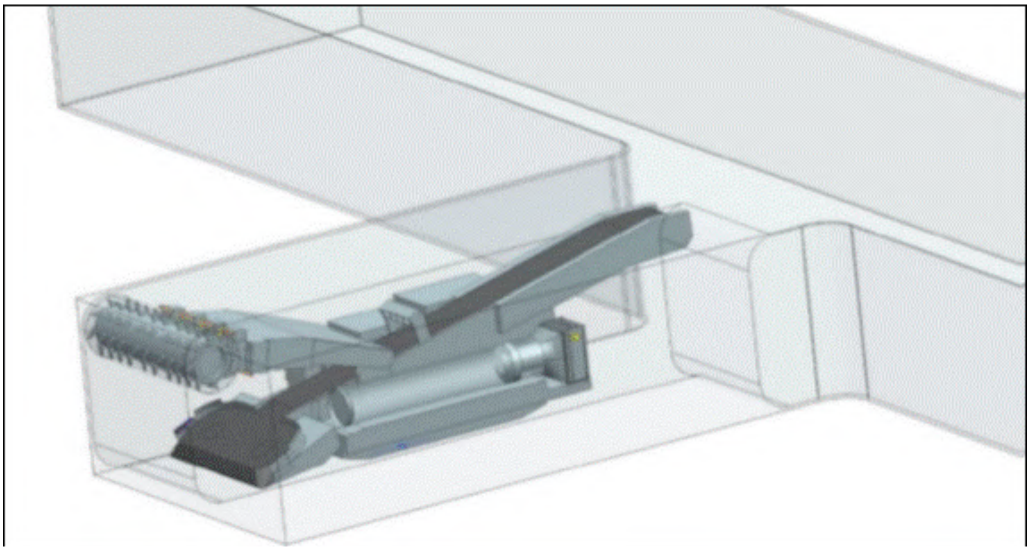

Figure 8 Showing the CAD model for the Single Scrubber configuration

4.2.2 *Test Conditions Used as Input Values for the CFD Simulation Model*

To be able to compare the different scenarios with each other, it was necessary to use the same test scenarios for all heading distances. Test conditions were as follows:

i. CM sumped in on the right side at 12.0 metres, 18.0 metres and 24.0 metres from the LTR, cutting head in the upward position;
ii. Heading dimensions = 3.5m x 7.0m (24.5 m^2);
iii. LTR air velocity = 1.4 m/s (34.3 m^3/s)
iv. Single linear discharge scrubber installed on CM;
v. Kloppersbos spray fan system (20 m/s); (Estimation of the air entrained through the energy of the spray nozzles)
vi. Total scrubber volume - a. Single Linear Outlet Scrubber = 10.2 m^3/s
vii. Methane release rates – (Based on a methane release rate of 59 litres/ton/minute and a production rate of 12 tons/minute)

a Cutting head = 700 l/min
b. Falling coal = 8 l/min
c. Spade area = 160 l/min
d. Conveyor = 40 l/min Total = (908 l/min; 15.13 l/sec; 0.0153 m^3/sec).

Ventilating a heading with only an on-board scrubber requires knowledge and understanding of the dynamics of the methane behaviour and the recirculation of airflow relative to fresh air supply as a function of methane dilution.

From the CFD simulation results it was determined that heading distances from the LTR impact directly on the air recirculation values and the methane concentration levels as measured by the on-board methane sensors. The methane and ventilation conditions are influenced significantly by the scrubber configuration and these are directly related to the calculated air recirculation values.

The individual methane readings from the sensors were simulated on the cutting head as were the methane concentrations at the cutting edge of the drum. Through CFD technology, it is possible to determine the amount of methane present at the tips of the cutting picks placed around the cutting drum. The methane values derived are a direct result of the volume of fresh air that reaches the cutting zone which determines the resultant methane dilution capacity.

The modelling results indicate that, as the heading is developed further away from the LTR, the simulated methane concentrations and methane accumulation at the cutting edge increase with distance as a result of less available fresh air. The benefit of CFD simulations is the ability to determine air recirculation and fresh air supply rates applicable to the situation. These values are then evaluated against the average methane concentrations that are recorded by the simulated on-board methane sensors.

There is a direct relationship between the air recirculation values and the amount of fresh that is delivered. The higher the air recirculation, the less fresh air is delivered and the higher is the possibility of methane build-up in the cutting zone.

Figures 9, 10 and 11 below provide a birds-eye view of the overall airflow patterns within the LTR and the heading for 12.0 metres, 18.0 metres and 24.0 metres from the LTR. The CM is sumped in on the right hand side of the heading. For ease of understanding. A cut plot was made at scrubber height and the velocity contour lines were plotted for the three distances. The vectors combined with the colour contours provides an insight into the airflow behaviour for every particular situation. The cutting head was disabled on the images to make the airflow more visible

At a heading depth of 12 metres the air from the last through road is predicted to flow directly into the heading and, some of the fresh air will reach the face area. The majority, however, will flow directly to the inlet of the scrubber. Under these conditions, the directional water sprays assist with air movement across the face and over the drum, thus possibly enabling some methane dilution.

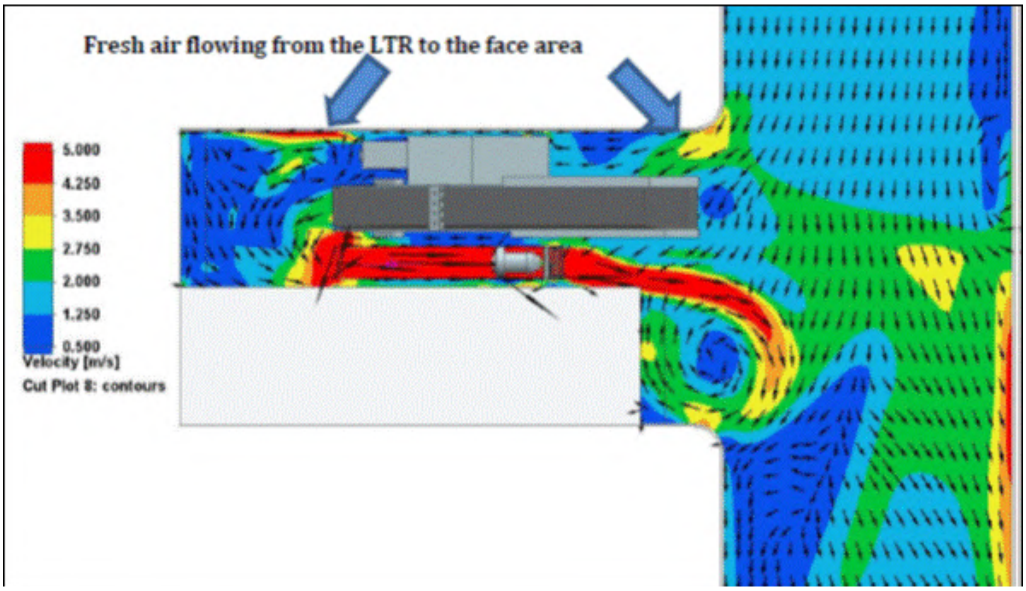

Figure 9 Airflow patterns with Single Scrubber at 12 metres

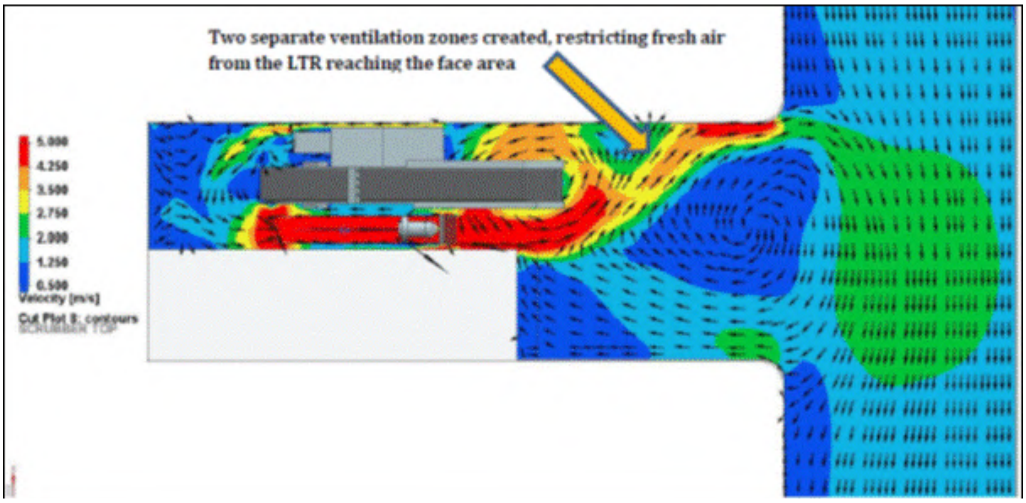

Figure 10 Airflow patterns with Single Scrubber at 18 metres

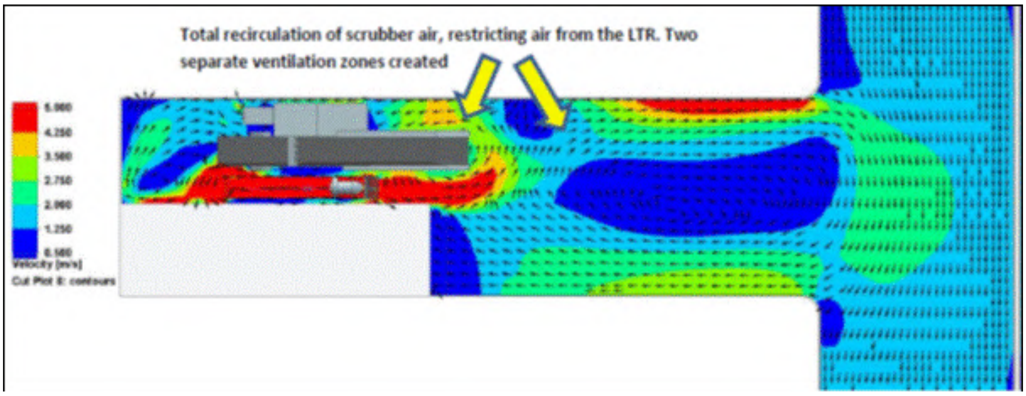

Figure 11 Airflow patterns with Single Scrubber at 24 metres

From the predicted airflow patterns beyond 18 metres and 24 metres, the airflow patterns reveal that there is a distinct increase in the recirculation rate. In addition, the rate of penetration into the heading towards the scrubber intake from the LTR is also significantly reduced. It appears as if two ventilation zones are created. The air from the scrubber re-circulates directly towards the face and the inlet, creating one ventilation zone. The air from LTR is concentrated at the back of the machine, creating an alternative ventilation zone.

It can therefore be demonstrated that, the further from the LTR the heading is developed, the less fresh air from the LTR would penetrate into the heading with less fresh air reaching the face area. These simulations were conducted to demonstrate the importance of introducing secondary airflow into a heading that can assist the on board scrubber in ventilating the heading. Conditions and airflow patterns will, however, differ from mine to mine with the varying ventilation systems and CM machines in use.

4.2.3 *Using an Effective Secondary Ventilation System*

Three basic secondary ventilation systems are currently primarily used throughout the coal mining industry to deliver fresh air into the headings. These are: Auxiliary Fans with Ventilation Ducting, Freestanding Jet Fans and Scoop Brattices. These three systems were evaluated for methane dilution and resultant airflow patterns, firstly by CFD which was then followed with regular underground verification through physical results. Various cutting cycles and sequences were evaluated, including heading development from start-up at the LTR, up to distances in excess of 30 metres from the LTR. Split development scenarios were also considered. For the purpose of this summary, only one particular heading scenario will be used to demonstrate and compare the behaviour of the three different systems. CFD simulations were solved using steady state and transient solutions.

In order to compare the different ventilation systems with each other, it was necessary to use the same test scenarios for all three systems. (See Figure 12 for the CAD model development).

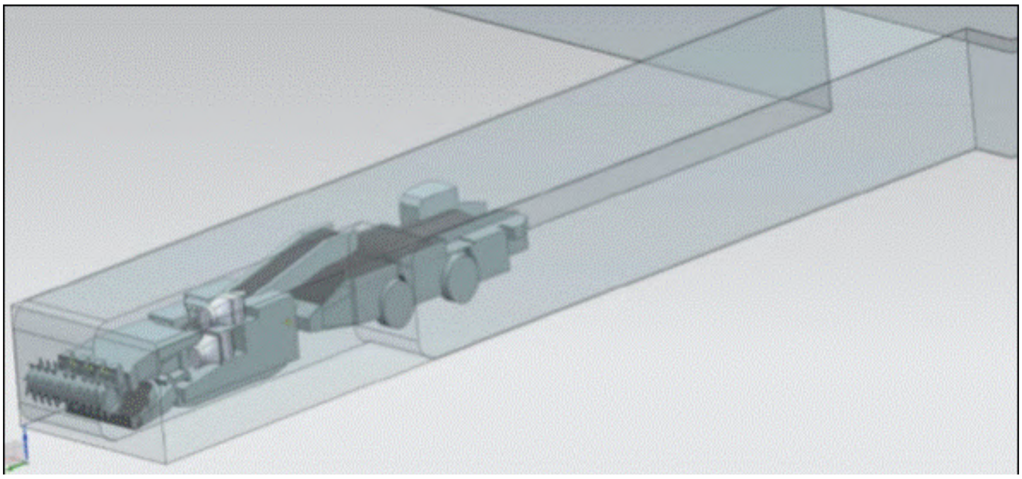

Figure 12 CM and heading configuration

4.2.4 *Test Conditions Used as Input Values for the CFD Simulation Models*

i. CM sumped in on the right side at 30m from the LTR, cutting head in the upward position;
ii. Heading cross-sectional dimensions = 3.4m x 6.9m (23.5 m^2);
iii. Heading depth = 35 metres;
iv. LTR air velocity = 1.4 m/s (32.8 m^3/s);
v. Twin curved scrubbers installed on CM;
vi. Kloppersbos spray fan system (20 m/s); (Estimation of the air entrained through the energy of the spray nozzles)
vii. Total scrubber volumes = 11.34 m^3/s
viii. Methane release rates – (Based on a methane release rate of 59 litres/ton/minute and a production rate of 12 tons/minute).

ix. Cutting head = 700 l/min
x. Falling coal = 8 l/min
xi. Spade area = 160 l/min
xii. Conveyor = 40 l/min Total = (908 l/min; 15.13 l/sec; 0.0153 m^3/sec).

5 DISCUSSION OF COALTECH PROJECT RESEARCH METHODOLOGY, LIMITATIONS, ADVANTAGES AND DISADVANTAGES

As with any work of this nature, the information derived from theoretical modelling exercises is subject to the limitations of the software utilised, the assumptions made and the accuracy and comprehensiveness of the relevant input data.

The work discussed above was conducted as part of the Coaltech project was subjected to rigorous scrutiny and also based on long-term experience and inputs by the researcher, the consultant contributors and the referee, alike.
In order that the confidence limits w.r.t. the work be further tested, several exercises were conducted (e.g. as described in the foregoing section dealing with the modelling and physical measurement of the methane incidence and levels around and under the cutter head). The measurement data as practically obtained was rigorously compared and scrutinised as this relates to the computational programme outputs and good general correlation was confirmed.

Similarly, the flow patterns within headings as predicted by the CFD modelling was compared to practical measurements and assessments conducted by R M Fourie in another project and these outcomes were presented in a paper by Thomson, Cook and Fourie(3).

Figure 13 reflects a comparison (of several) that were made between the empirical measurements by Fourie and the CFD plots by Meyer and indicate the level of similarity attained. As a consequence of this work, as well as the methane distribution modelling as discussed, it can be concluded that there is sufficient correlation between the CFD modelling outcomes and the practical measurements to justify the future, ongoing use of CFD modelling to predict outcomes of any conditions or changes to conditions that are considered in CM headings.

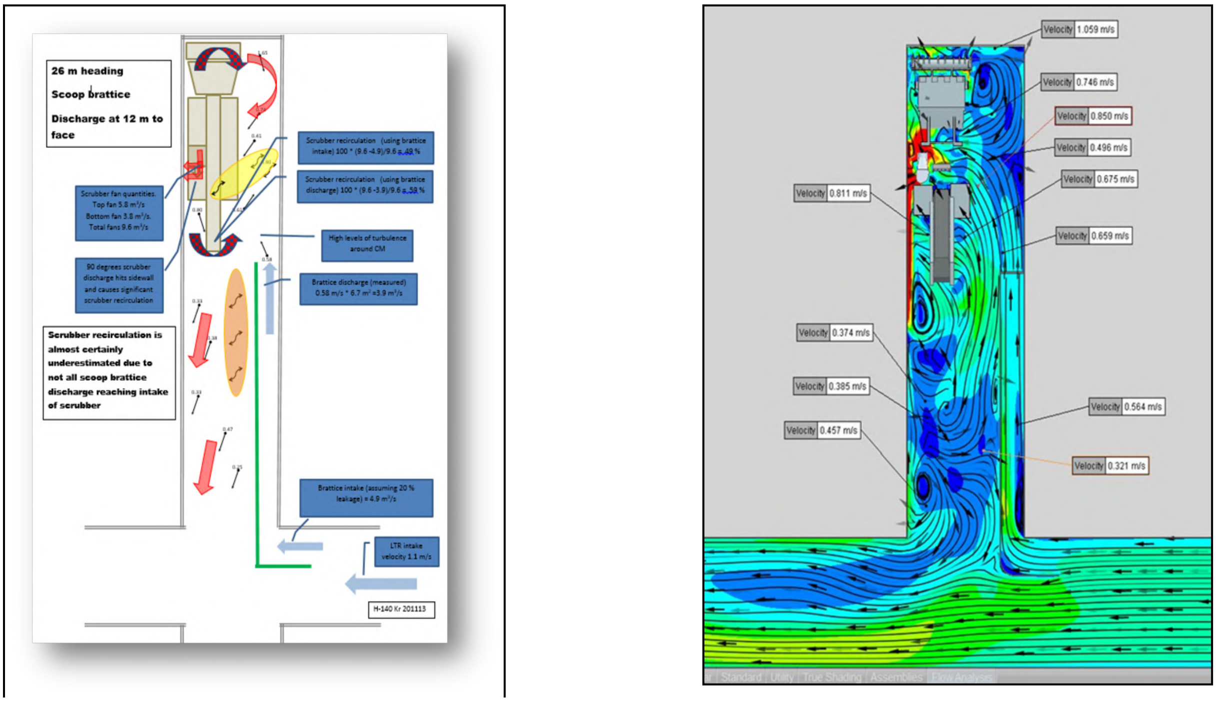

Figure 13 Example of Practical Measurement Outcomes compared with example of CFD Cut Plot

In broad terms it can therefore be concluded that the following apply when considering the use of CFD as a predictive tool for determining the effects of changes on existing or proposed future ventilation systems.

5.1 Advantages of CFD

- The CFD modelling approach is deemed to be sufficiently accurate for use by mines and manufacturers to verify and/or predict ventilation system performance and airflow patterns designed to dilute and remove contaminates from within CM headings;
- The CFD tool is extremely useful to quickly determine the potential effect and impact of proposed changes, without the practical issues associated with setting up full-size experiments in a test gallery or underground;
- The CFD tool does not require the potential production impacts underground which of necessity will impact available resources should in-mine testing be contemplated;
- The use of CFD would, when considering all parameters, probably be more cost effective as a predictive tool, compared to practical tests

5.2 Disadvantages and limitations of CFD

- The outputs from CFD models are, as in all cases involving computerised modelling, subject to the accuracy and validity of the input data, assumptions made and applicability to the circumstances/designs being modelled;

- Interpretation of outputs require a high level of experience so that anomalies are detected and corrected, where required;
- The software packages and associated hardware (for systems sufficiently powerful to compute the results to a sufficient degree of complexity and accuracy) are expensive;
- Specialised training and sufficient ongoing practice is required to effectively use this type of program;
- Practical assessment of implemented measures still require validation by means of field work to ensure that systems perform as designed and desired.

6 DISCUSSION

When comparing the work conducted under COL 518 with the work conducted under auspices of Coaltech approximately 20 years later, it is possible to evaluate and highlight the progress made subsequent to COL 518.

Firstly, however, it should be stressed that the work conducted at Kloppersbos was thorough and adequately reflected the requirements to be implemented to ensure that proper scouring of the face area would occur to ensure effective capture and scrubbing of the respirable fraction of dust generated in the face area. To the extent that this design was required to comply with the, then, legal objectives of maintaining an average level of 5 mg/m^3 respirable dust in the working area, it can be stated with hindsight that this objective was effectively met.

The drawback of the work conducted was that it was difficult to exactly quantify levels of dust (and therefore also of other contaminants such as methane) throughout the face and adjacent zones within the CM heading. The project also dealt with a single situation i.e. a CM inside a high heading with the boom at midpoint (halfway through the face cut) only. As previously discussed (refer to Figures 6 and 7) COL 518 does not adequately predict the contaminant flow for situations where the machine is actively cutting with the cutter head in either the fully “up” or fully “down” positions and, as such cannot be used as a predictive tool for altered conditions.

Therefore, the impacts and consequences of any other configuration, e.g much larger scrubbers, sideways discharging scrubbers, installation of obstructive systems such as boxes containing control gear and electronics, etc. could not be effectively predicted and quantified. Of particular reference, the impact of changes to air flow rates and the variable positioning of the cutter head together with the impacts of falling coal and the cutter head rotating, could also not be effectively quantified. Also, the much more complicated impact that occur when the CM is cutting either the right-hand or left-hand splits were also not fully investigated or quantified.

The Coaltech project, on the other hand, effectively served to demonstrate with the help of powerful computing power, all of the impacts these changes and/or combinations of changes had within the heading and it was established that conditions are much more complex than could be reasonably determined using hand-held instruments and smoke tubes.

6.1 Discussion on foregoing outcomes and the significance of historical changes since COL518

The following examples serve to demonstrate some of the impacts of changes made to systems over the years which have had an impact on airflows within the CM heading where Figures 14 to 16 serve as the "base case" approximately reflecting the original COL 518 design. In this example the machine is cutting at 24m depth (Cut #4) and air is supplied to the face zone via the last through road by mean of a scoop brattice system.

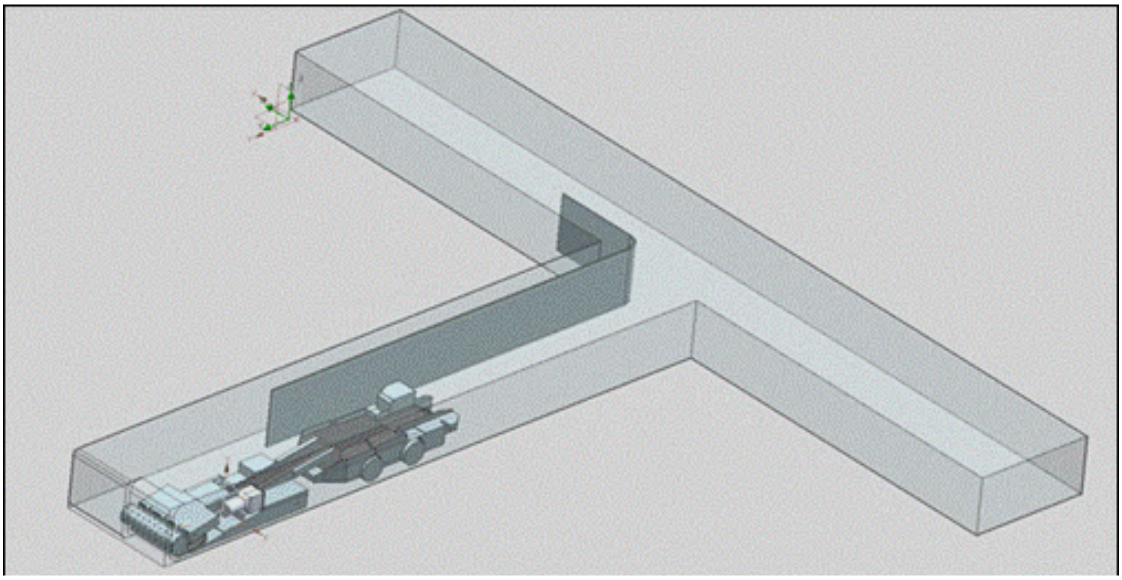

Figure 14 Basic configuration, Scoop Brattice System with Shuttle Car, Cutter Head Down

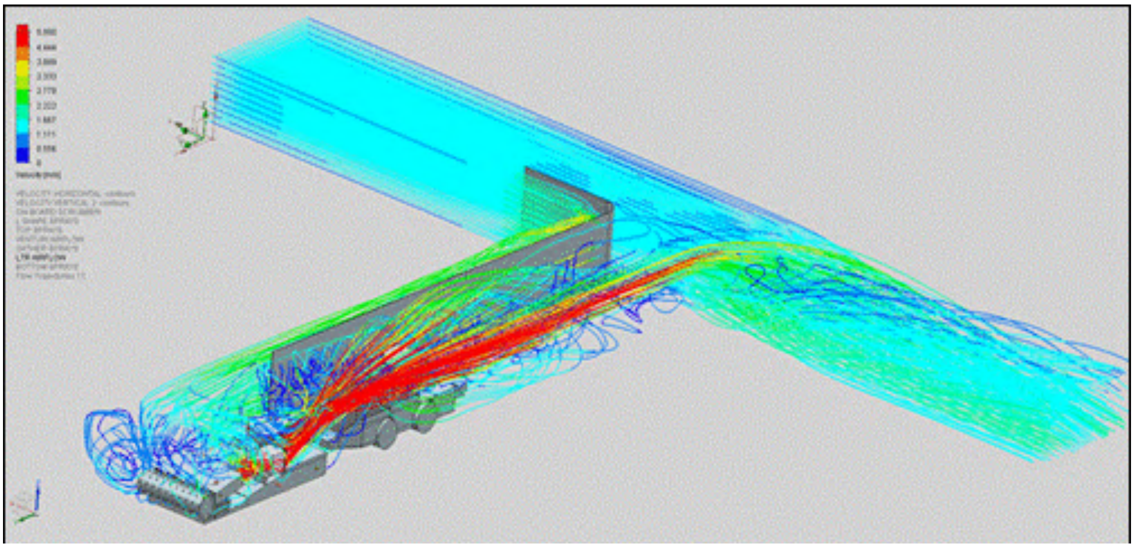

Figure 15 Basic configuration, Scoop Brattice System with Shuttle Car, Cutter Head Down Showing Airflow Pattern

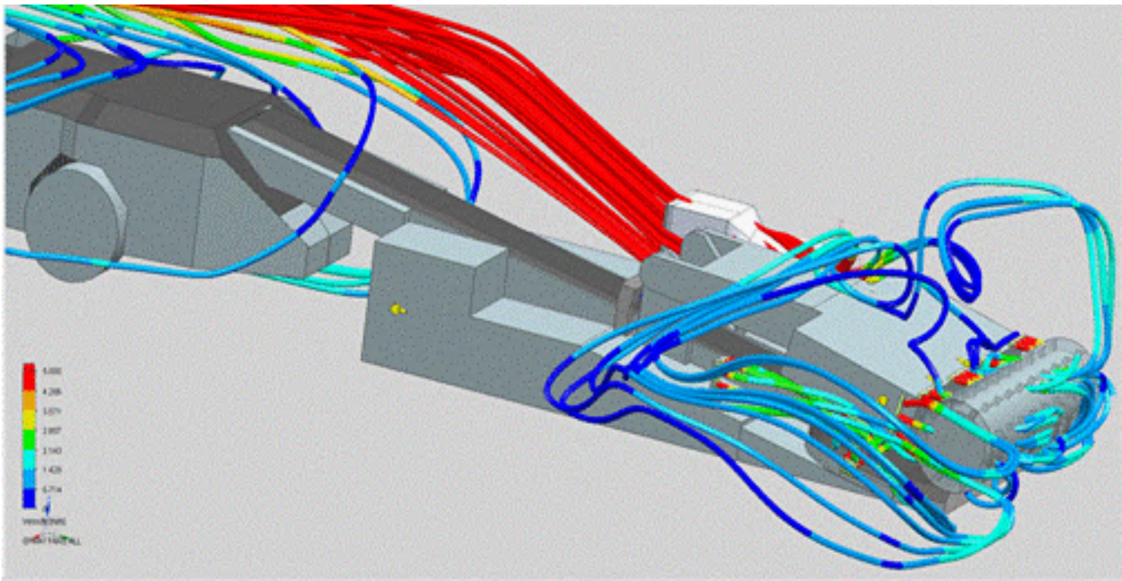

Figure 16 Basic configuration, Scoop Brattice System with Shuttle Car, Cutter Head Down, Showing Air Flow around the CM and Re-circulation Pattern

As can be seen from the foregoing, the Kloppersbos Design (COL 518) generally performs as intended, with “clean” air flow patterns and effective re-circulation.

Figures 17 to 19 show the same layout as above, with two changes, these being the implementation of a twin scrubber system, side discharging and increased air flow rates through the combined scrubber system and, in this case, cutting Cut No. 3 (24 m in), with LH 12m cut completed).

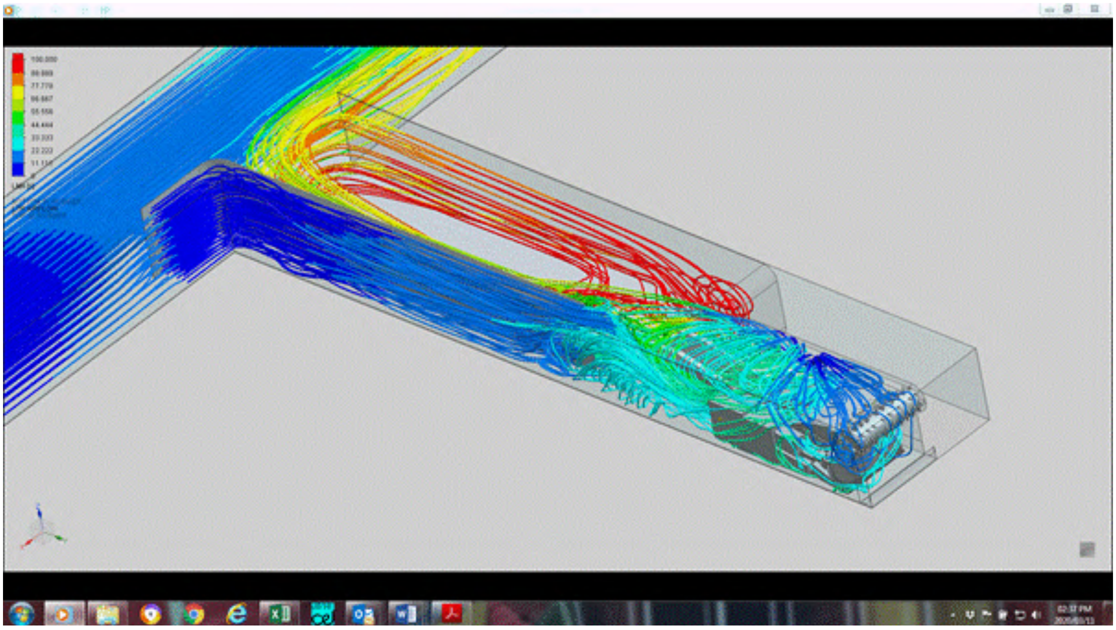

Figure 17 Global View reflecting air distribution throughout the heading

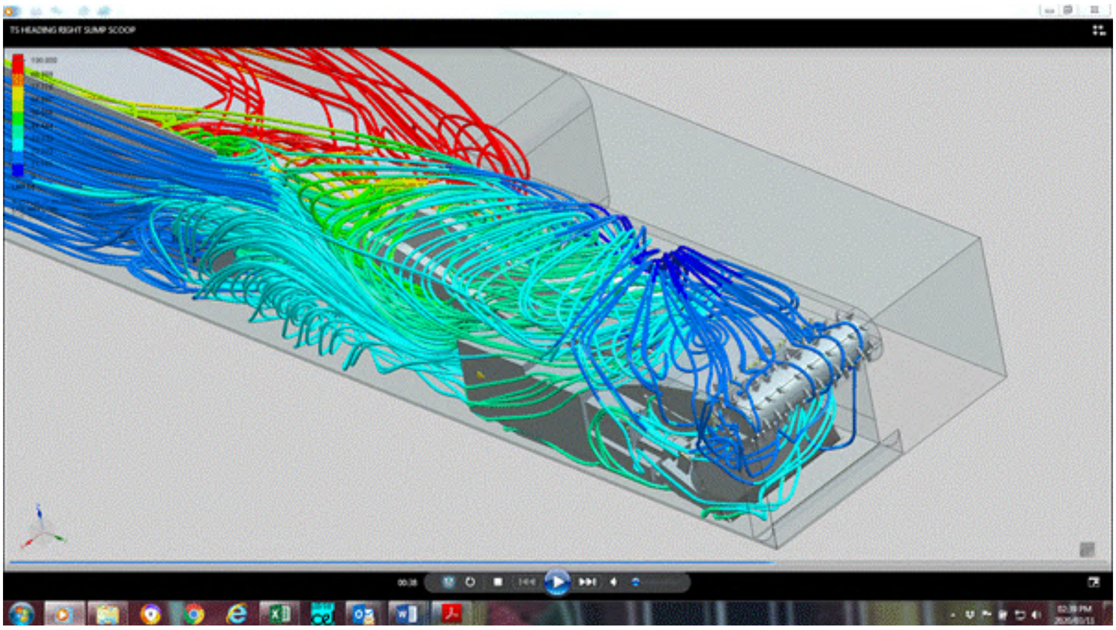

Figure 18 Right-hand View of Re-circulation Pattern induced by Side Discharging Twin Scrubber System

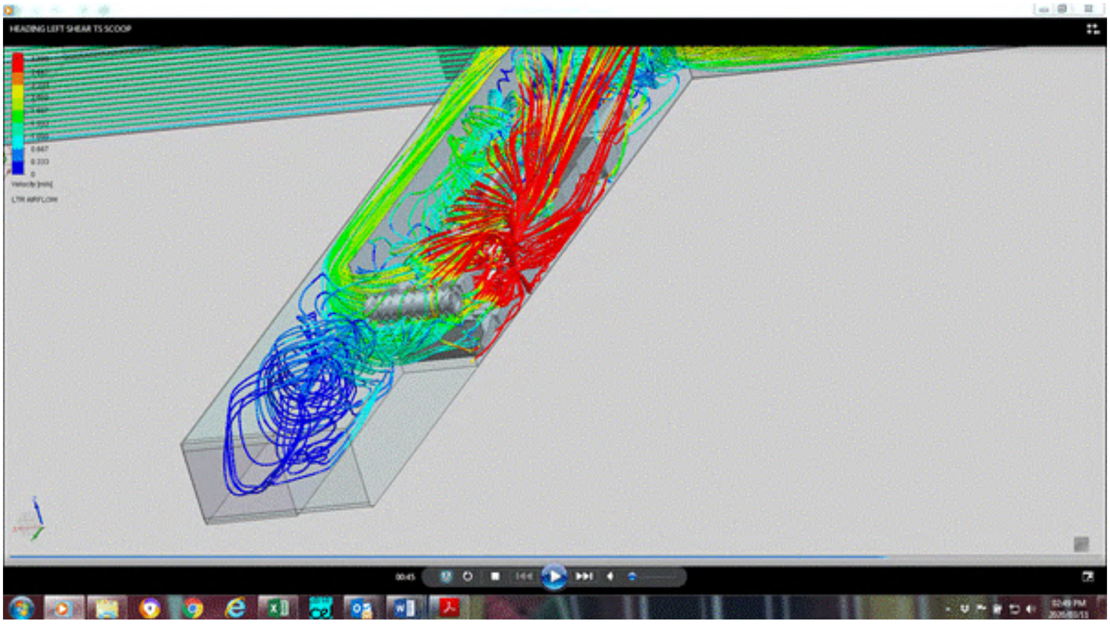

Figure 19 Left-hand View of Re-circulation Pattern induced by Side Discharging Twin Scrubber System

A further example of the effect of auxiliary ventilation systems on heading ventilation is shown in Figure 20. In this instance air is introduced into the heading by means of a jet fan and the effect of this change on the overall ventilation pattern is clearly demonstrated when compared to Figure 17.

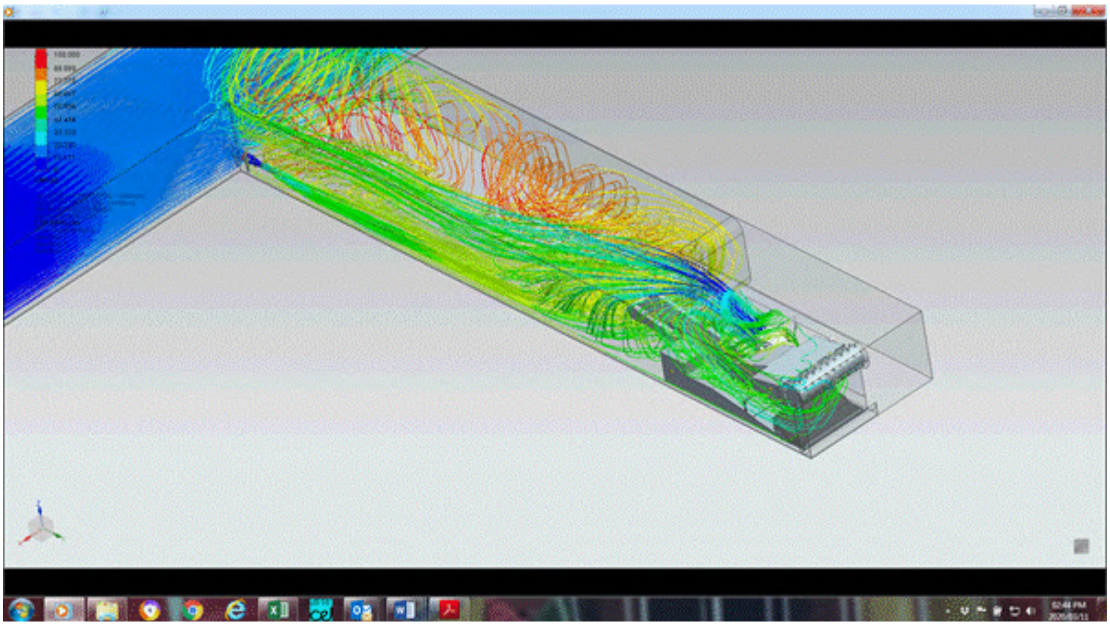

Figure 20 Effect of a Jet Fan on in-heading ventilation patterns – Cut *#3*

Finally, the impact of cutting splits were not addressed in COL 518. Figure 21 serves to reflect some of the complexities in ventilating these configurations. In this case, the primary ventilation is, once again, a jet fan positioned at the LTR intake whilst the on-board ventilation systems on the CM consist of the

Kloppersbos spray fan system and a twin, side discharge scrubber system mounted on board of the CM.

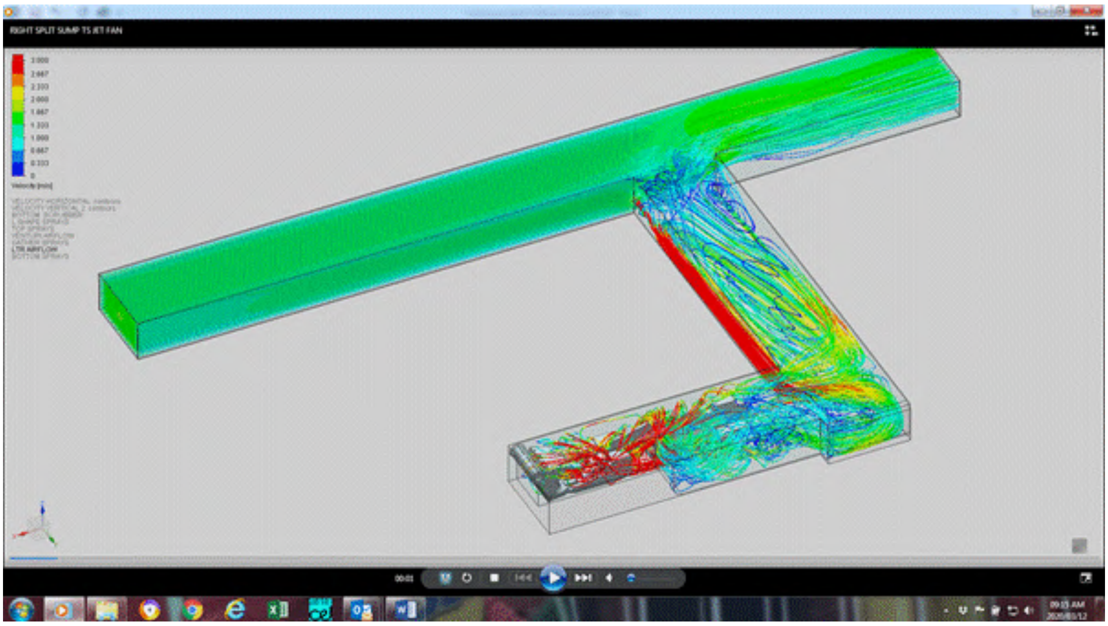

Figure 21 Complex ventilation flow patterns in a right hand split

7 CONCLUSIONS AND RECOMMENDATIONS

Since the COL518 work was conducted at Kloppersbos significant changes have taken place in CM headings. The use of on-board machine operators has been almost completely terminated and these machines are now remotely operated by operators positioned on foot, diagonally positioned behind these machines. The scrubber quantities and discharge directions have been modified, and the space behind the scrubbers is now often utilised for other on-board control systems. The size and coal cutting rates have increased considerably, being double or more than double as was tested in 1999.

The work conducted at Kloppersbos was thorough and adequately reflected the requirements of the, then, legal objectives of maintaining an average level of 5 mg/m^3 respirable dust in the working area, it can be stated with hindsight that this objective was effectively met.

The drawback of the work conducted was that it was difficult to exactly quantify levels of dust (and therefore also of other contaminants such as methane) throughout the face and adjacent zones within the CM heading. The project also dealt with a single situation i.e. a CM inside a high heading with the boom at midpoint (halfway through the face cut) only. Hence, COL 518 does not adequately predict the contaminant flow for situations where the machine is actively cutting with the cutter head in either the fully “up” or fully “down” positions and, as such cannot be used as a predictive tool for altered conditions.

Therefore, the impacts and consequences of any other configuration, e.g much larger scrubbers, sideways discharging scrubbers, installation of obstructive systems such as boxes containing control gear and electronics, etc. could not be effectively predicted and quantified.

It is apparent that relying on COL 518 may be not be sufficient as the guide for in-heading ventilation design for any configurations that are more complex or where material design changes, such as scrubber systems, have occurred.

Mines and manufacturers relying on COL 518 as the sole means of designing heading and on-board ventilation systems should therefore take cognizance of these limitations. They should therefore exercise due care and diligence as required in terms of the Mine Health and Safety Act to ensure that in-heading ventilation, health and safety conditions are, in fact, within acceptable limits when such changes are effected.

8 REFERENCES

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