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Life-of-Mine Ventilation System Upgrade at Springvale Colliery – A Case Study

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ABSTRACT

Springvale Colliery is an underground longwall mine situated approximately 10 km north-west of Lithgow in the western coalfields of New South Wales. Following a full-scale review of the mine's ventilation system in mid-2010, it was clear that the mine by early 2013 would become ventilation constrained as a result of the increasing size of the mine workings, the predicted worsening tailgate conditions and plans to introduce a fourth continuous miner unit. This realisation led Springvale to embark on a major upgrade of the mine ventilation system that would meet short-term and life-of-mine (LOM) requirements.

Included in the upgrade project was the installation of a new high pressure centrifugal main exhaust fan that is capable of overcoming the high resistances imposed frequently on the circuit by restrictions in the tailgate airway. The new fan featuring a 2.5 MW motor is designed to be capable of operating at a quantity of 250 m^3/s at a pressure of 7.9 kPa, a substantial improvement over the previous system, which had an operating duty of approximately 145 m^3/s at 1.9 kPa. The new fan is of a centre hung design and features a backup diesel motor to maintain ventilation in the event of a power outage.

Structural engineering analysis determined that under the operation of the new main fan the existing standard of ventilation control devices (VCDs) at Springvale would not be adequate to withstand the increase in differential pressures. As such, an upgrade of critical VCDs was undertaken utilising a novel high flexural strength (9 MPa) shotcrete and thin spray-on liner, which help serve to safeguard the structural integrity of the appliances and prevent increased leakage as roadway conditions at VCD sites deteriorate over time (a serious problem in many areas of the workings at Springvale).

In addition to the main ventilation system upgrade, a separate upgrade focusing on improving development face ventilation was also undertaken. This upgrade included the purchase of two high capacity (22 m^3/s) variable inlet vane (VIV) auxiliary fans to facilitate comfortable development face ventilation.

The upgrade of the mine ventilation system at Springvale has been three years in the making, but has removed a major business risk in that it has afforded mine planning and operational flexibility (a fourth unit can now be introduced) for the LOM, and importantly provided unprecedented levels of comfort to operators at the working faces where previously ventilation and heat issues were frequently reported. The impact of this on the morale of the workforce, and hence their output, should not be underestimated.

INTRODUCTION

The ventilation requirements of underground coal mines have often been an afterthought in the mine planning process following considerations such as production and resource optimisation (Chalmers and Moreby, 2002). A lack of planning with respect to mine ventilation, expansion of operations or a change in operational direction (Lim, 2011) frequently lead to changes and upgrades to mine ventilation systems in order to maintain effective ventilation. To prevent multiple iterations in the ventilation hardware and arrangements, a holistic, life-of-mine (LOM) approach must be adopted when undertaking any upgrade to the ventilation system of a mine.

Springvale Colliery is one such example of a mine that has required multiple upgrades and changes to the primary ventilation system. These upgrades and changes, spurred on by changes in the operating condition of the mine, have rarely been holistic in scope and arguably suffered from a lack of capital investment. As such, previous changes to the ventilation system have not been effective for a long period

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of time (short-term thinking prevailed) nor have they been designed to suit the hostile underground environment. Until now that is.

LIFE-OF-MINE VENTILATION REQUIREMENTS

Historical ventilation arrangement

Following the initial development of the main drives at Springvale, a downcast shaft and two drifts served as the primary intakes, with a single upcast shaft acting as the primary exhaust.

As the mine workings progressed a new ventilation shaft was developed to advance the position of the primary upcast shaft to relieve ventilation restriction, as shown in Figure 1. The former upcast shaft was decommissioned and converted to an additional downcast shaft, with the existing return line VCDs left in place to serve as a segregated intake airstream and egress.

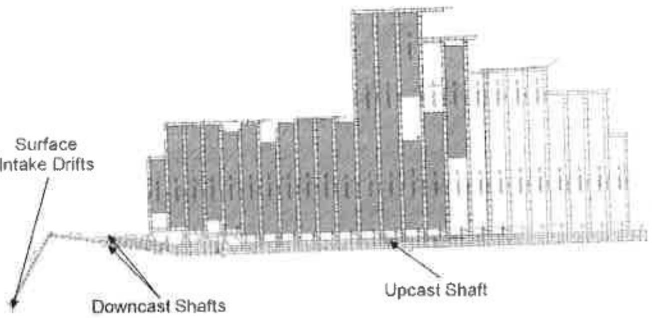

FIG 1 - Current and future mine Springvale workings with upcast and downcast shaft positions highlighted.

At the time of this change (commenced in 2004), the current upcast shaft was fitted with two identical 450 kW electric and diesel powered centrifugal fans, the electric unit typically ventilating the mine while the diesel unit serves as a backup. This arrangement ventilated the mine workings with an approximate quantity of 145 m^3/s at 1.9 kPa.

Ventilation restriction and constraints

The geotechnically hostile conditions at Springvale present numerous challenges to strata control, but also impact on the mine's ventilation. In a frugal effort to maintain tailgate serviceability, a high density of standing support is installed for the length of the tailgate airway prior to commencing longwall extraction. This high density of support (typically installed at 2 m centres), results in a high tailgate resistance contributing to a high mine resistance given the tailgate is usually the 'unregulated' air split. Significant amounts of roadway convergence (typically rib spall), as visible in Figure 2, are frequently experienced in the tailgate roadway on longwall retreat, further restricting the ventilation system. Over the course of longwall extraction, roadway crush and falls in the tailgate regularly limit tailgate access from the face and leave an air passage at the tailgate corner of less than 1 m^2.

The overall result of these tailgate conditions has been resistance values that have lowered air flows to the point that mains development has been stopped for prolonged periods of time (planned and unplanned) and flow across the longwall face has been little more than prescribed limits. Figure 3 shows historical mine resistance values for Springvale Colliery, where a maximum resistance of approximately 0.12 Ns^2/m^8 was reached in May 2010. This high mine resistance was the result of a severe restriction in the longwall tailgate by standing support and substantial roadway convergence shown in Figure 2, which has not been experienced to this extent at Springvale since, but will be superseded at the back end of this year in future LW416 tailgates.

FIG 2 - An example of tailgate convergence and standing support observed at Springvale.

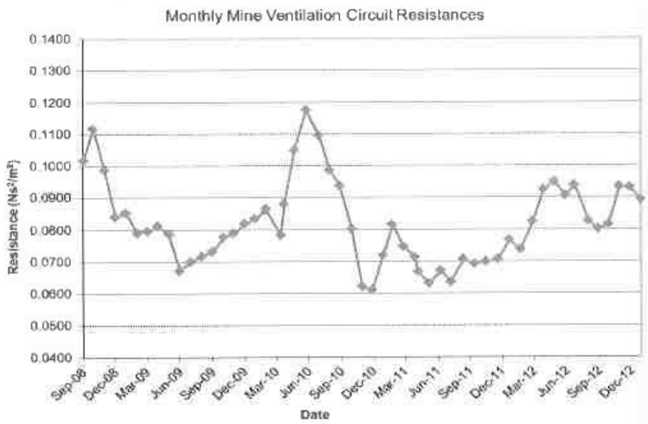

FIG 3 - Historical monthly mine resistance values at Springvale.

This experience, combined with the development of further mine workings and the prospect of a fourth continuous miner unit starting production in 2014, led to a review of the adequacy of the current centrifugal fan arrangement for the LOM ventilation requirements.

The analysis consisted of ventilation modelling of planned future mine working positions. This identified that the ventilation system would no longer be able to provide adequate ventilation capacity for the mine to operate as per the production model by early 2013. The results of this investigation prompted consideration of various means to meet the short-term and LOM ventilation requirements.

Analysis of life-of-mine ventilation options

An analysis of a number of potential solutions to the impending ventilation restriction was undertaken including consideration of:

- installation of an underground booster fan
- sinking of a new ventilation shaft to advance the position of the primary return
- construction of a new high capacity ventilation fan at the existing upcast shaft site.

Ventilation modelling of the planned LOM production sequence was undertaken in conjunction with each of the aforementioned options to determine the hardware requirements, limitations and cost implications of each design option.

New high capacity surface fan

Consideration for the construction and installation of a new high capacity centrifugal fan at the current upcast shaft site was undertaken. Due to the total length of workings, combined with the likely high tailgate resistances expected over the LOM, a fan with a high operating pressure would be required. As it became apparent that the installation of a new primary ventilation fan would be the most viable option, a quotation and tender process was undertaken for the design and supply of a fan to meet LOM requirements. Following completion of this process a cost analysis was undertaken, with consideration of the high operating cost associated with a large capacity fan. This analysis found the procurement and installation of a new ventilation fan preferable in comparison with sinking a new upcast shaft or installation of an underground booster fan. This result combined with the designed redundant capacity built into the system saw the decision to install a new high capacity ventilation fan as the preferred option to meet short-term (early 2013) and LOM ventilation requirements.

MAIN FAN UPGRADE DESIGN

Design brief

The design brief of the new main fan required the fan to service the likely LOM ventilation requirements for the colliery. For the purpose of tendering this was stipulated as being a nominal 220 m^3/s, based on LOM production panel requirements and likely leakage, at the historical maximum mine resistance of 0.12 Ns^2/m^8. This represents a worst case mine resistance that is not planned to be reached during regular LOM production, but should also allow for providing the ability to adequately manage any reasonable changes to operating conditions or mine redesign.

Also included within the brief was the requirement for the fan to have a backup diesel motor to provide a ventilation quantity of 200 m^3/s in the event of a power outage. Under normal operating conditions the mine workings can thus be adequately ventilated using the backup diesel motor. Further, the brief stipulated the requirement for the new ventilation fan to be integrated with the existing ventilation fan units at the current upcast shaft site.

Following consideration of various design submissions the team at Springvale decided to proceed with the procurement and installation of a Howden BAB145 type centrifugal fan, shown in Figure 4.

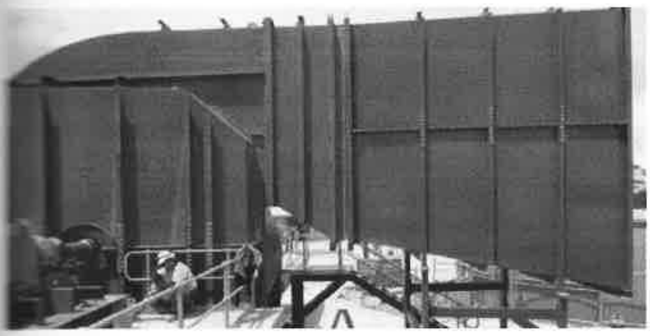

FIG 4 - The Howden BAB145 centrifugal fan under construction at the Springvale Colliery upcast shaft site.

Features

The Howden BAB145 main fan is operated by a 2510 kW electric motor, with a 1275 kW Caterpillar 3516 DITA diesel engine on the opposing side of the impeller (diameter 3.4 m) to act as a backup motor. The fan impeller is centre hung, with the impellor drive shaft mounted either side of the impellor, to facilitate the operation of the fan by the electric and diesel motors located on opposite sides of the impellor. In the event of a power outage, the diesel engine will start up automatically and as the impeller reduces in speed the diesel engine will engage the drive shaft to ensure no loss of ventilation or shock loading of the drive shafts occurs.

The shaft top bend associated with the fan and associated ducting contains approximately 10.24 m^2 of explosion panels exceeding the total area of the shaft being approximately 9.62 m^2 (diameter 3.5 m). The inclusion of this explosion protection will ensure serviceability of the main ventilation fan is maintained in the unlikely event of an underground explosion, and maintains compliance with industry best practice for main ventilation fan explosion protection (Royal Commission on the Pike River Coal Mine Tragedy, 2012).

The new ventilation fan has a horizontal discharge arrangement, differing from the vertical discharge arrangement of the two existing ventilation fans. Incorporation of a horizontal discharge was adopted to mitigate the potential for sound from the fan to propagate significant distances from the fan site when cloud cover was present in the immediate atmosphere around the fan site.

Mountings have also been built into the ducting such that a sensor system may be retrofitted to provide accurate continuous monitoring information adequate for the reporting of greenhouse gas emissions.

A trapped key or Castell key interlock system is used to achieve a Safety Integrity Level (SIL) 2 rated isolation system for the new ventilation fan. The fan also allows authorised personnel to adjust the fan's operating speed through remote electronic variable speed control.

Capacity

The maximum operating duty of the new Howden fan is 250 m^3/s at 7.9 kPa at 755 RPM, making the Springvale main ventilation fan one of the largest single centrifugal fans ventilating an underground coal mine in Australia by maximum operating pressure. Figure 5 shows the design operating curves for both the 450 kW existing fan and the new Howden BAB145 centrifugal fan situated at the upcast shaft. The substantial increase in ventilation capacity is evident.

Surface arrangement

As stipulated in the design brief, the new fan was required to be integrated into the surface arrangements at the site of the current upcast shaft site. To achieve this, design of a new shaft top bend was required to allow both of the current mine fans to remain connected to the ventilation circuit of the mine as shown in Figure 6.

It was further identified that the damper doors situated prior to the inlet to each of the existing fans were not substantial enough to prevent air from being drawn from the atmosphere through their respective evases under operation of the new ventilation fan.

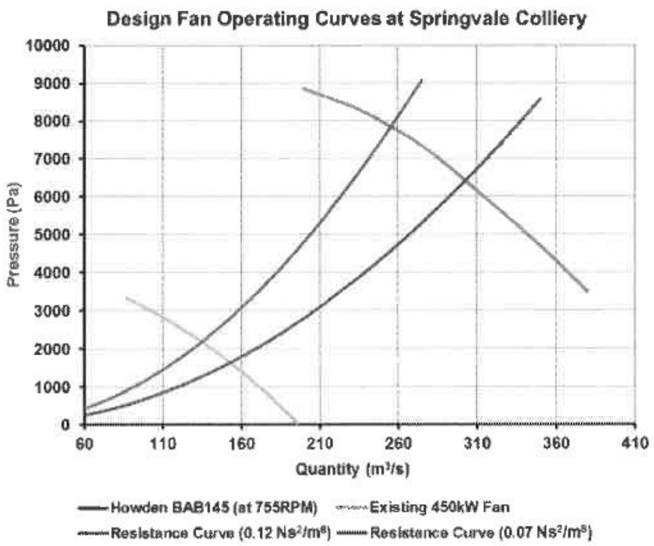

FIG 5 - Design fan operating curves for the existing and replacement Howden ventilation fans.

UPGRADE OF UNDERGROUND INFRASTRUCTURE

Assessment of current ventilation control devices

Due to the significant increase in main ventilation pressure anticipated under the operation of the new main fan, an assessment of the adequacy of the current VCDs was required.

Typical mains VCDs at Springvale have historically been constructed of dry stacked Hebel brick or fibre reinforced concrete blocks, referred to hereafter as 'block type' VCDs. These VCDs are secured under friction by packing timber wedges around the edges of the constructed wall between the surrounding strata. The VCDs are then sealed by packing cotton waste around the edges and spraying the face and strata interface of the VCD with spray grout. Various inclusions such as man and machine access doors and services were built into the VCDs as required.

While block type VCDs were historically adequate for mine ventilation requirements, no determination of the pressure rating of these stoppings had ever been made. As a result a structural engineering analysis was undertaken of all block type VCDs, with the goal of determining if block type VCDs would be adequate for the likely differential pressures under the new main fan.

Due to the method of construction of block type VCDs, an accurate engineering analysis of the VCDs was problematic. The high number of variables, including consistency of block alignment and most significantly the inability to assess the amount of friction acting between the timber wedges and the surrounding strata, led to an idealised and conservative analysis being undertaken. The results of analysis indicated that the maximum differential pressure that block type VCDs could be subjected to should not exceed 1.1 kPa applying a factor of safety (FOS) of 1.5.

Design of new ventilation control devices

Ventilation modelling indicated that critical VCDs within the mine would be subjected to sustained differential pressures of up to 5.5 kPa under the operation of the new main fan, representing a more than fivefold increase in differential pressures across VCDs. As this dramatically exceeded the rating of existing block type VCDs within the mine, design of a new VCD standard suitable for the operation of the new main ventilation fan was required.

The design brief was to develop a VCD suitable to withstand sustained differential pressures of at least 5.5 kPa, however, to remain consistent with industry standard VCD ratings a value of 14 kPa (2 psi) was specified with a minimum design FOS of 1.5. Additional consideration was also given to the

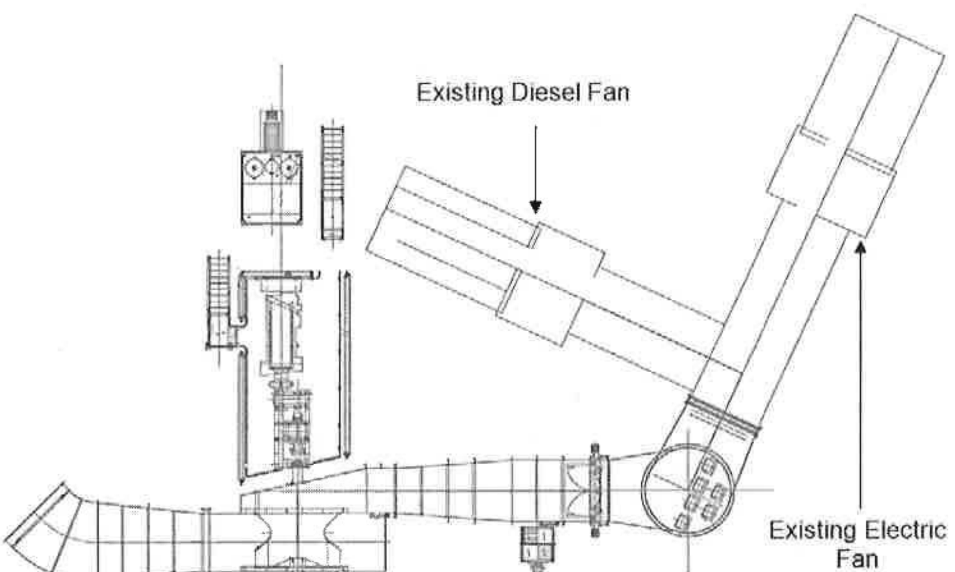

FIG 6 - Main ventilation fan surface arrangement at the upcast shaft.

potential variation in physical material properties through batching and mixing of the product.

Included within the design brief was a requirement for VCDs to be rated against failure between the VCD strata interface. This requirement was considered due to the nature of the roadway conditions at Springvale, whereby the inconsistent and irregular roadway profile, specifically the rib profile, has historically reduced the effectiveness of VCDs at the VCD strata interface.

As it became apparent that the VCD design was likely to be a shotcrete monolithic type seal, consideration was given to the impact of a likely level of roadway convergence experienced at Springvale on installed VCDs.

It had been observed that block type VCDs with access structures subject to roadway convergence have become unserviceable due to the deformation of access devices. In an attempt to mitigate the impact of deformation on access structures caused by convergence, a range of shotcrete products were investigated to identify a product with properties likely to limit the impact of convergence.

A shotcrete type product called Flexus, with a high flexural strength of up to 9 MPa, demonstrated in Figure 7, was analysed against a typical shotcrete product. This analysis identified that the properties of Flexus allowed for a lower wall thickness for a monolithic type seal in comparison with concrete for the required rating.

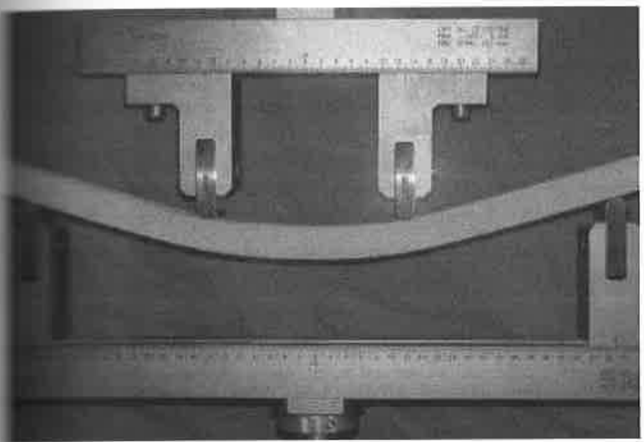

FIG 7 - A four point bending test of Flexus demonstrating its high flexural strength.

Cost analysis found that the lower required wall thickness of a Flexus seal resulted in cost savings in comparison with typical shotcrete, with the added benefit of a reduction in logistic requirements through less material needing to be transported underground to install each stopping. As a result it was determined to pioneer the installation of Flexus type VCDs to achieve the required pressure rating of the underground ventilation infrastructure for operation under the new ventilation fan.

In order to allow for safe egress of personnel and machinery through VCD airlocks under high pressure, selection of appropriate access structures was required. It was determined to install pneumatically operated machine doors for machine access, while a sliding access door with mechanical lever, called the 'vent safety door' (a door pioneered at Springvale) shown in Figure 8, was selected to provide safe access of personnel through stoppings.

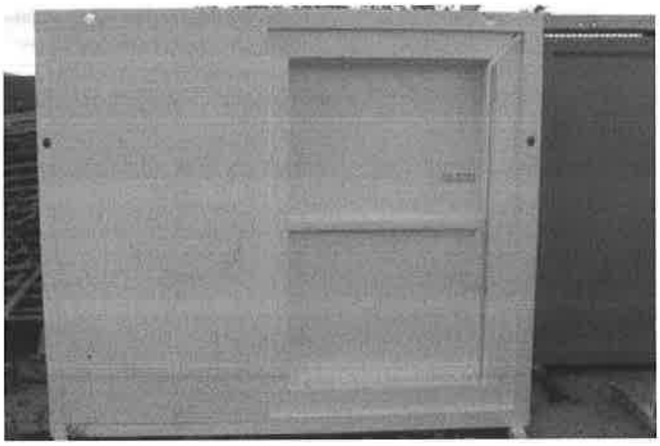

FIG 8 - The sliding 'vent safety door' used to facilitate safe egress through high pressure ventilation control devices.

Installation of these Flexus type VCDs has found a significant reduction in mine leakage, with an approximate gain of five to ten per cent improvement of total mine ventilation efficiency under the current ventilation fan arrangement. Additionally, Flexus type seals installed in areas that have come under roadway convergence have been shown to maintain their integrity.

COMMISSIONING OF NEW MAIN VENTILATION FAN

Shaft top bend replacement

As it was required for the existing fans to remain connected to the shaft top following the commissioning of the new main fan, fitment of an entirely new shaft top bend was required to connect all three fan inlets to the upcast shaft.

This process was estimated to take 12 hours, including the reinforcement of the dampener doors in the two existing fan inlets, with ventilation of the mine workings being interrupted during this time.

Risk assessment

In preparation for the shaft top bend replacement, a risk assessment was conducted to identify key hazards associated with the process and implement appropriate controls.

During this risk assessment it was identified that, due to the low seam gas content, the risk of a hazardous or explosive atmosphere developing was low.

However, the business risk of catastrophic inundation of the active workings by Springvale's substantial water make in the event of pump failure was identified as being extreme.

In order to effectively control this hazard, it was determined to seek exemption from the Inspectorate to permit critical pumping infrastructure to remain powered during the ventilation outage associated with the shaft top bend replacement, and to allow minimum personnel to remain underground to respond to pump infrastructure failure.

To safely allow personnel to remain underground during the ventilation outage the natural ventilation pressure and resultant flow of the mine had to be determined.

Determination of natural ventilation pressure

The estimation of natural ventilation pressure was carried out by two methods. The first method was the calculation of the likely natural ventilation pressure was by determining the difference in column pressure between the intake and exhausting air densities.

Secondly, the natural ventilation pressure was modelled with consideration of estimated rock conductivity and thermal gradient. The results of both methods were consistent and indicated that a natural ventilation pressure of approximately 55 Pa with an airflow of approximately 26 m³/s would be achieved during an outage of the main ventilation system.

Following the calculated estimation of natural ventilation pressure, it was required to determine the actual airflow under natural ventilation. To achieve this a short two-hour outage of the ventilation system was planned, being the maximum outage duration prior to removal of power under both the site management systems and current exemptions, during which primary intake airflow was measured and recorded by personnel underground.

This investigation found that total intake flow was approximately 25 m³/s and validated the calculated flow under natural ventilation pressure. However, due to the static flow and pressure being below the operating range of the instruments, it was found that the upcast shaft continuous monitoring system did not provide accurate pressure or quantity information during a main fan outage.

Management of personnel underground during main ventilation outage

On the basis of the investigation into mine natural ventilation pressure and flow a number of procedures were developed to manage the safety of personnel underground and the underground environment during a 12 hour main ventilation outage.

These procedures included the establishment of an Incident Management Team (IMT) to monitor and respond to changes in the underground environment during the outage. The IMT included site senior management, the ventilation officer, electrical engineering manager. The procedure also required a member of Mines Rescue to be on-site for consultation during the outage.

A Trigger Action Response Plan (TARP) was also developed specifically for the outage, with triggers relating to atmospheric contaminant levels and total mine ventilation quantity measured a regular intervals by a statutory official and reported to the Control Room.

Ventilation outage

Following the finalisation of all processes intended to manage the outage, subsequent approval from the Inspectorate and recommissioning of the new main fan the shaft top bend replacement proceeded.

In general the shaft top bend replacement was completed to plan, without incident and within the 12 hour time frame. It is notable, however, that a natural ventilation was observed to decline, as evident in Figure 9, during the fan outage due.

It is believed that this phenomenon is the result of the surface temperature increased over the course of the day the natural ventilation pressure of the mine decreased due to the difference between the intake and exhaust air densities. Immediately prior to restarting the main fan natural ventilation appeared to increase as the surface temperature reduced. Completion of the shaft top bend replacement and resumption of regular ventilation by the existing main fan was achieved before further information could be collected to further validate this hypothesis.

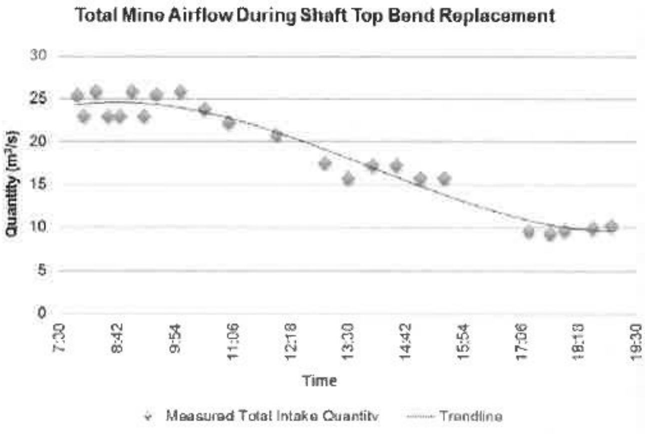

FIG 9 - Total mine airflow under natural ventilation pressure during shaft top bend replacement.

New main fan ramp up

Fan precommissioning

Prior to the commencement of the shaft top bend replacement, the operation of the new main ventilation fan under both the electric and diesel fan motors was tested as part of a precommissioning process. This process was undertaken to ensure that the system was operational prior to restricting access to components by placing the unit in line with the ventilation shaft.

The precommissioning process was completed successfully with both fans operating effectively under both motors. Further, the speed matching and drive shaft engagement feature of the diesel engine was tested when power was intentionally removed from the electric engine. This feature was observed to function effectively, with no interruption or stoppage of the fan impellor observed, ensuring that no interruption, however brief, would be experienced in the event of loss of electrical power to the main fan.

Fan ramp up

Due to various operation issues and delays, the works upgrading the VCDs within the mine to suit the differential pressures of the new fan under full operation were not complete at the time of fan commissioning. As a result the main fan could not operate at peak capacity immediately, however additional ventilation capacity was required immediately following the completion of the shaft top bend replacement.

To address this ventilation modelling was conducted to identify the maximum safe operating duty of the main fan without inducing failure of critical VCDs. This analysis permitted the ramping up of the main fan from existing fan duty, 140 m³/s at 1850 Pa, to 160 m³/s at 2170 Pa.

Following this analysis, the main fan was ramped up incrementally to the nominated duty point, with both surface and underground monitoring of ventilation and key VCDs conducted during the ramp up. This ramp up was achieved without incident or failure of any VCDs.

At the time of writing, VCD upgrade works were still in progress, preventing the operation of the main fan at full capacity, however, as works continue incremental increases in fan duty can be achieved.

DEVELOPMENT PANEL VENTILATION UPGRADE

Auxiliary fan upgrade

In recent history 18 m^3/s auxiliary fans have ventilated development units at Springvale Colliery. While face ventilation conditions were compliant, even in dual miner units at the furthest extent of the pillar cycle, heat management has been problematic despite the relatively mild climate of the western coal fields.

As a result it was decided to adopt a best practice approach to development ventilation, to provide a comfortable working environment to operators in excess of the legislative requirements. The potential for the mine to operate four continuous miners in the near future also contributed to the need to further improve the auxiliary ventilation capacity of the development units.

The pursuit of this goal led to the procurement of two high capacity (22 m^3/s) auxiliary ventilation fans, shown in Figure 10, with VIVs to reduce ventilation capacity if required. Design of the two fans was tailored to suit their operating environment. The mains development auxiliary fan was of a conventional skid mounted design suitable due to the large amount of pit room in the mains district. However, a different, purpose built 'structure mounted' design was adopted for the gate road development unit where the fan is situated on the conveyor belt structure. This approach was selected due to the restrictions placed on egress when an auxiliary fan is positioned alongside the conveyor belt.

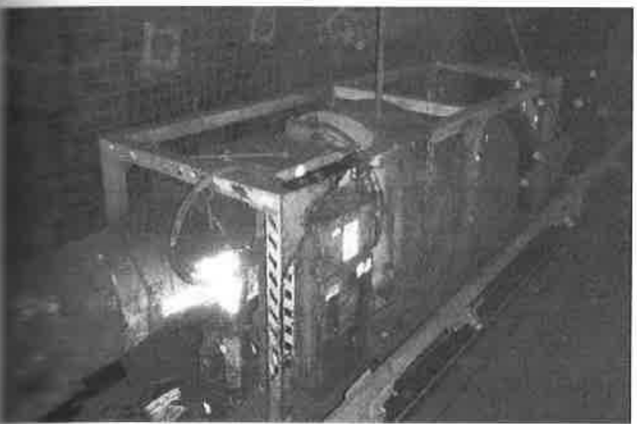

FIG 10 - High capacity 22 m^3/s auxiliary ventilation fan.

Following the introduction of the new high capacity auxiliary fans, face ventilation quantities have generally increased by approximately 15 - 25 per cent when compared to similar ducting lengths under the previous 18 m^3/s fans. Workforce feedback regarding the installation of the new fans has largely been positive, with the improvement in comfort at the working face as a result, well received.

Importantly, the upgrade has allowed Springvale to continue to use a single fan to ventilate a dual miner unit, which was seen as a big win by the development process team and the operators underground given the additional resources and time that would have had to be allocated to a belt move should a second auxiliary fan been used in the panel.

Gate road VCD sealing

The typical spray grout used to seal the flexible stopping used in gate roads was found to deteriorate over time and under convergence due to its brittle properties once set. This deterioration resulted in increased leakage in the gate road panel ventilation, placing a considerable burden on the mine ventilation system, especially when gate road development is in later stages. Leakage in the gate road development panel has historically been as high as 55 per cent.

To address this issue a polymer based thin spray-on liner (TSL – MEYCO MasterSeal 845 now MEYCO TSL 865) produced by BASF, with high flexibility once set, was selected to replace the existing spray grout product for the purpose of sealing gate road VCDs. Application of the thin spray-on liner is achieved through the use of a shotcrete or shotcrete type spray pump (typically Piccola or Reed) and adheres effectively to both the strata and stopping material. The application of the thin spray-on liner product to flexible stopping material has resulted in a reduction in leakage through stoppings from between 50 - 60 per cent compared to flexible stoppings sealed with regular spray grout. The use of this product at Springvale is being expanded to seal other VCDs including overcasts and brick stoppings that form part of the segregated second means of egress as it saves the need to re-spray every 12 to 18 months.

CONCLUSION

The upgrade of the ventilation system at Springvale Colliery has been conducted with a holistic, best practice approach to mine ventilation design. Operating within the limitations of an existing ventilation system, Springvale Colliery is an example of how the necessity to improve the ventilation system has served as an opportunity to ensure that the likely LOM ventilation requirements can be comfortably met.

Further, the investigation of natural ventilation pressure and management of personnel working underground during an extended main ventilation system outage provides valuable insight into the behaviour of natural ventilation in a large underground coal mine.

Installation of the new Howden BAB145 centrifugal fan, associated VCD upgrade utilising innovative products, in addition to the procurement of new high capacity auxiliary fans provides Springvale with flexibility in terms of future mine planning and production scheduling for the LOM. Importantly, the ventilation upgrades have seen operators now in a comfortable underground working environment at the production faces – an impact which should not be underestimated. Although Springvale is not a gassy mine and should have hence been a considerably easy mine to manage from a ventilation perspective, the opposite was the case until now.

The approach taken by the Technical Services team to ventilation planning and improvement at Springvale was a far-sighted one, but should be considered an example of best practice and safety conscious design and management for underground coal mining operations within Australia and abroad.

ACKNOWLEDGEMENTS

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