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Australian longwall panel ventilation practices

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AUSTRALIAN LONGWALL PANEL VENTILATION PRACTICES

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ABSTRACT: A study has been undertaken into mine ventilation systems currently in use within Australian modern coal Longwall (LW) extraction mines. It reviews systems and discusses evolving changes being adopted to address the more complex challenges. There is a strong move to longer panels, wider faces, greater extraction heights, increased production rates, more efficient ventilation and decreased personnel. In addition mine workings are moving deeper which results in increased ventilation control issues such as higher total and respirable dust levels, greater seam gas contents in parallel with lower *in situ* permeabilities, spontaneous combustion and heat management issues. Currently there are a variety of LW panel ventilation circuits used in Australian underground coal mines due to various combinations of seam characteristics, gas emission rates, spontaneous combustion, geological features and surface constraints. The main issues usually addressed in the designing and planning of ventilation circuits for LW panels are airway velocity, gas concentrations, LW cutting methods (e.g. Bi-di, Uni-di or half web), ventilation of control devices, pressure differentials and leakage paths and understanding gas concentrations across the length and width of the goaf. If the ventilation circuit can manage the applied contaminant load (gases, heat and dust) at an acceptable cost and circuit duty, then supplementary controls, such as gas drainage, refrigeration and dust sprays and scrubbers, may not be required. The study has been undertaken based on reviews of LW mining operational practices in Australia.

INTRODUCTION

The purpose of this paper is to establish the state-of-the-art of Australian underground LW coal mining ventilation practices. Within Australia the two states where almost all underground coal mining activities take place are Queensland and New South Wales (NSW). The mining history, geology and regulations vary between these two states. This current study demonstrates significant changes from similar reviews undertaken by Schaller and Savidis (1983) and Mayes and Gillies (2001). In the first study it was found that mines almost exclusively used an "R" or "Z" ventilation approach similar to European practice whereas more recent studies show that many mines tend to use some form of U ventilation as used in the United States to ventilate their LWs. In the last ten years there has been a move for many mines to increase ventilation with the assistance of back boreholes and back airways or occasionally bleeders.

Currently there are a variety of LW panel ventilation circuits used in Australian underground coal mines due to various combinations of seam characteristics, gas emission rates, spontaneous combustion, geological features and surface constraints. The main issues usually addressed in the designing and planning of ventilation circuits for LW panels are face velocity, maingate intake velocity, tailgate and face return gas concentrations, flow direction in maingate conveyor roads (for heat, gas and dust management), LW cutting methods (e.g. Bi-di, Uni-di or half web), ventilation of maingates inbye of the faceline for (seal installations and holing of development roadways), contamination due to intake air passing goaf seals (if present), dilution of returns gas concentrations (mixing stations) if required, location of regulators with respect to pressure control, pressure differentials, leakage paths and of understanding gas concentrations across the length and width of the goaf. If the ventilation circuit can manage the applied contaminant load (gases, heat and dust) at an acceptable cost and circuit duty, then supplementary controls, such as gas drainage, refrigeration and dust sprays and scrubbers, may not be required. Various additional controls need be considered and incorporated into the ventilation circuit design where the ventilation circuit alone cannot handle the contaminant load.

The data for this review has been obtained from surveys of 13 LW mining operations in Queensland in the last ten years. Australia had in total about 30 operating LW mines in 2012 producing approximately 89 Mtpa. About 40 percent of these mines operate in Queensland. The average tonnage of individual mines in Queensland exceeds those in NSW. All Queensland LW mines operate in the Bowen Basin. The NSW LW mines operate within the Western, Southern, Hunter and Newcastle regions of the NSW Sydney Basin. Most Australian coal mines operate a single retreat LW installation but at any point in time a small

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number will have two retreat LWs in operation. By comparison the Australian underground coal production has increased significantly since the survey of Mayes and Gillies (2001). It was reported that in 1999 there were a total of 34 operating LWs in Australia producing approximately 67 Mtpa, 11 of which operated within the Queensland Bowen Basin and the remaining 23 within the Western, Southern, Hunter and Newcastle regions of the NSW Sydney Basin. All of these mines operated a single retreat LW except for one with two retreat LWs which was in the Illawarra Coalfield of NSW.

INDUSTRY CONDITIONS AND SURVEY

Over a number of years several formal or ad hoc surveys of coal mine ventilation were undertaken as part of mine design exercises. These have focused on a number of major issues including mine statistics, physical mine environment, main ventilation environment, development ventilation, LW ventilation, ventilation network analysis, ventilation monitoring and future considerations. The physical mine environment section deals with the physical parameters of the mine including seam cross section, roadway dimensions and physical layout of the pit. The main ventilation environment deals with main fan installations, issues affecting ventilation and related incidents and location of the critical or open splits. The development ventilation deals with ventilation layout in development and most importantly considerations for breaking through in development. The LW ventilation deals with extraction method and equipment, panel ventilation and sealing practices behind the active LW face. Ventilation network analysis and monitoring deals with the level of monitoring of ventilation parameters within the mine and how computerised network analysis is being utilised.

Currently there are a variety of LW panel ventilation circuits used in Australian underground coal mines due to various combinations of seam characteristics, gas emission rate, spontaneous combustion, geological features and surface constraints. The main issues to be addressed in designing and planning of the ventilation circuits for LW panels are as follows:

1. Face velocity,
2. Maingate intake velocity,
3. Tailgate and face return gas concentrations,
4. Flow direction in maingate conveyor road for heat and dust management,
5. LW cutting method for example, Bi-Di, Uni-Di or Half Web,
6. Ventilation of maingate inbye of the faceline for seal installation and holing of replacement development,
7. Contamination due to intake air passing goaf seals (if present),
8. Dilution of return gas concentrations (mixing stations or sewers) if required,
9. Location of regulators with respect to pressure control,
10. Pressure differentials and leakage paths,
11. Understanding gas concentrations across the length and width of the goaf,
12. Use of back airways or bleeders US style at back of LW panel.

If the ventilation can manage the applied contaminant load (gases, dust and heat) at an acceptable cost and circuit duty, then supplementary controls may not be required. However, where alternative control measures are required due to unacceptable conditions then the following as listed in Table 1 can be considered:

Within Australia the major factors that determine LW ventilation requirements and panel circuit design are heat, dust and seam gas concentrations. The control of heat is generally a function of intake air conditions and the amount of heat added to the air from the maingate LW equipment. This often is addressed during the summer months by introducing refrigerated air via a back panel shaft and homotropal LW belt ventilation arrangement. Pre drainage of seam gases prior to LW production can lead to the planned working section being largely dewatered and so dust inbye of the shearer generally cannot be controlled by ventilation alone. It is expected that the shearer cutting operations will generate considerable dust. Velocities of no more than 5.0 m/s of air across the LW face are necessary to avoid raising additional dust. Dust controls such as additional systems of sprays, scrubbers and shearer clearers are considered in this situation.

Table 1 - Control measures and its effect for efficient longwall panel ventilation

	Control Measures	Effects of the Controls
1	Pre-drainage of working section	Reduce rib and LW gas emission
2	Post (goaf) drainage	Reduce LW gas emission
3	High capacity back return shafts	Goaf drainage with returns
4	Increase production to 7 d/week	Reduce gas emission peaks
5	Seal design and balancing	Use of adjacent development for intake
6	Dust suppression and water infusion	Allows intake velocities greater than 5 m/s
7	Increased local velocity or refrigeration	Heat management

Due to the statutory limits for methane concentrations in return airways and at the tailgate drive, the use of ventilation air as the sole control on the LW for gas control will require large and impractical quantities of air. Therefore gas concentrations on the LW face and in the tailgate will be controlled primarily by goaf drainage. Reduced gas content using pre-drainage reduces Specific Gas Emission (SGE) and insufficient pre-drainage results in increased SGE and hence increased LW gas make and increased goaf gas extraction rates. This means the maximum air quantity adopted for the LW face is generally between 40 and 80 m^3/s depending on the extracted seam height. Many modern Australian LWs extract a seam mining height ranging from 2.6 to 3.4 m and some times more.

Many modern mines have suitable reserves and design for a 300 m LW face width and variable annual LW production of up to about 8.0 Mtpa. A few faces are up to 400 m in length. There are various options used to reduce the CH_4 levels in LW return airways such as:

- Increased LW ventilation air quantity,
- Configuration of LW ventilation design,
- Increased goaf gas extraction efficiency,
- Increased seam pre-drainage to reduce face emission,
- Increased pre-drainage of adjacent seams to reduce SGE and/or
- Reduced LW production rate to hence reduce face emission.

Production from Australian LWs varies from about 0.7 to 8.0 Mtpa. The latter figure is from some of the newer "thick seam" mines. All underground mines have a combination of shaft and/or drift access for personnel, materials and ventilation. The production method on the face is predominantly Uni-di cutting due to gas and/or respirable concentrations of dust. Some mines in recent years have tried alternative methods for ventilating gateroad development including three heading development. However the additional cost of three headings has meant that these mines have reverted to two headings after mining of a few panels. Sealing practice has varied between the two states because of prescriptive new Queensland regulations introduced in the late 1990's requiring explosion pressure rated ventilation structures. However, NSW practice has largely been falling into line with Queensland's evolving practices.

Monitoring of gases within collieries is provided by both tube bundle and telemetry systems. Typically CO_2, CO, CH_4 and O_2 are reported. Those collieries with ventilation issues involving gas typically have a gas chromatograph to assist with the analysis of bag samples for other indicator gases. Ventilation network analysis is in most cases facilitated through the use of a mine ventilation computer network simulation program. The operation of these computer models is often supported by consultants who have assisted in the creation of up to date ventilation simulation models and then their maintenance.

LW VENTILATION DESIGN CONSIDERATIONS

The skeleton layout of an Australian LW mine is shown in Figure 1. In terms of ventilation nomenclature intake roadways are shown as blue, single arrow roadways while returns are shown as red, double arrow roadways. In this figure a borehole exists behind the current goaf and is shown as a circle with an intake roadway connecting to the LW face roadway. Mines onerous ventilation conditions very often incur the expense of excavating a borehole.

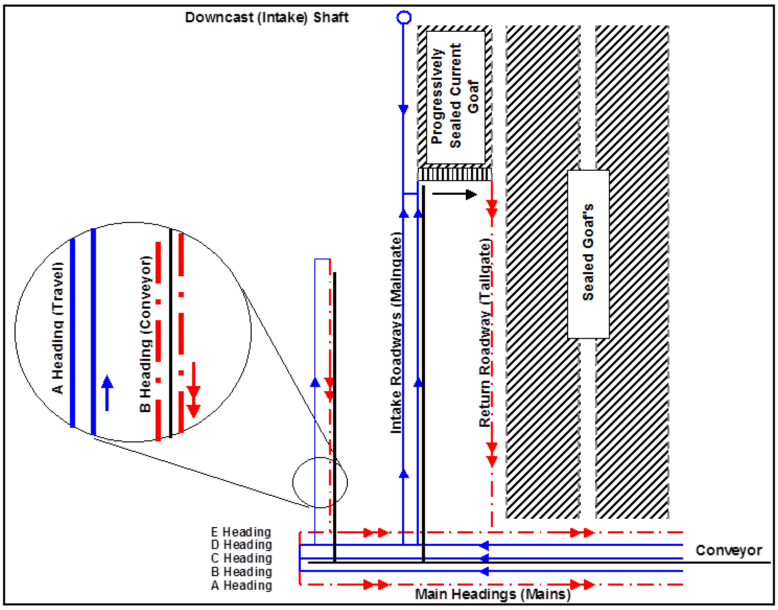
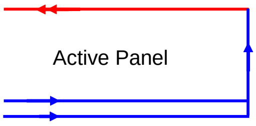


Figure 1 - Typical layout aspects of Australian LW mining

Australian LWs principally use a panel or section "U" ventilation layout with two roadway maingate development and have typically between five and seven mains roadways. In development, A Heading (as shown in Figure 1) is an intake roadway with B Heading the return roadway through which the panel conveyor runs. In the Mains, B, C, and D Headings are typically intake with flanking return roadways, A and E Headings. When all LWs are being extracted on one side of the mains only, D and E Headings may be used as return roadways with A, B and C Headings as intake roadways. The conveyor runs in the intake headings typically in C Heading. In Queensland C heading is segregated from either one or both of the other intake roadways. In NSW belt segregation is generally not undertaken to the same extent. The previous goafs are often sealed from the tailgate of the current LW with 140 kPa rated seals. The current goaf is progressively sealed on the maingate side as the LW retreats.



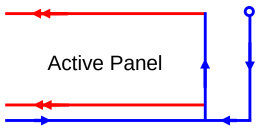


Figure 2 - Antitropal belt air **Figure 3 - Homotropal belt air** **Figure 4 - Downcasting borehole air**

Figure 2 shows an example of a traditional U ventilation approach. This is the most commonly used LW ventilation base model. This method minimises the induced ventilation pressure difference over both the current goaf and previous sealed goaf. This aspect is important when considering ventilation engineering design for operations in coal seams that have been demonstrated to have propensity for spontaneous combustion. The maingate belt headings have intake air flowing in the direction to the face, as shown, and termed antitropal. Air flowing in the reverse direction is termed homotropal.

The homotropal mode shown in Figure 3 is used for management of toxic seam gases, heat and dust. This method allows for a split of intake air to return via the B Heading to remove forms of ventilation contaminant away from the LW face. By locating the start of the split inbye of the location of the maingate B Heading contaminant source the contaminated air is not directed onto the LW face. However ventilation efficiency is lost as the air that passes along the maingate B Heading is lost from active use ventilating the LW face. The quantity of air lost from passing across the face varies but may be 20 to 25 m^3/s. The management of this homotropal split location can represent an operational issue as the split location is affected by constantly moving LW face/support equipment and discrete cut through locations.

Mine practice following the Moura No 2 mine disaster enquiry has generally been to install a pressure rated seal in the cut throughs behind the LW as the face retreats. The approach achieved popularity in

Queensland and is now well accepted in NSW. With more substantial structures present seal sites must be accessible for installation and ongoing access for inspection and maintenance. To provide access along the length of the A Heading roadway in the maingate in this ventilation approach auxiliary ducting ventilation is utilised. The use of auxiliary ventilation over increasingly longer distances as the LW retreats is problematic and hence this form of U ventilation is not employed without some variation.

Mines with more onerous ventilation requirements use a variation on the traditional "U" ventilation approach where a small diameter borehole (typically raisebored at 1.0 m diameter or more) has been excavated behind the current LW. The hole may be operated in a downcasting or upcasting mode and may be free venting or may be connected to a fan on the surface that is either pushing or pulling air. A free ventilating raisebore of diameter less than 1.0 m is generally only capable of providing or exhausting small quantities of air of the order of 10 m^3/s.

Figure 4 shows a LW panel with downcasting air in borehole. The use of a borehole will give a small drop in the overall mine resistance and an increase in airflow in the LW and on the face. Downcasting borehole air may become contaminated by gas as the goaf breathes out diurnally before the airflow reaches the face. This contamination may be considerable over distances such as when borehole air is used during installation of the last of a panel goaf seals. Borehole air can be routed to allow for access to the next LW's tailgate roadway which is a requirement for seal installation, inspection and maintenance. Sometimes downcasting boreholes pass refrigerated air in summer temperatures.

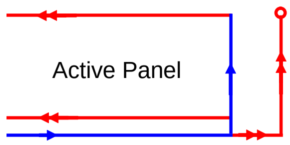


Figure 5 - Upcasting borehole

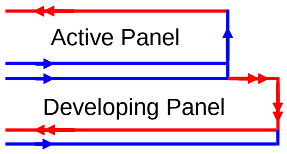


Figure 6a - Exhausting air via next panel

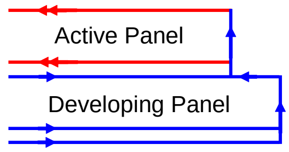


Figure 6b - Additional intake air from next panel

Figure 5 shows how boreholes may be operated in an upcasting mode. This method requires the installation of a surface fan on the borehole to provide the necessary pressure against the induced main fan ventilating pressures. This additional fan increases the number of operational issues when considering the running of multiple surface fan installations. Recirculation may be a possibility if multiple fans are not interlocked. The quantity provided by this additional fan is dependent on the sizing of the fan and hole dimensions. The distribution of pressures in the ventilation circuit has to be considered especially for spontaneous combustion reasons if exhausting large volumes of air with associated higher pressures. However, most of the pressure loss will be in the raisebore itself and not in the working horizon. The raisebore may be lined to prevent air leaking through cracks in the strata.

Exhausting boreholes assist removal of potential contamination from a seal installation site but can reduce the available quantity of air on the LW face. This method might also serve to offload some of the mains return requirements. Use of upcasting borehole air is far less popular that use of downcast air.

When an operation is well ahead in development it can make use of the newly completed next panel development to enhance ventilation in the current active panel. This approach is based on the "U" LW ventilation approach bringing intake air up the maingate of the current active LW panel and across the LW face before passing via the tailgate to the mains return. The workings in the adjacent newly developed panel can be used advantageously in either of two ways.

1. Some air from the active maingate A Heading can be brought past newly installed seals and then across the next LW's newly mined installation face road and returned to the mains return via the new B Heading belt road. This homotropal belt road return is also diluted with intake air from the next LW's maingate as shown in Figure 6a. The air provided inbye of the LW face in A Heading would be classed as return in some cases but would only carry contaminant sourced from the current active goaf's breathing.
2. Alternatively intake air from the newly developed panel having passed across the new face line is delivered to the inbye end of the current maingate. As shown in Figure 6b his extra intake air can then be used to assist dilution around the periphery of the current goaf by passing along the back road behind the active goaf.

Use of adjacent newly developed airways eliminates some of the need for borehole/small diameter shafts and associated capital costs behind the LW panels to provide ventilation to A Heading in the maingate for seal installation, maintenance and inspections. The added cost of this method is the development in advance of the next LW panel. Again in allowing ventilating of A Heading this approaches requires that seal installation follow closely behind LW operations. If the last open cut through inbye of the LW face is not sealed immediately following the LW retreat intake air may course indirectly behind the LW face through the goaf to the maingate or tailgate return. The introduction of air into the new goaf may have spontaneous combustion and/or face dust implications.

Figure 7 shows a panel ventilation approach based on a "Z" LW ventilation pattern. Part of the intake air comes up the maingate of the current panel workings. Additional intake air is brought up the tailgate (beside old workings) and across the LW face. Air exhausts behind the LW through the goaf. This method allows air to be coursed through the two caved roadways (maingate and tailgate) and through the next LW's tailgate roadway. All air is exhausted via a set of submain bleeders behind the LW panel.

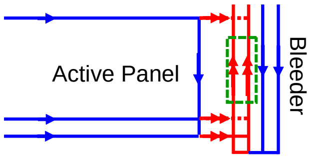


Figure 7 - "Z" LW ventilation with mixing chamber

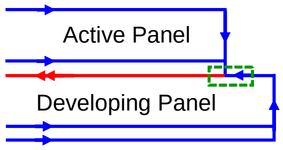


Figure 8 - Development air with mixing chamber

This ventilation method allows for significantly increased airflow in the pit. Much of this air is not necessarily directed onto the LW face due to ventilation induced face dust problems with excessive face velocities. The increased air available in the pit is used to dilute excessive quantities of gas present in the working section. Significantly increased ventilation pressures can also be achieved and directed across current workings and an incompletely sealed old group of goafs. This aids in draining seam gas from the goaf which is acting as gas reservoirs. This method would not be used in a seam that had demonstrated propensity for spontaneous combustion. A mixing chamber (restricted access/barricaded zone) may utilised to allow high concentration goaf gas to be diluted by uncontaminated air behind the current goaf.

Figure 8 shows a hybrid ventilation method utilising aspects of both U and Z ventilation approaches. Intake air is coursed towards the LW face along both the tailgate roadway and panel belt roadway. Intake air is also sourced from the next completely developed LW panel and passes along the sealed current goaf. Air returns from the LW face through the goaf to the last open cut through behind the face. At this point return air mixes with intake air from the next panel and is returned through a single roadway to the mains. This single roadway is barricaded, has restricted access and can be considered a "sewer" roadway. This ventilation method has being used to remove excessive quantities of gas present in the working section with consideration given to a seam with moderate propensity to spontaneous combustion. In this method the mixing chamber concept is utilised in the location where return air from the LW face is mixed with the intake airflow from the next LW panel. Due to the reorientation of the sewer roadway, development can be reversed from the traditional to minimise seal preparation and stopping destruction. Pressure distributions are very important due to face air intentionally passing through the immediate goaf to A Heading in the maingate. Seal installations have to be undertaken and monitored as soon as practicable coordinated with LW retreat.

RECENT DEVELOPMENT DATA IN LW MINES

Discussions with mine site ventilation officers have established the following parameters for typical current homotropal ventilation circuit design data:

1. LW belt road on homotropal ventilation running about 25 m^3/s at the maingate regulator,
2. 25 m^3/s passing around the back road or bleeder,
3. Up to 80 m^3/s air passing across the face into the tailgate,
4. 30 to 35 m^3/s air used for Mains with single continuous miner development,
5. Maintenance of LW panel circuit pressure of no more than 1.4 kPa.

6. Secondary supports are required in Tailgates outbye of the LW face and the minimum practice is 200 m of secondary supports.
7. LW panel pressures has been increasing when compared with mines in Central Queensland developed in the 1980s and 1990s.

A database of Ventsim models for 13 LW mines gathered over the last ten years by the authors is shown in Table 1. It can be noted that Mine D has two working LWs. From this information the reviewed LW panel ventilation pressures were varying from 250 to 1320 Pa (average 790 Pa) with LW face quantities ranging from 37 to 77 m^3/s (average 57 m^3/s) and roadway mining heights varying from 2.7 m to 3.8 m (average 3.2 m). Significant use of back boreholes (or shafts) within LW panels in Australia is a relatively new occurrence. Until the middle of the 1990s it was considered by many that the overlying strata was insufficiently competent for a borehole to be reliably drilled and to stand up for design life. Experience with sinking of shafts in many cases supported the view that overlying strata was weak and often incompetent; in this period a number of shafts and boreholes took much longer to complete that design expectation. Reference to Table 2 shows that in Queensland the situation is that back boreholes are now an integral part of most panel ventilation systems and is very much the norm to make use of. Of the 14 LW examples referred to in Table 2 nine are using back boreholes. These range from use of one or two small diameter boreholes each (less than 1.0m diameter) in four mines to cases where the borehole is greater than 2 m in diameter in three mines.

Table 2 - Summary of Queensland mines' LW panel ventilation and roadway dimension data

Mine	Panel Ventilation			Roadway		LW Panel			Comments	Beltway
	Pressure (Pa)	Total Q (m^3/s)	Face Q (m^3/s)	Width (m)	Height (m)	Face Height (m)	Length (m)	Face Position (m)		
A	1000	90	60	5.4	3.5	3.5	2170	2170	Highwall LW panel	Homotropal
B	250	93	70	6.2	3.5	3.8	860	860	1st LW; next panel intakes	Homotropal
C	1250	92	65	5.3	2.7	2.6	3650	3450	3 Hdgs; back shaft (2.5m) intake	Homotropal
D LW1	1200	110	77	5.4	3.4	3.4	3300	2550	Back shaft (2.2m) intake	Homotropal
D LW2	500	87	55	5.4	3.4	3.1	1650	550	Back Road intake	Homotropal
E	300	79	69	5.8	3.8	3.8	1200	520	Next panel intakes	Antitropal
F	480	54	37	5.3	2.9	2.9	3000	2780	Back Borehole (1.2m) intake	Homotropal
G	1300	70	48	5.2	3.2	3.2	2800	2475	Back Boreholes (0.6m & 0.8m) intake	Antitropal
H	1320	113	77	5.2	3.4	3.4	3050	1950	Back shaft (2.2m) return	Homotropal
I	300	70	43	4.8	3.3	3.2	1600	1300	Highwall LW panel; next panel intakes	Homotropal
J	1000	77	45	4.8	3.3	3.1	3000	2600	Back boreholes (0.6m & 0.5m) intake	Homotropal
K	930	79	45	5.0	3.0	3.0	3500	1200	Back boreholes (3 x 0.5m) intake	Homotropal
L	525	65	60	5.5	2.8	2.9	2800	2400	Back boreholes (2 x 0.7m) intake	Antitropal
M	650	73	50	5.2	2.6	2.2	2300	2100	Back boreholes (2 x 1.0m) intake	Homotropal
Average	**786**	**82**	**57**	**5.3**	**3.2**	**3.2**	**2491**			

Higher production in recent years with increased seam gas demands availability of more ventilation air for dilution in the LW panel. This has been achieved by a number of alternative strategies including

1. Use of back boreholes in most cases delivering down cast air for diluting the back road and tailgate ventilation,
2. The early cutting of development roadways in the next planned panel (adjacent to the current panel) and then use of these roadways to assist ventilation, as for three mines in Table 2.

A small number of mines find they have not needed to use back boreholes or air from the early development of next panel as they are working panels directly connected to a previously mined highwall and so do not need to ventilate a traditional mains. Australian mines before the mid 1990's generally passed intake air down the maingate to the face along both the transport and belt headings in an antitropal ventilation system. However depth, higher seam gases and higher temperatures mean that most mines now use homotropal maingate ventilation (with one heading carrying intake air and the other carrying return air) meaning that relatively less fresh air reaches the face. The conclusion is that over a relatively short period additional pathways for high quantities of intake air to reach the panel face have been required. The industry has had to by necessity use back boreholes or, on occasions where development is ahead, use the newly excavated roads to supply required of air.

Within Australia there is currently limited use of true bleeder ventilation due to the propensity of Australian coal to spontaneous combustion. True bleeders refer to the US style of ventilating gas at the back of a panel with a number of parallel return roads. To provide ventilated access to the current goaf seals some mines are boring raises behind the LW panels and using in a downcasting mode for intake to the LW face or upcasting mode providing return capabilities. These back boreholes can be utilised for other purposes during LW installation (e.g. concrete drop holes) or during emergency scenarios as another means of access to the working seam and/or surface.

CONCLUSIONS

From the case studies discussed it can be seen that there are several underlying themes that are common within Australian LW mines. At the same time, however, there are also some extreme variations of ventilation approaches utilised to facilitate management of severe ventilation issues. Each of the 30 operating LW mines in Australia manages some or all of a combination of issues including spontaneous combustion, total and respirable dust, heat and explosible and toxic gases. The increasing depth of operations exacerbates most of these issues. The utilisation of two headings in maingate development is by far the most common approach across the industry. This limits the number of different LW ventilation methods possible and hence most operations use a variation of the traditional U ventilation approach. This method is also utilised to assist with the minimisation of pressure differential induced across the current and previous goaf's for spontaneous combustion reasons. A small number of operations use a variation of the Z ventilation approach but only to facilitate the ventilation management of extreme quantities of gas in a seam with little or no potential for spontaneous combustion. The use of panel back boreholes and small diameter shafts has become very popular. This shift has occurred in parallel with a move to use of homotropal LW maingates. 11 of the LWs in Table 1 have maingate homotropal airflow and only three have antitropal flow. Homotropal maingates have many advantages but in general need boreholes or extra development roadways to allow sufficient air to reach the face. Boreholes assist with reducing mine resistances in some instances and allow the ventilation of blind headings subject to gas inundation and development breakthroughs.

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