MINE VENTILATION PLANNING OF BHP STEEL DIVISION COLLIERIES

by
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ABSTRACT

The design of mine ventilation systems for the BHP Steel Division Collieries is based on the acquisition of ventilation survey data for the establishment of a realistic computer network model. The branches which form the network for the computer models are calculated from a range of resistance factors incorporating both a frictional and shock loss component. Since shock losses can account for up to 30 per cent of the total energy losses in mine airways the use of friction factors alone without accounting for shock losses will result in the choosing of an insufficiently performing fan. Published tables of friction factors have invariably been taken from metalliferous or single entry studies and consequently are not reliable for Australia's mining conditions where multiple entries with regularly spaced cut-throughs are the normal practice.

Typical resistance factors for roadways of rectangular cross-section 5.5 m x 2.0 m, with coal sides, have been found to vary from 0.11 $Ns^2/m^8/km$ where no timber supports are used, to 0.98 $Ns^2/m^8/km$ where double centre legging together with wooden chocks is used. In addition to the range of resistance factors due to varying support methods, the nature of use for a roadway is very significant because of the condition of repair and upkeep maintained. Typically, the resistance factors for transport/travelling, belt and return roadways increase accordingly. Additional intake roadways not normally used for travelling are treated as returns in the choice of resistance factors due to their increased deterioration.

The values for these resistance factors can only be obtained from practical exercises and it has been through a series of mine ventilation surveys that a record of these resistance factors has been obtained which will allow future planning exercises to be undertaken with confidence.

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INTRODUCTION

The Broken Hill Proprietary Company Limited operates 14 collieries within the Steel Division. Many of these mines, centred in the Newcastle and Illawarra coalfields of New South Wales, are either expanding their operations with the introduction of longwall retreat mining or are developing at great distances beyond their existing primary ventilation source.

Detailed ventilation studies have been necessary to update the ventilation systems of these mines and to determine typical roadway resistance factors. Due to the method of working our coal, published values of friction factors are unreliable because of their tendency to relate to metalliferous or single entry conditions. These don't include the additional losses which occur at cut-through intersections (Singha, 1982). Studies by Edwards and Perlee (1977), have shown that losses occurring at splits and junctions are predominantly shock losses with loss factors as much as four times the velocity pressures. These shock losses are a significant contribution to the total losses along the mine airway system and can account for up to 30 per cent of all losses (Hartman, 1961). In order to include these losses in the ventilation planning of the collieries it was decided to use resistance factors calculated from mine ventilation surveys which incorporated the total pressure (energy) losses along multi-entry systems and across splits and junctions.

A library of resistance factors for various categories of roadways using different support methods is being established for network design on a digital computer. To date, six collieries have been recently surveyed to enable mine ventilation systems to be designed for the introduction of longwall mining.

VENTILATION PLANNING OF COLLIERIES

The design of a mine ventilation system for any of the BHP Steel Division Collieries is an on-going operation which continues from the original analysis of the proposed mine network to the completion of mining operations. This is important since the original analysis of mine systems relies on many intuitive decisions which must be confirmed as the mine network expands. The procedures described by Luxbacher and Ramani (1979) are used in the formation of a ventilation system. These are:

- data acquisition,
- system planning,
- design,
- construction and maintenance,
- monitoring, and
- evaluation and modification.

Each of these stages is necessary for establishing a complete mine ventilation system. It is noted that the reliability and degree of certainty claimed for any particular stage is dependent on the level of accuracy obtained in the previous phase of the ventilation planning, commencing with the acquisition of realistic data.

DATA ACQUISITION

The acquisition of accurate data is necessary for the ventilation design of a new or existing mine to be undertaken with confidence. For this reason all ventilation data is acquired from mine surveys and the expected geological conditions interpreted from borehole and seismic data.

Ventilation Surveys

Accurate predictions of roadway resistances for future ventilation planning of collieries is fundamental to the selection of mine fans, the correct location of shafts, and the numbers of roadways to be driven. Solution to ventilation problems rely on the choice of friction factors, shock losses, leakage quantities as well as the physical conditions likely to be encountered. Although these may all contribute some uncertainty to the problem of solving future mine ventilation requirements, the use of mine ventilation surveys will certainly reduce this error of judgement involved.

Mine ventilation surveys are being systematically conducted at all the collieries to establish an accurate record of the distribution of air, including face quantities, leakage losses, pressure losses and quality of the mine air. Apart from establishing a basic mine ventilation network for a colliery, the results are used to determine the effectiveness of individual branches of the network for the present and future ventilation of the mine and to determine the resistance factor for the various physical types of airways.

Mine surveys, as far as practically possible, have been conducted during periods of non-production and apart from the three week period over the Christmas/New Year shut-down, requires work to be done during a non-production shift where variations to the ventilation are minimal. Pressure surveys are carried out using 4 magnehelic guages with ranges 0 - 120 Pa, 0 - 500 Pa, 0 - 2 kPa and 0 - 5 kPa. The largest scale is only used for pressure readings across shaft bottom doors. Pressure losses over distances up to 300 metres are measured using a flexible reinforced nylon hose of 6 mm internal diameter. Total pressure differential measurements are taken across the tube continually throughout the airways of the mine commencing at the mine surface and traversing both intake and returns. Closures across stoppings are taken regularly at panels and main air junctions to form loops to allow survey balancing and the isolation of errors to be easily made.

Quantities are measured using vane anemometers incorporating automatic timing mechanisms attached to a 1 metre rod where air velocities exceed 0.2 m/s and by smoke tubes for flows less than this. Cross-sectional areas of roadways generally vary between 8 m^2 and 14 m^2 and are usually sectionalised between the rib sides and timber supports for measurement. At least three measurements of height and width are taken for each section.

Air densities are determined from readings of an aneroid barometer and a whirling hygrometer. Because of the relative shallow gradient of the seams at all collieries and low airway pressure losses the air densities vary greatest in the shafts than along the workings themselves.

Many of the mines on the South Coast have a horizontal entrance as much as 3.5 kilometres from the seam outcrop on the Illawarra escarpment, with ventilation shafts further west from the top of the escarpment itself. As a result the elevation and temperature can vary quite considerably between mine entrances. It is therefore important that Natural Ventilation pressures be determined and included during the computation of results so that the pressure-drops along mine roadways are correct. Generally only the main intake or return branches have a NVP value included in the final network analysis.

Geological Conditions

A good knowledge of the expected geological conditions to be encountered in proposed mining areas is fundamental for mine design and consequently for ventilation planning. The roof conditions and therefore methods of roof support can be proposed and together with a knowledge of the seam height over the mining area the choice of roadway resistance factors can be made. Figure 1 shows a typical plan from which seam conditions can be assessed for future mine development.

Roof support methods can vary greatly between mines and also between districts within a mine with a result that roadway resistance values may vary quite considerably. This is more pronounced in return airways where, due to roof problems and general deterioration of the roadways, it is not uncommon to have a myriad of timber props set haphazardly at intersections with a greatly increased resistance. Although it is impossible to predict such circumstances with much accuracy, a working knowledge of the mine's typical support methods and the roadway conditions after standing a number of years will avoid the underestimation of fan duties and the number of intake and return airways.

Due to the different depths and localities of the mines, the methane level can vary quite considerably from 50 m^3/tonne mined (Battino and Reagan, 1982) to less than 2 m/tonne mined. Projections of expected methane levels can be obtained from both borehole samples and workings in nearby collieries. In a few instances where workings are proceeding under large bodies of water it is also expected to anticipate a rise in methane level.

The nature of the immediate roof rock with respect to its caving properties is also taken into consideration as this can have a significant effect on the method of ventilation of sections in pillar extraction and whether or not bleeder

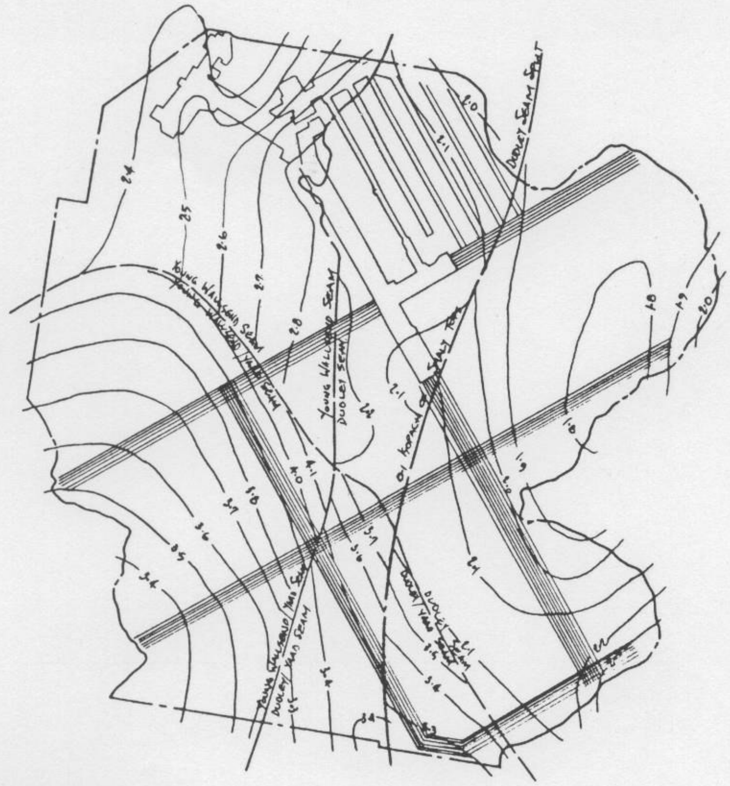

Fig. 1. Seam Thickness Isopachs, Macquarie Colliery

headings will be successful.

SYSTEM PLANNING

The quantity of mine air is dependent upon the proposed mining operations in conjunction with the effects of the geological conditions.

The mining plan will involve the following criteria which directly effect the ventilation:-

(a) The proposed methods of working and production levels;
(b) Methods of face ventilation; and
(c) The use of diesel equipment.

The methods involved in winning the coal have a major effect on dust and gas liberation into the roadways. From survey data where gas levels have been recorded in cubic metres per tonne mined, the projected methane levels can be obtained for future mining operations at a colliery or for a new mine which is adjacent to an existing colliery.

Longwall mining has increased the levels of methane in the return airways not only due to the increased production rate but also due to the large area of influence of the destressed region surrounding the goaf which can effect underlying seams causing a greater liberation of methane into the longwall goaf and returns.

Face Ventilation

The method of face ventilation and number of headings being ventilated has a significant effect on the resistance to airflow inbye the last line of cut-throughs. A system of brattice ventilation is many times more restrictive than an auxiliary fan ventilation system because the fan itself overcomes all face and blind heading resistance and the last cut-through is usually left open for the excess air quantity to pass. Generally, the panel quantities can vary between 13 m^3/s to 25 m^3/s depending on the conditions that are predicted for the panels. A minimum of 13.0 m^3/s is set for the operation of a standard centrifugal auxiliary fan used at most collieries. Figure 2 shows the performance curves of auxiliare fans used at the Steel Division Collieries.

Diesel Equipment

The use of diesel transport vehicles, locomotives and LHD machines is increasing and although good ventilation will normally more than adequately satisfy the conditions for operating the machines, there may be areas within a mine due to multiple inlets or splitting of air, where the ventilation may not be adequate without altering parts of the mine ventilation by

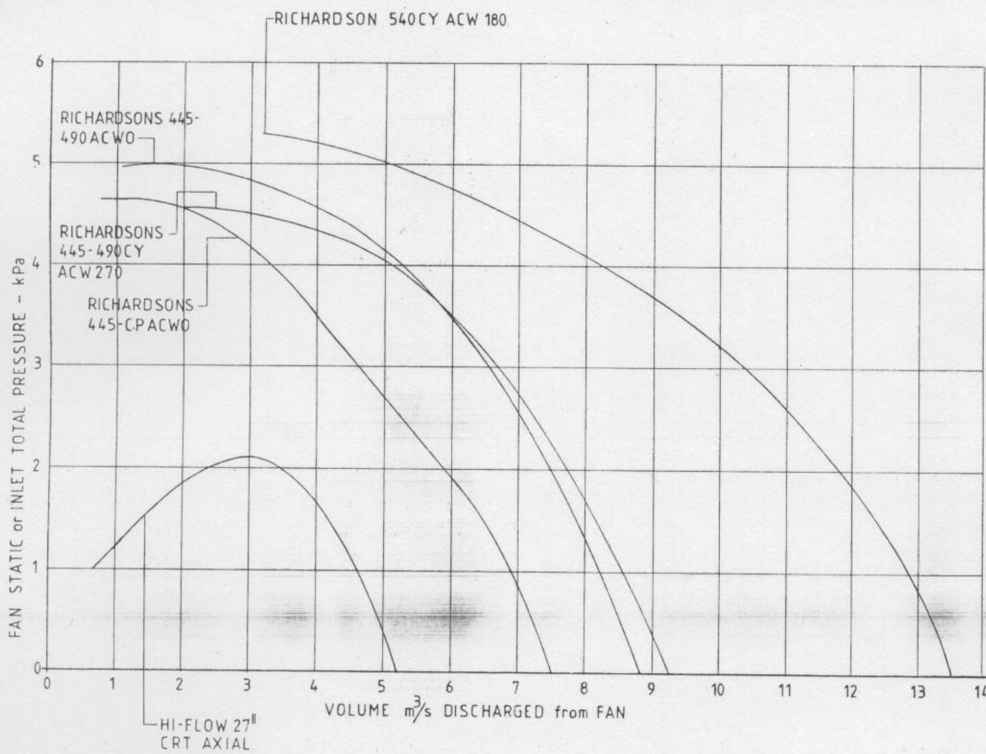

Fig. 2 Pressure/Quantity Curves for Auxiliary Fans Used at B.H.P. Steel Division Collieries

regulation. It is important that the consequences of such action be known on the rest of the mine system. Table 1 lists the types of diesel equipment used at the collieries and ventilation quantities required.

In main travelling roads up to six diesel man cars can be operating at the one time travelling in series to or from the mine faces. The concentration of exhaust fumes and their dissipation is therefore important along these roads.

TABLE 1
DIESEL EQUIPMENT AT
BHP STEEL DIVISION COLLIERIES

Equipment	Engine	Maximum Power (kW)	Ventilation Requirement m^3/s	m^3/s per kW
Minesmobile (2WD)	Perkins 4-212	36.6 (derated)	3.54	0.097
Minesmobile (2WD)	4-236	40.3	3.6	0.089
Minesmobile (4WD)	Perkins 4-248	56	3.6	0.064
Horwood-Bagshaw LHD	Caterpillar 3304 NA	75	4.13	0.055
Eimco 912 LHD	MWM D916-6	74	4.13	0.056
Bulk Stone Duster	Perkins 4-212	38	3.6	0.095
Mine Personnel Car	Perkins 4-248	44	3.6	0.082
Mine Personnel Car	4-236	40.3	3.6	0.089
Mine Personnel Car	4-212	36.6	3.54	0.097
Mine Personnel Car	MWM 916-4	48	4.2	0.087
Mine Personnel Car	Toyota Heino 700	45	4.20	0.093
Malcolm Moore 25 t loco	Gardiner L3/8	135 (derated)	8.5	0.063
Baldwin 40 t loco DH-40-MB	Caterpillar 3406 PCTD	280	10.85	0.039
Fox 30,000 lb loco	Caterpillar D333	112	7.10	0.063

Air velocity as well as quantity must be sufficient to allow diffusion of the exhaust contaminants and their dilution to accepted levels. In New South Wales collieries the maximum accepted level for diesel exhaust pollutents after conditioning is 0.0005% CO and 0.0005% combined oxides of nitrogen.

DESIGN OF VENTILATION SYSTEM

Ventilation survey data is used for determining the resistance of each branch of the network of the mine and also for calculating the typical resistance factors for the various types of roadways. During the survey the total pressure differences are measured to give the true energy losses throughout the mine system incorporating both frictional and shock losses. By reading the total pressure an absolute pressure drop is always read in the direction of the air flow despite changes in air velocity which do effect the static head, especially where abrupt area changes occur. A frictional co-efficient for an airway can be obtained by removing the velocity pressure component, however, it is considered that the true resistance loss due to both friction and shock incorporated in an airway resistance factor, is easier to use. The total pressure loss values used for determining a typical resistance factor over a length of roadway, or parallel roadways, include losses due to bends, cut-throughs, intersections, general expansion or retraction within roadways, splits, junctions and those of permanent obstructions such as belt conveyors. The resistance factor from a survey is given by:-

$$R = \frac{P}{Q^2} \quad (Ns^2/m^8) \qquad (1)$$

where p = pressure loss over a section of roadway

Q = average air quantity over the section

For multiple roadways the resistance factor for any individual roadway is:-

$$Ri = R \left(\frac{Q}{Qi}\right)^2 \qquad (2)$$

These resistance factors relate to a roadway of particular physical dimensions and therefore to equate these resistance factors found from surveys for similar types of roadways for averaging, a standard size and length of rectangular roadway is adopted. This is taken as 5.5 metres in width, 2.0 metres in height and a length of 1,000 metres. For future planning of mine ventilation networks, roadways of rectangular cross section which differ to these standard dimensions are calculated from the relationship.

$$R = R_s \times \left(\frac{A_s}{A}\right)^{2.5} \times L/1000 \quad (Ns/m^8) \qquad (3)$$

where R_s & A_s = standard values for the resistance factor and roadway area respectively

L = roadway length

A number of standard resistance factors for the different types of roadway for each colliery has been established. These generally include, transport headings, belt headings, additional intake headings not normally used for travelling, return headings, continuous miner face areas and longwall faces. These again are then differentiated into the different types of support methods used.

Table 2 lists the average resistance values for various types of roadways and supports.

The proposed mine layout is transferred to a ventilation network on an in-house digital computer using the standard resistance factors modified for the actual roadway dimensions. Where parallel roadways exist, this section of airways is represented by a single branch in the network, the resultant resistance calculated from

TABLE 2

RESISTANCE FACTORS IN Ns^2/m^8/km FOR IN SEAM ROADWAYS
AT BHP STEEL DIVISION COLLIERIES - AIR DENSITY IS 1.2 kg/m^3

	ROADWAY SUPPORT METHODS								
Type of Roadway *	W Straps No Props	W Straps With Legs at 1 m Centres	Bars, Props, Straps at 1m Centres	Bars, Props, Straps and one Centre Leg	Bars, Props, Straps and two Centre Legs	Bars, Props, Straps, Centre Legs & Chocks	Face Brattice Vent	Face Auxiliary Vent	Longwall -Face Chock Shield Support Ns^2/m^8 Per 100 m
Track/Transport	0.115	0.190	0.268	-	-	-	0.30	0.05	0.092
Belt	0.177	0.223	0.328	0.426	0.528	-			
Combined Track and Belt	-	0.240	0.285	-	-	-			
Non Service Intake	0.125	0.223	0.320	0.389	0.637	0.980			
Return	0.125	0.223	0.320	0.389	0.637	0.980			

* Roadways are of dimensions 5.5 m wide x 2.0 m high

the relation:-

$$R = 1/ \left(\frac{1}{\sqrt{R_1}} + \frac{1}{\sqrt{R_2}} + \ldots + \frac{1}{\sqrt{R_n}}\right)^2 \qquad (4)$$

where $R_1, \ldots, R_n$ = resistance values for each of the n branches in the parallel section

Because resistance factors are used rather than friction factors, allowance has already been included for losses due to splitting and merging of the parallel branches. Sections of roadways which require special attention are those parts of return airways at overcasts. These are invariably high friction and shock loss areas and resistance values which are greater than the typical return airway value are used for these areas. Generally it has been found that the total pressure (energy) losses across overcasts are from 1.7 to 2.0 - the losses occurred along equivalent lengths of return airways.

Leakage losses are fundamental to the mine network design and typical resistance factors for stoppings and overcasts are found from mine ventilation surveys. Leakage co-efficients have been found to vary from mine to mine even when the same stopping material is used. A number of factors contribute to this variation including method of construction, competence of the brick layer, floor and roof conditions, roadway pressure and age of stopping. Resistance factors for brick and mortar stoppings have been found to vary from 2,600 Ns^2/m^8 to 7,100 Ns^2/m^8, but generally for each mine they are within a narrow range. Although separate values have been obtained for overcasts, a leakage co-efficient of 2.5 times that of a stopping is the average.

Final determination of the number of roadways to be driven is affected by the performance of an existing fan, rate of development to be maintained, maximum number of main headings desired, maximum air velocity to be tolerated or allowed by regulations, possible locations of future shafts and an economic assessment of energy losses in the roadways. A ventilation network design typical of those used for the collieries is shown in Figure 3.

CONSTRUCTION AND MAINTENANCE

This is outside the basic planning of the ventilation system, however it is a vital contribution to the retention of satisfactory ventilation standards throughout the mine. The use of suitable materials for stoppings and overcasts has a major effect on the efficiency of the mine ventilation system and awareness is placed on mine management on the constraints and shortcoming of certain material for ventilation structures.

MONITORING AND EVALUATION

Once the mine ventilation system has been adopted for a proposed mine development a feedback of information is obtained as the mine workings expand. This information is used to remodel and update the computer network as required, and also for comparison with the originally proposed ventilation figures, especially for short term planning. Information which is gathered from the collieries on the present state of the ventilation includes the following:-

i) fan operating duty;
ii) blade angle or VIV setting on fan;
iii) motor power or current;
iv) air quantities in major splits and at working faces;
v) location, area and air quantities at regulators;
vi) any alterations or proposed alterations to the underground ventilation system; and
vii) change in seam or roadway conditions.

Certain changes to the original mine ventilation design are unavoidable such as unpredicted geological conditions for which re-evaluation of the network is required. Such re-assessment may involve the revision of proposed fan duties and shaft locations. The complete ventilation system design process is similar to many which are now being practiced and is shown in Figure 4 (Luxbacher & Ramani, 1979) (Robinson et. al., 1982).

CONCLUSIONS

The adoption of resistance factors from mine ventilation surveys has enabled mine ventilation networks to be within a good order of accuracy for short term mine planning. Because of this ability to get a closer prediction to future ventilation quantities throughout a mine, mine management has been able to plan and alter where necessary, the ventilation of a mine with a greater assuredness of the results. However, since mine workings and ventilation are never steady, it is necessary to continually re-work the proposed mine ventilation system using updated information, otherwise unnecessary constraints may be placed on future mining capacities due to previously short-sighted or unmonitored decisions.

A fine inter-relationship exists between all phases of mine planning and design and a ventilation system design. This has been obtained within the Company and good mine ventilation is the result of this practice.

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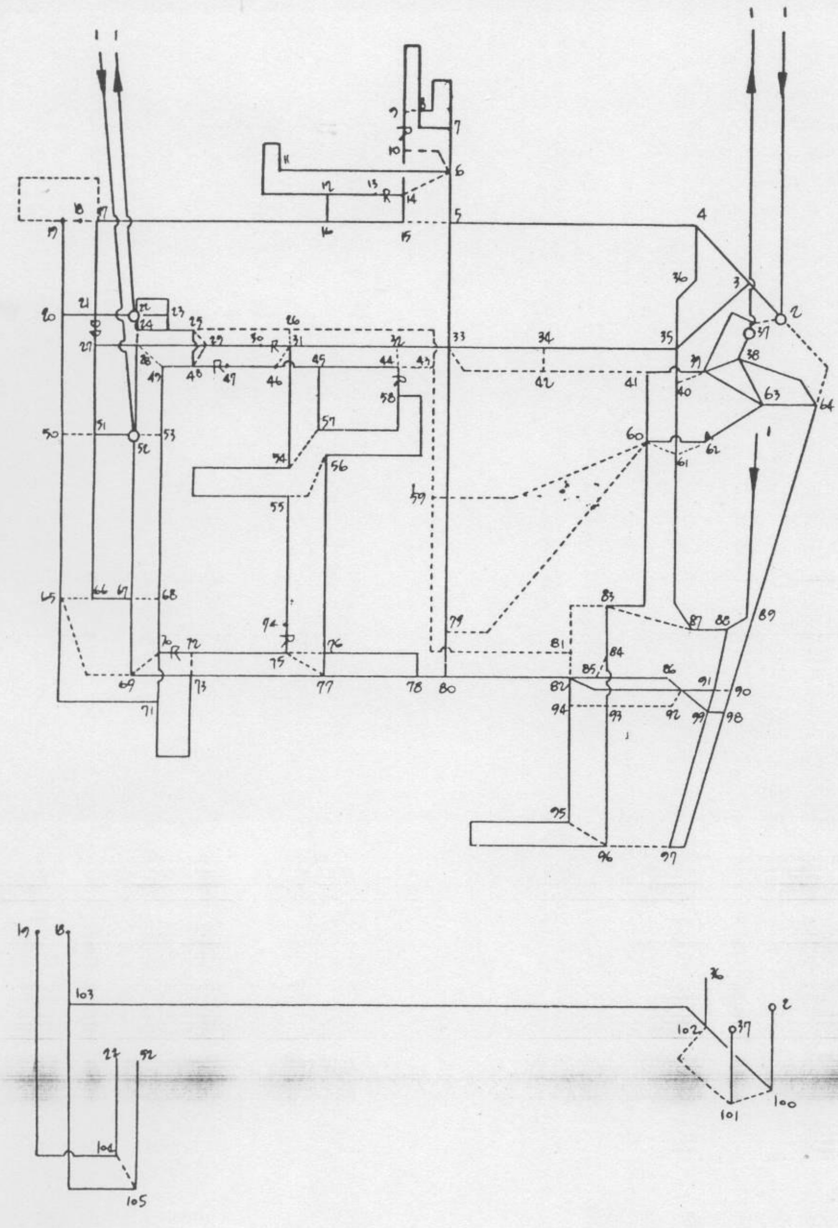

Fig. 3. Ventilation Network Stockton Borehole Colliery

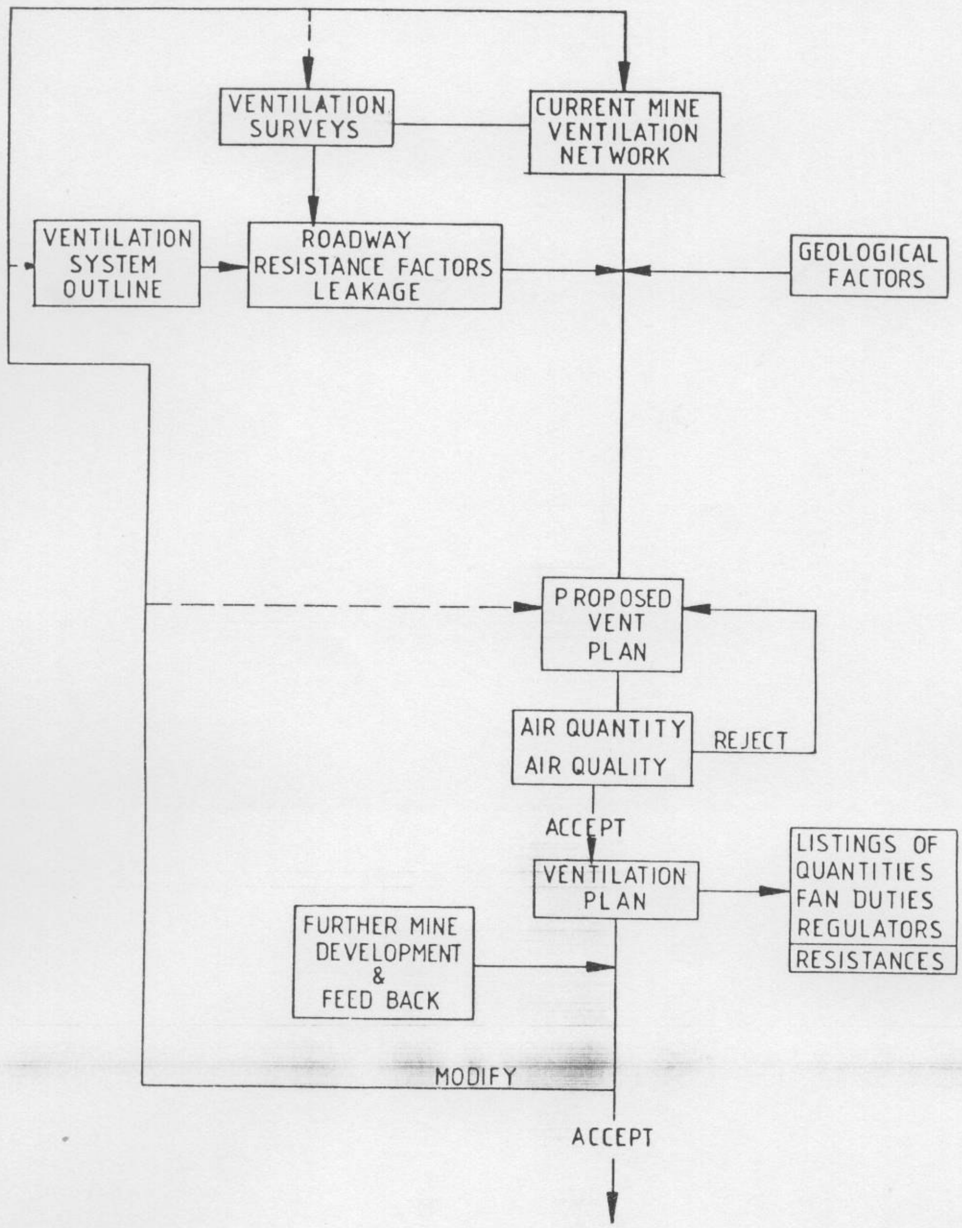

Fig. 4. Ventilation Planning Procedure

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DISCUSSION

O. KREILIS (Southern Engineering Services): How are eddy-currents and that sort of thing determined when purlins and the sort of roadway support shown is in use? How accurately are the allowances made for the eddy-currents that must occur with, say the purlins used instead of balks. The purlin must have a tendency to create eddy-currents in the system.

P. MITCHELL (BHP Steel Division Collieries): Well certainly, the use of steel sections or timber half rounds has an effect on the flow of air through the roadways and that is shown in the figures in Table 2 of the paper. Roadways which have flat W straps bolted to the roof are much less resistant to air flow than the roadways which have steels or half rounds bolted to the roof or set to the roof. Roof bars certainly cause a higher frictional resistance to the roadways along the roof and, referring to those figures, it can be seen to be at least twice as much resistance. As far as eddy-currents go - these aren't measured independently.

O. KREILIS: It seems that there should be ways of looking into the programme where any difference between balks or roof bolts or W straps could be allowed for by a factor, for instance where most of a roadway is done with W straps, the k factor, or whatever variable, is a certain figure.

P. MITCHELL: To overcome this the roadway is divided up into a number of branches and each branch would simulate the various typical kinds of roof support.

B. HAM (MIM Holdings Ltd): In the ventilation simulation an accuracy of about 5% was stated. This seems to be remarkably good. What sort of accuracy is obtained in measuring the volumes in the ventilation surveys?

P. MITCHELL: Certainly when undertaking surveys using anemometers etc., it is probably lucky to get between 5% - 10% accuracy with those types of instruments. When it is said that the simulation is within 5%, it is within 5% of the measured survey, which may not be within 5% of what truly might be going through the mine. This possibly wouldn't be known anyway. The 5% accuracy is predominantly for the main ventilation branches. Certainly some leakage branches and flows through old or goaf workings possibly wouldn't be within that 5%. Leakage branches are not always within 5% because it is not possible to have leakage branches for each stopping. A number of stoppings are usually combined to make one branch for leakage.

S. GILLIES (University of Queensland): The paper made mention of airflow along parallel entries and the importance of shock losses where cross cuts are found every 50 or 100 metres. Can this statement be expanded?

P. MITCHELL: When the ventilation networks were originally set up on the computer, surveys had been done at most mines but these were 10 years old, and to bring the ventilation system up to date to what the current workings were it was initially attempted to use resistance values obtained from those surveys. These values were compared with published tables on friction factors, especially those done by McElroy (1935) which were based on metalliferous workings or workings which didn't reflect the multi-entry system in use today where there are cut-through intersections every 50 - 100 metres. At each intersection the air expands as it flows out into the cut-through and suddenly contracts again into the heading. At each such intersection shock losses occur in the overall pressure loss throughout the mine. Imagine mines which have quite a few cut-through intersections along their roadways. Each of these will contribute a bit extra to the pressure loss throughout the mine system and all published data didn't seem to reflect this, it's only recently that work has been done on the additional losses involved in cut-through intersections. The survey method using a total pressure drop along the roadways will correctly indicate not only friction losses but shock losses as well. Shock losses will occur in multi-entry systems even when for example, there is a reduction from three to two headings which is quite a common practice. The colliery suddenly drops one heading and wonders why the air quantity reduces sooner than expected. Total pressure losses certainly reflect all these types of energy losses in the system.

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