Ventilation Optimization – Balancing the Need for More Power Against Environmental Concerns

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ABSTRACT

This paper shows how the Nanisivik mine was able to improve the underground working environment, decrease operational costs, and reduce its impact on the environment through optimizing their ventilation system. Through re-organizing their ventilation system, the overall flow through the mine increased by at least 20%, and local flows increased by over 100%. This change also resulted in a 45% reduction of fan motor power. And as a consequence of reduced power demands the mine has decreased its Green-house gas (GHG) emissions. Currently, ventilation is typically responsible for 40% of a Canadian mine's underground electrical consumption. This could dramatically change as the relationship between air supplied by fans and the power consumed is a cubic. Nanisivik is just one example of how the Canadian mining industry is striving to remain competitive under the general pressures to supply more or better quality ventilation for the workforce but on the other hand reduce power consumption.

KEYWORDS

Mine ventilation, ventilation surveys, tracer gas, ventilation network simulation, ventilation design, diesel exhaust exposure, blast clearance, GHG emissions, natural ventilation

INTRODUCTION

There are ever increasing pressures on the mining industry to provide improved health and safety for its workforce, to be environmentally conscious and yet be cost effective. CANMET believes that one aspect of the mining process that can address all three concerns is the efficient supply of ventilation. As a result of this, the Canadian government in partnership with industry, continues to put considerable resources into the optimization and automation on mine ventilation systems. An introduction of some of the more topical considerations follows.

Ventilation and Health & Safety.

The primary function of a mine ventilation system is to supply oxygen and to dilute and/or remove pollutants so providing a suitable working environment for the underground workforce. In the majority of Canadian mines, the use of diesel-powered equipment is the most demanding factor controlling ventilation. Considerable volumes of air are required to dilute diesel engine's exhaust down to safe levels and maintain the air's oxygen content.

Today, a major concern for the industry is the exposure of their workforce to diesel particulate matter (DPM), which is a potential carcinogen, and its increasingly more stringent regulations. Currently, according to most provincial codes, in Canadian non-coal mines, the recommended 8-hr time weighted average (TWA) limit for respirable combustible dust (RCD) is 1.5 mg of dust per m^3 of air.

In the near future this exposure level could be dramatically reduced as a result of the American Conference of Government Industrial Hygienists (ACGIH) recommendation of a 0.15mg/m^3 threshold limit value (TLV) for DPM (ACGIH, 1997).

There are four ways to control the production of, or exposure to, DPM in underground mines:

- Reduce DPM production through the use of new cleaner engines, improved fuels and good maintenance.
- Entrapment of DPM with the use of exhaust filters.
- Isolation of the equipment operators from DPM either in a micro-climate such as a machine's cab with a filtered air supply, or by virtue of the direction of airflow.
- Dilution of the DPM with additional ventilation.

Within these, reduction, entrapment of DPM, or worker isolation can have significant impact on the volume of air required to provide a suitable working climate as a result of using diesel equipment. The subject of DPM control in Canada is currently being address through a consortium of industry, trade unions, equipment manufacturer's and government agencies in the Diesel Emissions Evaluation Program, (DEEP, 1997).

Cost Effective Ventilation

Typically 40% of an underground mine's electrical usage is consumed by the motors of fans required to mechanically induce ventilation through the mines (Udd *etal.*, 1996) (Gangal & Pathak, 1992). In addition to this, additional energy can be required to either heat or cool the air to provide a suitable working climate. Together, these two energy demanding processes result in the provision of suitable ventilation being expensive. Furthermore, due to the cubic relationship between the ventilation volume and the power, or cost, needed to provide it, increasing the volume can substantially increase the cost.

Therefore it is imperative for mines to provide ventilation in an efficient manner to minimize both the cost of operating the system, and the magnitude of any heating or cooling. This is especially important in the near future, otherwise, the need for more ventilation to dilute such pollutants as DPM could make mines uneconomic.

For a ventilation system to be its most efficient, mine operators must ensure that the air it supplies is performing the maximum amount of work possible to dilute and remove pollutants and that the air is not unnecessarily wasted without performing any work. It is for this reason that the "Ventilation-on-demand" principle and ventilation optimization and automation continue to be proposed to the industry (Hardcastle, *etal*, 1998).

Environmentally Conscious Ventilation

As a consumer of energy, the Canadian mining industry is also responsible for the generation of "Greenhouse" gas (GHG) emissions. This is an area of increasing environmental concern due to the depletion of the earth's ozone layer and consequential climatic change. The Canadian government's position at the Third Conference of Parties on Climate Change, Kyoto, Japan, 1997 was to reduce GHG emissions to 3% below 1990 levels by 2010 and a further 5% by 2015.

According to "Canada's Energy Outlook 1996-2020" (NRCAN, 1998) and subsequent analysis (Hardcastle *etal*, 1998), assuming "business as usual" the mining industry's demand for energy will increase at an annual rate of 2.4%. This predicted rate of increase is greater than both those of the industrial sector, and the overall national demand. As a consequence of this increased energy demand, the industry's contribution to GHG emissions is also predicted to increase annually by between 1.6% and 3.3%. Whereas the national average annual growth rate is only 1%.

If the mining industry is to contribute its fair share of the reductions put forward at Kyoto, it would have to reduce its future predicted 2015 emissions by between 40 and 64%, or its measured 1995 emissions by 30-45%. This can only be achieved through a comparable reduction of energy demand, within which ventilation is a major factor.

NANISIVIK MINE

Breakwater Resources' Nanisivik Mine is one example of the many mines that CANMET has assisted with its ventilation. Through a ventilation optimization and redesign process, as will be subsequently shown, this mine has successfully improved the magnitude of its ventilation and the efficiency with which it is delivered. This has resulted in a better working environment for the underground workforce and a system with fewer fans that is cheaper to operate.

Nanisivik mine is the second most northerly mine in Canada after Cominco's Polaris operation. It is situated at the northern end of Baffin Island just above the 72nd parallel. It is a 2200 tpd producer of zinc/lead/silver ore from horizontal mineralizations in a mountain that can be accessed laterally through portals. All the ore handling within the mine is by diesel equipment. The ore is processed into a concentrate and stockpiled on-site. It is then transported by sea during a short shipping season.

At this northern location, the mine is responsible for its own electrical generation, which can be costly, and the supply is also limited by the size of the on-site diesel generators.

Nanisivik's Ventilation System

Figure 1 shows a generalized schematic of the mine's ventilation system when it was evaluated in August 1995. It should be noted that there are imbalances between the airflows shown within the mine, this is due to some minor branches being omitted for clarity and measurements being taken on different days.

An intake volume of 123m^3/s (260 kcfm) enters the mine through the narrow 17N portal. It is induced into the main ore zone by four parallel configured Joy 2000 Axivane fans, Model #60-26-1170 fitted with 75 hp motors. This air passes the main compressor room prior to entry into the large open main ore zone.

The intake flow in the main ore zone splits into two primary flows, 33 m^3/s (70 kcfm) to the west and 94 m^3/s (200kcfm) to the east. The smaller west flow predominantly passes through a narrow drift that crosses through a dyke. Beyond the dyke the air enters the main service area of the mine which contains the powder and cap magazines, maintenance shop, lube-station, parking areas and crusher feed. From this area, air is free to exit the mine by one of the several portals, 01, 02, 09 or SZ, or under the mechanical influence of a fan servicing the conveyor gallery. The larger east flow was gradually reduced by secondary fan systems that were used to induce flow into the lower ore zone. These include 19 m^3/s (40 kcfm) to the 24-66 raise manway, and 38-40 m^3/s (80-85 kcfm) to both of the 27-70 and 32-77 ventilation raises. The flow in the 27-70 ventilation raise was induced by a single Joy 2000 Axivane fan, model #60-26-1170 fitted with a 75hp motor, identical to the main intake. And the flows in the 24-66 raise manway and the 32-77 ventilation raise were induced by single Joy 1000 Axivane fans, model # 54-26-1770, fitted with 125hp motors. The remaining east flow could exit the mine freely through 39N portal or under the mechanical influence of a fan installation in the Shale Hill zone.

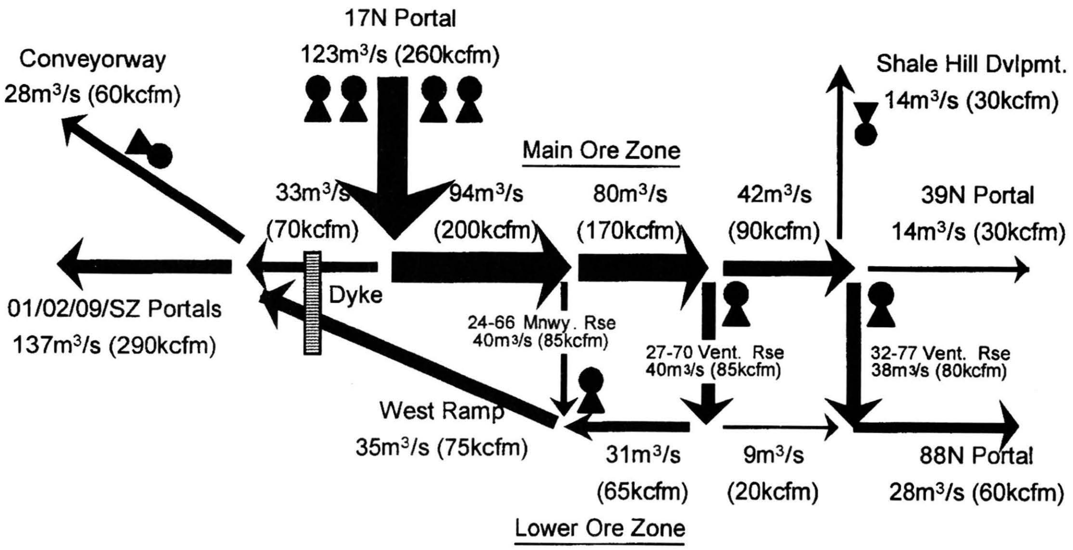

Figure 1. Generalized schematic of airflow distribution at Nanisivik Mine (August, 1995.)

In the lower ore zone, after being induced by one of the three fans, the air would again travel either to the west or east. Air traveling to the west in the lower ore zone, 35 m^3/s (75 kcfm), ascends back to the main ore predominantly via a ramp through the dyke to the main service area and exit along with the west flow of the main ore zone. Air passing to the east in the lower ore zone has two main options: to remain on that level and exhaust through the 88 portal or ascend via a ramp back to the main ore zone again to leave the mine with the flow through that region. This latter option was normally regulated with a ventilation brattice.

Within the primary ventilation, the summated fan motor sizes for the four intake fans and the three raise fans were 410 kW (550 hp). Although this value might seem small in comparison to other mining operations, it is significant at this operation due to its necessity to generate the power required to drive these fans.

Ventilation Concerns

When CANMET were approached to re-design the mine's ventilation system there were ten concerns.

Insufficient Total Volume Due to the general layout of the ventilation system which resulted in the total flow being split into four major secondary flows, east and west through both the main and lower ore zones, it was felt that the total volume might be insufficient.

Inadequate Blast Clearance Times Due to the size of the openings in the main ore zone, 10-20 m high by up to 120 m wide, the lateral air velocities were very low. This combined with the 3.6km length of the orebody, resulted in very slow blast fume clearance times and consequently long re-entry times to resume production.

"Dead-Zones" As a consequence of having to use secondary fans to induce airflow into the lower ore zone, stagnant areas were created between their discharges. This was evident between the 27-70 and 32-77 ventilation raises as shown in Figure 1.

Impact of a Compressor Room Fire As the main compressor room was situated in the mine's only fresh air route, a fire had the potential to contaminate the whole mine.

Seasonal Variations of Natural Ventilation There were distinct seasonal differences in the mine's ability to ventilate the lower ore zone, and the volume leaving the mine from the lower zone 88 portal. These were a result of changes in the air density between surface and inside the mine that created different air buoyancy regimes. Typically the air temperature in the mine was a constant –12°C irrespective of the season. However outside the ambient temperate ranged from -40°C in winter to +15°C in summer.

Wind Effects It was also believed that winds blowing into the portals at either the east or west end of the mine could suppress the flow out of the portals.

Double Handling of the Air by Fans In what appeared to be a very low resistance system, there was a question as to why large secondary fans were necessary in the raises to induce flow into the lower level.

Uncontrolled Recirculation As a consequence of using secondary fans, the mine introduced the potential for uncontrolled recirculation of air back from the lower ore zone to the main mining horizon via the east ramp. This resulted in some of the mine's air passing through the secondary fans more than once.

Electrical Power Due to the mine's location and its need to generate its own electricity, the mine was limited in regard to increasing the size or number of fans operating in the system.

Thawing of Strata The mine was also concerned in respect to their ground thawing during the summer due to the introduction of warm air. This would always be a concern at the air's point of entry to the mine and could require special ground support. However, of more importance would be the location of the thawing in respect to the mining operations and potential safety concerns of ice formations on the mine floor.

VENTILATION SURVEY

Nanisivik mine contracted CANMET to perform a barometric/tracer gas pressure-volume survey in August 1995.

A tracer gas based volumetric survey using sulphur hexafluoride, SF_6, unique to CANMET, was used to accurately determine the airflow in the major branches of the ventilation network. This method, where suitable, is based upon simple dilution principles and is superior to conventional anemometry as it can determine the volumetric airflow within ±5%. In comparison, anemometry has been shown to over-estimate the average air velocity in an airway by up to 20% (Hardcastle *etal*, 1991), and this relative error can be increased when combined with the determination of an airway's cross-sectional error. The level of accuracy offered by a tracer gas method is essential in determining the resistance of "critical" airways that determine the overall flow through a mine when a mine is being re-designed. This is because the relative error in the quantity determination is doubled due the square term in the "Airflow Square" Law, equation 1:

$$\text{Pressure} = \text{Resistance} \times \text{Quantity}^2 \qquad (1)$$

The tracer gas methodology is also ideal for measuring the airflow through inaccessible or problematic airways such raises, shafts and fans, or those with irregular flow regimes. This is because the method is purely based upon dilution, and as long as a sufficient distance and time are employed for the gas to reach an equilibrium condition with the host airflow between the gas's release and sampling points, the air quantity will be the natural result. The method is also advantageous over anemometry in that the dilution measurement is performed directly in a raise or shaft without the summation of contributory flows. The sampling can also be performed remotely in that it is not always necessary to collect a tracer gas/air sample within the airway but at a convenient discharge point. However it should be noted that this airflow measurement method is not suited to routine applications. This is due to the requirement for laboratory based gas chromatographic equipment to perform the gas analysis.

CANMET also prefers to use high accuracy digital barometers over manometers to determine frictional pressure losses or fan pressure inputs. These units can be more flexible than the conventional "gauge-and-tube" survey due to its need to use a long tube for a measurable frictional loss. However the barometric method does require the reduction of the measurements with elevation information and psychrometric (temperature) data.

Survey Results

Airway Data Because of the open nature of the mine, especially in the main ore zone, the multiple airpaths and low air velocities, the amount of useful data that could be collected was limited. This was despite the most accurate instrumentation available being used. Overall, the survey found that there were only a few airways that had a measurable flow and/or frictional pressure drop. (Note: there must be both a measurable frictional pressure drop and airflow in order to use Equation 1 to determine the airway resistance).

The survey was successful in identifying the resistance of the following "critical" airways that dictated the overall flow characteristics of the original ventilation system:

- The 17N portal containing the intake fans.
- The Shale Hill system with its independent exhaust fan system.
- The interconnecting raises, 24-66, 27-70 and 32-77 and their associated fans.
- The west ramp between the lower and main ore zones.
- The conveyor gallery and its independent exhaust.
- The 88N portal exhaust route from the lower ore zone.

Apart from these, the remainder of the mine openings in both the main and lower ore zones exhibited virtually no resistance to airflow because of their dimensions. However, it should be noted that the openings in the main ore zone were significantly larger than those in the lower ore zone. Therefore, although not measurable, the lower ore zone would have a higher resistance than the main ore zone. This would result in the airflow preferentially flowing through the main ore zone if it was not forced to do otherwise by fans and regulation.

Fan Data. Although the survey was generally successful in determining the volumetric delivery through each fan system, it could not determine directly the associated operating pressure of all the fans. An indication of this pressure could be derived from the fan manufacturer's characteristic curves. However, the survey was successful in determining the useful pressure supplied by the fans to the system after shock losses.

Generally it was found that all the fan systems suffered from significant shock losses that in some instances were several magnitudes greater than the useful pressure they supplied. In the main intake, 17N portal, the losses were the result of a bend immediately after the fans, and rapid changes in cross-section that resulted from an additional slash taken from the wall to accommodate a fourth fan. In the two ventilation raises between the main and the lower ore zones, 27-70 and 32-77, the fans incurred losses as they freely discharged into the much larger cross-sectional area raise. In the 24-66 raise/manway, the fan predominately worked against the resistance of a length of auxiliary ducting used to take the air to a specific location in the lower ore zone.

System Simulation. A ventilation simulation network was created with 3D-CANVENT (Hardcastle, 1995). This used the field derived resistance information for the critical branches, and theoretically derived values for the remainder. These were calculated from mine supplied dimensional data and a typical K factor for clean unlined airways in hard rock.

Fan pressure-quantity operating curves were derived from the manufacturer curves and mine supplied blade angle. The system resistance of the fan installations was derived from the difference in theoretical pressure and measured useful pressure for the surveyed quantities.

Once a basic model was established that replicated how the original ventilation system performed, the process of redesigning the system could start.

VENTILATION REDESIGN

From discussions with the mine's engineering staff, it was thought that the intake volume was not unreasonable in regard to the total diesel powered fleet operating in the mine at any specific time if it could be used efficiently.

The total potential size of the diesel fleet, some 41 vehicles, was 5,750 kW (7700 hp) with a total ventilation requirement of 345 m^3/s (731 kcfm) according to local statutes, however the average operating time of this equipment is only 37% of the 18 hr operational period each day. Within this inventory the 16 heavy-duty vehicles (>112 kW (150 hp)), of scooptrams, loaders, haul trucks and a water truck, had a combined engine size of 3,530 kW (4730 hp). These require 212 m^3/s (448 kcfm) and their average operating time is 9.3 hrs/day. The remaining 25 light duty vehicles had an average operating time of 5.0 hrs/day. However, the option for more air is always attractive.

Of more concern was the mine's inability to direct this air to the required locations and that it failed to satisfactorily flush the mine of pollutants in a timely manner. The primary cause of this problem was that the mine lost control of its intake air once it discharged from the 17N portal. Beyond this point, the air was free to split and travel unregulated to either the east or the west in the larger cross-sectional area main orebody. This resulted in the mine being unable to employ all the intake volume at the desired locations.

Although the mine was successful in inducing a major part of the intake flow into the lower ore zone, once there it again had little control over dictating where it went without the use of a significant number of auxiliary systems. This solution was not viable due to power supply restrictions. Therefore, similar to the main ore zone, the air in this lower ore zone was free to find a route to either the east or west to exit the mine.

This natural splitting of the intake flow into four resulted in a typical average flow of 34 m^3/s (71 kcfm), at the east and west ends of the main and lower ore zones. However within this regime, as shown in Figure 1; i) the flow in the main ore zone immediately east of 17N was significantly higher at 94 m^3/s (200 kcfm), and ii) the flow in the l lower ore zone between the two ventilation raises was substantially lower at 9 m^3/s (20 kcfm).

To improve conditions the mine considered two primary options. Firstly to maintain the exiting infrastructure layout but increase the overall flow. Or second to totally overhaul the system.

Option 1 – Same Layout with Larger Fans

The fans in 17N could produce more air with larger motors. However the question was "Would this be practical?" in light of the following:

- This entry route to the main ore zone had the highest resistance of all the portals, either intake or exhaust. Therefore the fans would have to work harder for less volume at this location.
- This location incurred significant shock losses of the generated fan pressure that could not be easily eliminated again resulting in a loss of potential volume.
- There was still the concern of the impact of a fire in the compressor room.
- Any gain in intake flow would be subdivided between the four splits.
- Due to power restrictions, an increase in demand by these fans would reduce the number of fans for secondary and auxiliary distribution.

It was because of these factors that the redesign quickly moved on to a total overhaul of the system.

Option 2 – New Layout with Same Fans

Once the decision had been made to move the intake fans, the next question was "Where?" The obvious answer was to create a "through" ventilation system with the fans at either the western or eastern extremity of the mine. The benefits of this concept were immediately obvious, as with the appropriate control of flow between the ore zones, the flow would only have two natural splits.

Exploratory simulations with the fans at the eastern end of the mine tended to indicate that two fan installations would be required, one serving each of the main and lower ore zones. This potential solution also had some practical disadvantages in that electrical cabling in excess of 2km would have to be installed. These two factors made installation of the fans at the eastern end of the mine

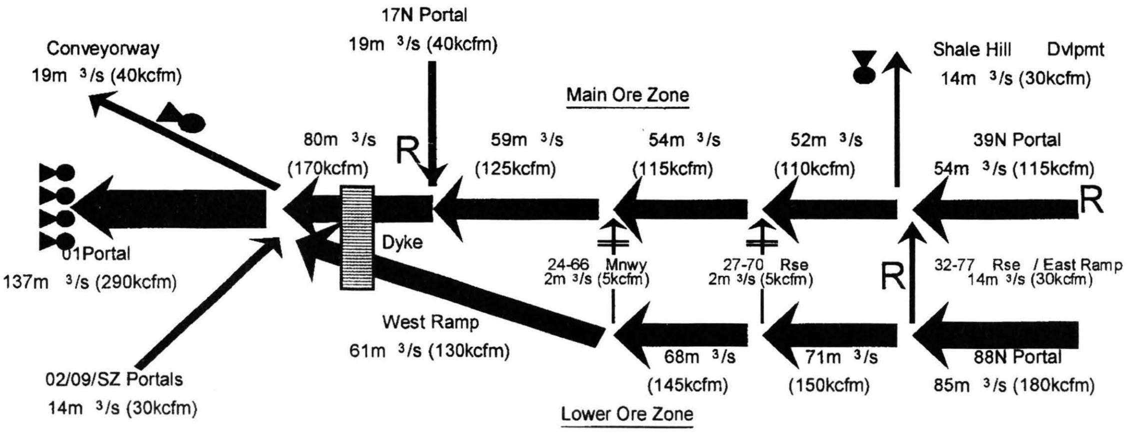

Figure 2. Schematic of predicted airflow distribution at Nanisivik Mine (3D-CNVENT).

unattractive.

The next series of simulations explored the option of the main fans being installed at the western end of the mine. This would require minimal cabling but would require ventilation doors or bulkheads to be installed in several portals at that end of the mine to avoid short-circuits. This option was the most attractive to the mine and was subsequently pursued.

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The next question was "How to control or direct the flow within the main body of the mine?" when considering the air's natural preference to pass through the larger cross-section main ore zone. Initially it was thought that the existing fans between the main and lower or zones could be utilized. However, it quickly became apparent that these were now redundant if the flow could be limited through the main ore zone and that the potential routes for air to pass from one zone to the other were eliminated.

Simulations showed that the migration of air from one ore zone to the other could be minimized by capping all the interconnecting raises. Furthermore, the flow entering or leaving the mine through 88N portal on the lower ore zone could be controlled by regulating the flows through 39N portal on the main ore zone.

The last aspect of control required was limiting the flow through the main ore zone. Initially, regulation at 39N portal was suggested as the primary control, but doors should also be installed in the eastern ramp to prevent air switching between the two ore zones. However, this type of control could be a problem as the mine was starting to remove the sill pillar between the two zones. This could provide uncontrolled leakage routes. As a result of the mining implications, the mine ultimately decided to install a ventilation door/curtain in the main haulage route through the dyke in the main ore zone to control the flow.

The final question that had to be answered was the general airflow direction in the mine. Here the mine decided that the fans at the west end of the mine should be exhausting. This decision was based upon maintaining a constant thermal environment for the benefit of the workers in the service and storage areas and to avoid ground control problems from thawing and safety concerns due to ice formations.

The final design put forward by CANMET is shown in Figure 2. Here it can be seen that:

- The Shale Hill development is ventilated by its own independent system.
- The compressor room in 17N is still ventilated with fresh air but a regulator controls its contribution to the mine. It could even be taken totally out of the main system with its own independent auxiliary system within 17N.
- A fan system is still required on the conveyorway if it is to exhaust. This fan system may have to be upgraded to generate pressures of similar magnitude to the main fan system.
- Doors and bulkheads limit the flow between the lower and main ore zones on the east ramp, and the 24-66, 27-70 and 32-77 raises.
- Doors limit the short-circuiting of flow through the 02, 09 and SZ portals at the west end of the mine.

This figure also shows the new flow regime predicted through simulations with the original four intake fans now exhausting through 01 portal. The simulations predicted that these fans should now be able to induce a flow of 137 m^3/s (290 kcfm). Also, with the appropriate controls the flow throughout the entire main and lower ore zones should be in excess of 52 m^3/s (110 kcfm). This is a considerable improvement over the original system.

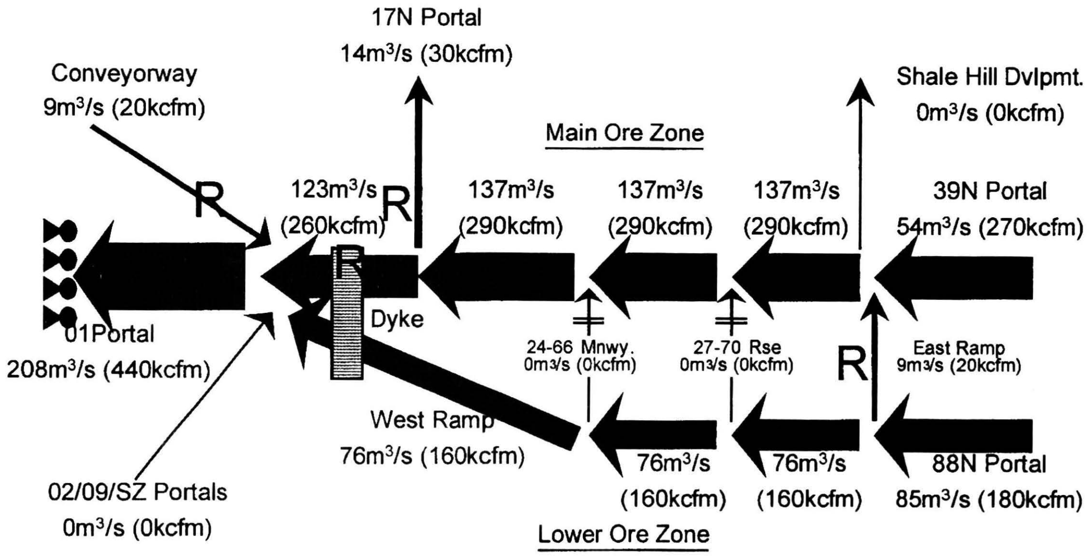

Figure 3. Schematic of actual airflow distribution at Nanisivik Mine (May 1998 by Anemoneter).

As a result of CANMET's survey, modeling and redesign recommendations Nanisivik Mine relocated their primary fans October 1996. And the complete re-organization/ installation of controls, such as doors, was finished July 1997. Figure 3, shows the doors installed on all of the western portals, and a regulator door in the haulage route through the dyke in the main ore zone. Unnecessary air routes between the main and lower ore zones were sealed. An independent air supply was also installed for the compressor room in 17N, but this route still supplies or removes a small amount of air from the system dependent upon natural ventilation. As predicted the conveyor fan was no longer able to exhaust air when competing with the primary fans, this has now become a controlled intake leakage route. Also there is no longer a requirement to ventilate the Shale Hill development.

The net outcome of these changes is that the mine achieved a new flow regime that was better than anticipated (Figure 3). As measured with an anemometer, the total flow through the exhaust fans has increased to 198-212 m^3/s (420-450 kcfm), and the combined flow through the main and lower ore zones has become 184-208 m^3/s (390-440 kcfm).

The flows in the mine, upon implementation of the changes, were greater than anticipated because it was impossible to accurately define the resistance of the airways within the main and lower ore zone. This was due to their size producing very small resistances and consequent limitations of ventilation simulation programs. In this new system there are no significant "critical" branches that dictate the overall flow and its distribution. Therefore the fans tended towards their free-air delivery. Also, the flow distribution shown in Figure 3 is based upon anemometry, whereas those in Figures 1 & 2 were based upon a tracer gas assessment. And as previously stated anemometry has been shown to overestimate the flow by up to 20%.

Despite the difference in airflow measurement methodologies, the air volume through the mine is now 20% greater than anticipated. However, the most significant improvement is the combined volume flushing the whole length of the main and lower ore zones, the typical increase in this flow is >100%.

Apart from the obvious increases in flow there were also the following benefits:

- The improved volume and utilization of the air with a "through" ventilation system has resulted in increased dilution of diesel fumes to benefit the workers.
- This improved "through" ventilation system has reduced the clearance time of blast fumes within the mine which has reduced the after blast re-entry times so permitting a longer productive period.
- The new system has removed the need for secondary fans between the main and lower ore zone. This has reduced the required total fan motor size requirement by 45% from 410kW to 224kW (300hp). So reducing the mine's power demand.
- "Dead-zones" in the ventilation system, have been eliminated.
- With the removal of the secondary fans, the double handling of the air and the potential for uncontrolled recirculation has been removed.
- The impact of a compressor room fire will have minimal impact on the mine as it has its own independent circuit.
- The seasonal changes in natural ventilation no longer retard the ventilation.
- The effects of wind direction and magnitude will not impair the system as it will either assist the fans, or be combated by the reserve capacity of the fans.

The only disadvantage of the new system is:

- The efficiency of the main fans has dropped from ≈70% to ≈60% but changing the fan impeller and its blade setting can counteract this.

DISCUSSION

This paper has shown one of the ways in which a mine ventilation system can be operated more efficiently to benefit of the worker, the company and the environment. Namely, optimizing the utilization of the air to maximize the work it performs to dilute and remove pollutants. In addition this optimization process has resulted in the mine requiring less infrastructure in the form of fans, and less electrical power, so reducing operational costs. Also through the reduced need for power, the mine's GHG contribution is also reduced.

However improved health and safety and greater cost effective operation is not always as simple. In other mines, there is not always the latitude to move the fans. In such instances, the mine operator may have to employ some level of automation and employ the "ventilation-on-demand" principle (Hardcastle, 1998) where the ventilation distribution is matched either quantitatively or qualitatively against production need. This would require such mines to have a vehicle tracking system that is capable of determining where, when and which vehicles are operating in specific areas. They would also require the infrastructure necessary to manage the flow, such as remote on/off and variable duty fans, and automated regulators and doors. In addition to this they would also require environmental monitors for airflow and gases.

In other situations, it may be necessary to look at the utilization of the air, the relationship of diesel-powered equipment operators to the ventilation and even the application of mining regulations. The use of "rule-of-thumb" regulations of a specific volume of air per engine power unit (i.e. cfm/bhp), irrespective of the engine type, fuel and exhaust treatment device can result in certain mining operations being over/under ventilated. For example, a draw point operation with its own exhaust that results in a vehicle operator being continually in fresh air, should not require the same volume of air as an operator in an auxiliary ventilated room-and-pillar stope who could always be in contaminated air.

Furthermore, the industry should always be looking to introduce new technology to reduce certain demands on ventilation. For example, the volume of air required for new electronically controlled fuel injection diesel engines is continuing to decrease. Also the products of combustion from these engines can be reduced through the use of catalyzed and/or particulate filters. This again can reduce their requirement for ventilation.

It is through the use of such new technology and the logical design of ventilation systems that mines will retain the greatest potential to remain within the same air quantity envelope and yet be able to address new concerns as they arise.

CONCLUSION

The optimization (and automation) of mine ventilation is essential for Canadian mines to remain economic. Mines are being continually pressured to supply more or better ventilation to reduce workers exposure to environmental pollutants such as DPM and combat heat as they go deeper. On the other hand, Canadian industry is being challenged as a whole to reduce power usage to reduce GHG emissions. These are opposing concerns because increased ventilation and refrigeration, if required, are energy demanding. Therefore, it is only through the process of continual improvement that the industry will be able to meet increasing pressures for worker health & safety, and concerns for the environment, yet remain economic.

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