Ventilation Requirements for Today's Mechanized Underground Metal Mines

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***Abstract*—Ventilation is a basic part of all underground mine operations. The main objective of underground mine ventilation is to provide sufficient quantities of air to all the working areas. Today, in modern mechanized underground metal mines, diesel-powered mobile equipment is extensively used for high production rates. Ore can be extracted from many production stopes due to the production rate in a mine. Amount of airflow required for an underground mine depends on several factors, including daily production capacity, number of diesel equipment, ambient temperature, mining method, mining depth and airway type. After implementation of Stage IV Emission Standards for nonroad diesel engines, it is getting more complex to determine airflow quantities required for underground mines wherefore reduced diesel emissions. Required amount of airflow for a mine is obtained by ventilation fans and the largest cost aspect in mine ventilation is the power costs of running the ventilation fans which can reach as high as 50 percent of a mine's entire electrical power cost. The cost of electrical power has increased significantly in recent years and is likely to continue increasing in the future. That is why it is getting more important to determine proper ventilation design for underground metal mines.**

***Index Terms*—Mine ventilation, underground, mechanized mining, diesel equipment**

I. Introduction

Ore deposits can be mined by surface (open pit) and underground methods depending on the deposit features. According to one source in 2014, there were 2500 mines operating with 52% being surface mining, 43% underground mining and 5% other [1]. In many underground mines, continuous operation of ventilation systems represents a significant percentage of the power used. Ventilation can cover 35–45% of a mine's total energy consumption. Since the introduction of diesel powered equipment into underground mines around the world after 1960's, their popularity has increased due to their productivity and flexibility [2]. At the same time, inadequate ventilation can expose miners to high levels of dangerous gases, dust particulates, and excessive heat. The main aim of ventilation planning is to design a system that will be capable of adequately ventilating all working faces, airways, and areas underground at minimum costs. Determination of optimum airflow quantity is both a difficult and essential step in the mine design process. There are many factors that influence the selection of mining equipment (e.g. host rock strength, mining method, production rates, location, depth, etc.) and wide variations in emissions characteristics even amongst vehicles of similar size and power. Navigating these uncertainties and arriving at a reasonable estimate of total airflow, while difficult, remains one of the most important aspects of underground mine design. Once the selection of the necessary equipment is done, the process of determining the total amount of airflow required can be completed.

II. Underground Mine Ventilation

Ventilation can be described as the lifeblood of a mine, where the intake airways, acting like arteries, carry oxygen to the working areas of the mine and the returns, acting like veins, conduct pollutants away from the working areas of the mines to be expelled into the atmosphere [3]. Ventilation provides a flow of fresh, cool air to the underground workings of a mine to dilute and remove dust and noxious gases (typically NO_x, SO_2, methane, CO_2 and CO) and to regulate temperature. The main aim of an underground ventilation system is to provide fresh air in a sufficient quantity and quality to dilute contaminants to safe concentrations in all parts of the mine where personnel are required to work or travel [4]. Mines can use 15-20 tons of air per ton of ore [1].

Fresh air enters the mine from the surface through a ventilation shaft rise or adit and is then distributed through the mine by internal ventilation rises and ramps. Flows are controlled by regulators and permanently mounted ventilation fans. An auxiliary ventilation system takes air from the main stream and distributes it to the mine workings through temporarily mounted ventilation fans and spiral ducting. Air always flows along the path of least resistance, but this may not be where it is required for use. To direct the air where it is needed, air control devices are used. There are two main categories: active devices that add energy to air to direct it to where it is needed, or passive devices that add resistance to flow routes to assist the air to flow along other routes (Fig. 1).

Active devices include main fans and booster fans. Passive devices include air doors, regulators, air crossings, stoppings and seals. Main fans are the primary means of producing and controlling the ventilation airflow. Main fans (singly or in combination) supply all the air passed through the mine and are usually located at or near the surface [5]. The two most commonly applied fans in mine ventilation are centrifugal fans and axial fans, although in some situations mixed-flow fans are used.

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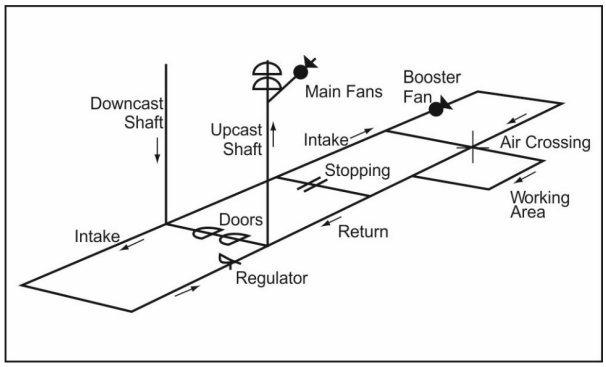


Fig.1. Components of mine ventilation system [3].

III. Estimating Primary Airflow Requirement

In fully mechanized underground mines, diesel equipment is used extensively and diesel exhaust dilution requirements are used to determine the airflow volume at the face. Traditionally, the ventilation requirements have been based on the power of the diesel equipment fleet with a multiplier applied to determine the total airflow volume requirements of the entire mine or individual sections or working areas [6].

There are a variety of methods of estimating primary airflow requirements in a mine [7, 8, 9] including:

• Benchmarking against operations with the same mining method and then pro-rating for different production rates [10];

• Ventsim™ modelling at key, specific milestones in the mine life [11];

• Manual allocation of airflows to individual activities on individual working levels by month or quarter (or year) for the life of mine [12]; and

• Estimations based on the total diesel engine fleet capacity (kW) and a statutory requirement, such as 0.05 m^3/s per kW of rated engine power [13].

The basic rule is that there should be sufficient ventilation to dilute the exhaust gases and particulates to below their threshold limit values. For design purposes, many ventilation engineers accept 0.06 to 0.08 m^3/s of airflow for each kW of diesel power, with all equipment being cumulative in any one air split which is mainly related to exhaust gases [5].

Small mines have less ventilation per diesel power than the larger mines. This is likely the result of small mines being highly mechanized for fewer tons produced than larger mines. As seen from Fig. 2, the survey results show that many mines design airflow requirements based on 0.04 to 0.08 $m^3/s/kW$ where block cave mines need more air because of the big spans and more diesel equipment.

Figure 3 shows a graphical representation of the relationship between the initial design parameters with the selection of equipment fleets and ultimately, ventilation rates. This process correctly incorporates the separate calculation of airflow rates (Q) for each of the four contaminant products (i.e., gases, particulates, heat and dust) with the total ventilation amount (or rate) required equivalent to whichever is greatest.

The gaseous products of combustion (POC) from diesel engines include CO, CO_2, and NO_x. The dilution of gaseous POC is achieved by a sufficient quantity of fresh air, with the velocity of airflow also playing a part in removing contaminants from the source where workers are likely to be exposed.

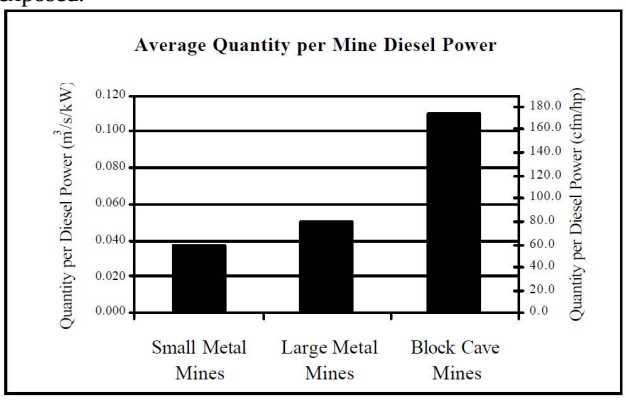


Fig.2. Ventilation rates utilized for various mines [7].

The production of diesel particulate matter (DPM) varies considerably among sizes, types, manufacturers and even series of diesel engines. Being sub-micron in size, DPM behaves as an aerosol, and its control is similar to that of any other gaseous contaminant; dilution and removal by the ventilation system.

The heat added to the ambient environment due to the operation of diesel equipment is the result of many factors including the fuel consumption, efficiency and the inlet air temperature and density. Sufficient quantity of fresh air acts as a heat sink, removing heat from the equipment and transporting away from the source. Diesel engines do not directly produce mineral dust but help propagation of mineral dust during mining operations.

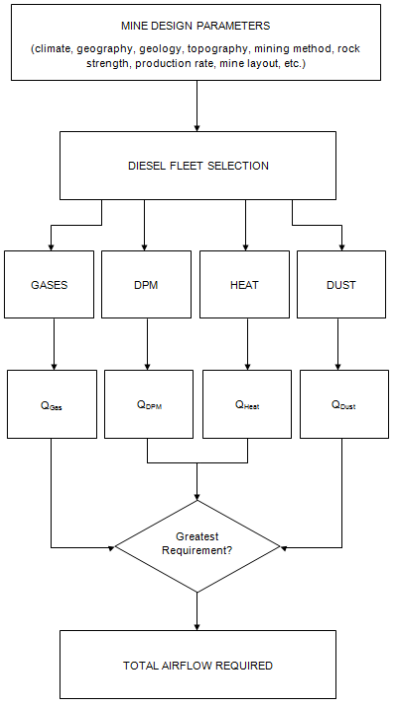


Fig.3. Design parameters and ventilation rates [14].

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In recent years, continuing developments in both fuel and engine technology are providing lower engine emissions while catalytic converters, wet scrubbers and ceramic filters may further reduce the leaving concentrations of carbon monoxide, oxides of nitrogen and diesel particulates respectively. In an effort to improve overall air quality, the US Environmental Protection Agency (EPA) mandated compliance with the so called "Clean Air Rules of 2004", that were designed to decrease emissions from nonroad diesel engines by more than 90%, with the final Tier 4 regulations becoming effective in 2014 (Fig. 4).

In countries governed by the European Union (EU), non road diesel engine emissions are controlled by Stage I through Stage IV regulations that are roughly equivalent to Tier 1 – Tier 4 of the US EPA standards. Other nations that have implemented specific standards applicable to non road diesel engine emissions include Japan, South Korea, India, China and Brazil. In some locations without specific laws governing the use of diesel equipment in underground mines, large, international mining companies voluntarily adopt more stringent standards recognized by the international community (EPA Tier 4 or EU Stage IV).

Tier 4 (including Tier 4 interim), the final, and most restrictive regulations of diesel emissions, began in 2008 and is gradually implemented through 2015. According to last regulations, the engine-out NOx is reduced 80%, while DPM emitted by diesel engines is reduced by approximately 90%.

Despite the uncertainty associated with the changes to diesel equipment emissions resulting from the EPA Tier IV-EU Stage IV regulations, it is important to note that mine airflow requirements are unlikely to decrease by 90% as a result of the 90% reduction in gaseous POC emissions associated with new diesel engines. Also there is emerging evidence that the addition of diesel particulate filter to new diesel engines can alter the particle size distribution of the emissions, ultimately increasing the fraction of the smallest and most harmful particles. If proven, this could represent a significant risk to the health of those exposed to these particles, and this risk should be recognized and mitigated.

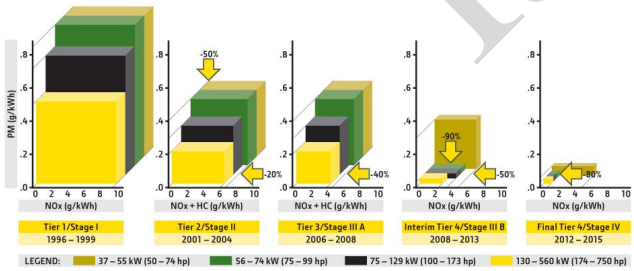


Fig.4. EPA and EU nonroad emissions regulations [15].

All diesel equipment operating underground also generate two other important contaminants; heat and dust, which are also mitigated primarily by the ventilation system. Whereas before the total quantity required for a given system could be determined based on the amount required for the dilution of exhaust gases from the diesel equipment, the calculation must now consider the heat generated by the equipment, and the removal of dust from the working environment [16]. Even with drastic reductions in the gaseous and particulate emissions realized by Tier 4 engines, the heat generated by those engines mandate a ventilation rate that is not significantly lower than what is commonly used before.

IV. Conclusion

As Tier IV engines become more available in underground mines, their actual gaseous and particulate emissions should be catalogued so that empirical data can be formed and updated. Heat and dust are two other important contaminants that must be more focused in next researches. What is more likely is that other parameters will take precedence, and that in the future, airflow calculations will become slightly more complex and based on a combination of factors that will be unique to each mine. By revisiting the methodology for making total airflow determinations for diesel equipment in mines and accounting for all of the associated contaminant products of that equipment, it will be possible to create a healthier environment for the underground workforce. Although the total amount of airflow (quantity) may be reduced, the determination of the quantity required is now a slightly more complex and time-consuming process.

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