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INCREASING QUALITY OF VENTILATION FOR UNDERGROUND MINE WORKERS

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ABSTRACT

In view of mining, Ventilation is a major aspect of an underground mine, in which it is to control the atmosphere to support miner's life and improve their efficiency. It leads to an increase in productivity and also to flush out the harmful and noxious gasses to their permissible levels. In the field of mines, there are dozens of methods concerned with the optimization of ventilation systems in underground mines. The main scientific and practical results of the study and assessment of ventilation control in coal mines using the Methods of decomposition, statistical dynamics, set theory, fundamental laws of mining aerodynamics, and discrete mathematics will lead to increased safety and reduced accident rates in mining operations at coal mines. This study is carried out to know how to improve ventilation system conditions of mine which relates to the ventilation (i.e., Air velocity at roadways in mine, the existence of humidity in particular areas of the mine, the efficiency of fans at a rate of ventilating air into the mine, equivalent orifice (or) resistance of a mine, method of ventilating the air into mine, the ventilation distribution in mine and some other conditions). For ventilating the working faces, the proper controlling devices are used for coursing of air and sufficient ventilation survey techniques are to be developed to maintain the quality and quantity of air. This present paper covers a detailed view of the underground mine ventilation system, ventilation survey and different parameters that contribute to provide ventilation effectively and what method we can adopt to improve the ventilation system form existing methods.

Keywords: Mine Ventilation; Ventilation Survey; parameters; controlling devices; decomposition.

1) INTRODUCTION

The mining operations usually create a negative environmental impact both mining activity and also after the mine has abandoned this is because of, we are going averse to the environment there will be a lot of problems (or) difficulties occurs during the Mining operation like, (producing contaminant gases & dust during drilling, blasting, transportation, etc.,) in which reduces the miner's efficiency & production (or) productivity of Mine.

In the view of mine ventilation, it is an important aspect of underground mining in which it is required to clear all harmful gases, as in coal mines removes fumes from blasting and occasional exhaust from diesel equipment and also at the same time it provides fresh air to the miner's which improves their efficiency. so, the careful study of mine ventilation is needed and it is vital to create a safe and healthy environment.

Well-timed delivery of the necessary amount of air to work areas at any given time, ensuring the smooth progress of the mineral extraction process, and maintaining safe working conditions for miners are pressing issues. One of the challenging aspects of air distribution management in mines is the development and implementation of measures under topologically and aerodynamically stable conditions. Additionally, operational redistribution of airflow across ventilation network workings was investigated depending on deviations of monitored parameters from technological standards mandated by safety regulations (SR) and mine operation protocols (MOP). Therefore, it can be very difficult to determine the best option in terms of health and safety conditions in the drifts and working faces.

Some software like Computational fluid dynamics software (CFD) has been used in the last few years to determine, with high accuracy, the behavior of the underground environmental conditions, such as airflow, temperature and pollutants with the aim of optimizing and improving the working conditions in working faces and reducing mine expenditures.

Moreover, the need for an optimized ventilation system has become imperative due to energy costs, safety and health requirements, and recirculation. The aim of this paper is to proposed the best ventilation management solution in terms of duct position and auxiliary ventilation systems in working faces to remove pollutants and maintain acceptable temperatures.

2) OBJECTIVE

Here there are some objectives that we are going to give a brief explanation regarding the underground mine ventilation in which we are taking increasing quality of ventilation management system as our main objective or motive and the following objectives that we are going to addresses are:

a. To study different ventilation systems used in mines.

b. To study about ventilation devices, ventilation parameters and ventilation survey

c. To analyze a ventilation management solution for the operational redistribution of airflow across ventilation network workings to ensure compliance with technological standards mandated by current mine safety regulations based on Computational fluid dynamics software (CFD) and Ventsim software (Howden, 2018).

3) TYPE OF VENTILATION SYSTEMS

Depending on the type of mine and disposition of local geology, the ventilation system is chosen, the basic ventilation systems are:

U-Tube System.
Through-flow arrangement system.

Other types of ventilation system likes Ascensional Ventilation, Descensional Ventilation, Antitropal Ventilation and Homotropal Ventilation

Ventilation system in Board and Pillar mining method- Bi-directional or W system, Uni-directional or U-tube system

U-Tube System:
In the u-tube system air flows towards and through the working area then returns along the adjacent airways, often separated from intakes by long pillars of stoppings. The airflow between the intake and returns is facilitated by access doors fitted in the stoppings.

Through-Flow System:
In the through-flow system, the intakes and returns are usually separated geographically from adjacent airways, which are either all intakes or returns, hence reducing the number of leakages paths. There are fewer stoppings and air crossing but additional regulation like regulators (or) booster fans to control the airflow.

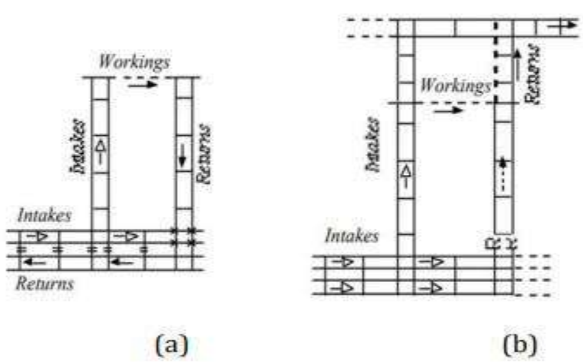

Fig.1. Basic ventilation systems (a) U-tube and (b) through- flow.

4) OTHER VENTILATION SYSTEMS

Different types of ventilation are as follows:

(i) Ascensional Ventilation
In this system fresh air is taken down to the bottom-most faces of a working district and is allowed to travel up the dip along the faces picking up heat from the freshly exposed rock at the face, this can be adopted as lit leads to the development of NVP that aids the fan pressure.

(ii) Descensional Ventilation
It implies, taking the air to bottom-most faces from the rise side of a district to the lower levels along with the working places and return is at the bottom end of the working place. It has been claimed to reduce the amount of heat added to the air in workings, besides making the workings less dusty.

(iii) Antitropal Ventilation
When air and mineral flow is in opposite directions the ventilation is said to be an antitropal system of ventilation.

(iv) Homotropal Ventilation
In a homotropal system the air and mineral flow in the same direction.in this system, the velocity of air relative to coal is less compare to an antitropal ventilation system.

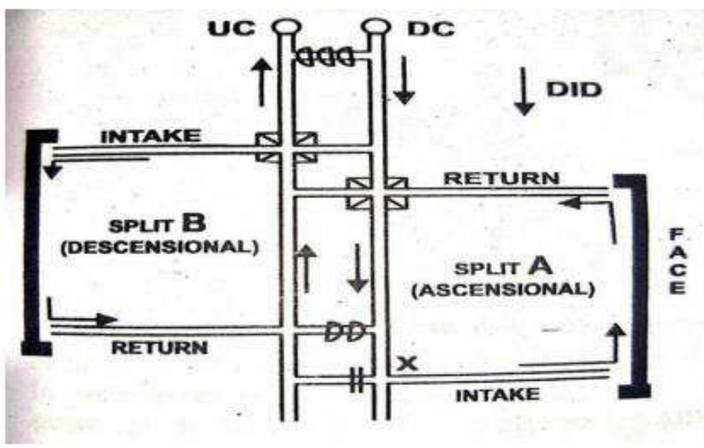

Fig.2. Ascensional Ventilation& Descensional Ventilation.

5) VENTILATION SYSTEM IN BORD AND PILLAR MINING METHOD

They are two methods of ventilating a bord and pillar development panel:

(a) **Bi-directional or W system** in which intake air passes through one or more central airways with return airways on both sides. This system is commonly adopted in the seam of coal mines where both intake and return shaft are located at the center of the property.

(b) **Uni-directional or U-tube system** with intakes and returns on opposite sides of the panel. In both cases, the conveyor is shown to occupy the central roadway with a brattice curtain to regulate the airflow through it. This system, the air flows from intake to the return through the workings and commonly adopted where the intake and return shafts are located at strike boundaries of the mine.

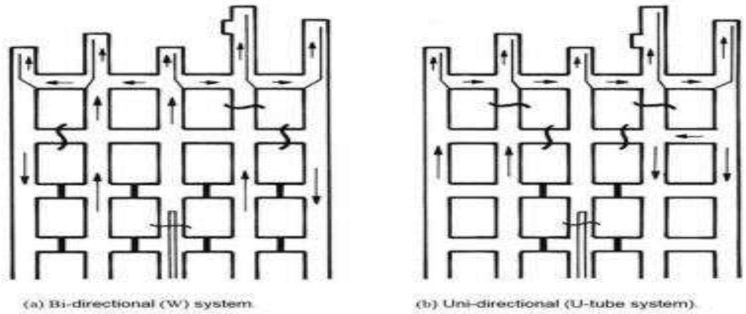

Fig.3. (a) Bi-directional system, (b) Uni-directional system.

6) VENTILATION CONTROL DEVICES

The air in a mine is coursed to the working place by the use of brick, stoppings, doors and brattice cloth, air crossings, air pipes, and regulators. The various devices used for distribution and control of air in a mine are shown on the mine plan by signs. Some of the control devices are:

a. Stoppings:

A stopping block of a mine opening to prevent the flow of air between intake and returns, when these are no longer required for access or ventilation, to prevent short-circuiting of the airflow. Stoppings can be constructed from masonry, concrete blocks, or fireproofed timber blocks. Stoppings should be well keyed into the roof, floor and sides, particularly if the strata are weak or in coal mines liable to spontaneous combustion.

Fig.4(a). Stoppings.

b. Air Crossings:

Where intake and return airways are required to cross over each other than leakage between the two must be controlled by the use of an air crossing. Normally air crossing constructed at the place where it has reasonable long life and ground free from rock movement.

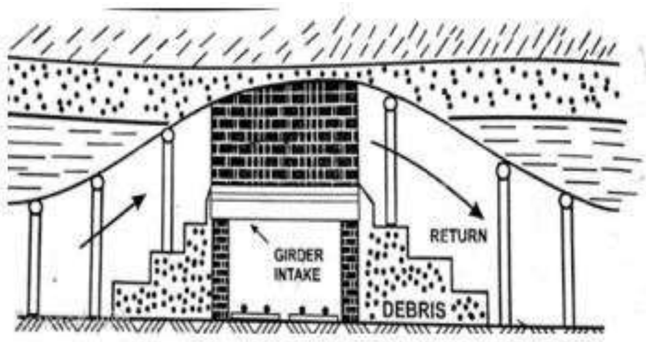

Fig.4(b). Air Crossing.

c. Regulators:

Air regulator is a device for creating a shock loss to restrict the passage of air through an airway, these are usually rectangular adjustable openings left in stoppings. The air quantity can be adjusted by varying the size of the opening. Regulators are located in the return airway to minimize interference with traffic. Locating the regulator near the junction with the other splits of air will minimize leakage of air.

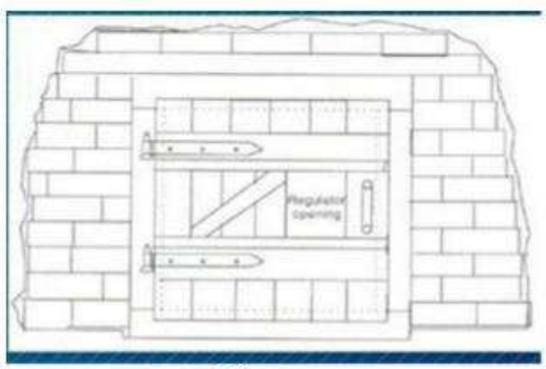

Fig.4(c). Regulator.

d. Brattice Cloth:

A partition erected in the opening to divide it into the intake and return airways is termed as line brattice, the partition is simply a sheet or sheets of canvas hung from props and planks to prevent the short circuit of air from intake to return, so causing the ventilation air to reach the faces.

Fig.4(d). Brattice Cloth.

7) VENTILATION PARAMETER

Generally, there are most important parameters that are required to design the ventilation management system, which helps in to maintaining the distribution of airflow in the proper direction and also to improve the efficiency of miner's and helps in increasing the productivity of mine and the following parameters are:

a. Natural Ventilation Pressure (NVP):

Airflow through the mine opening causes by natural means due to difference in air densities in an upcast and downcast shaft, aids to natural ventilation. Natural ventilation pressure in a mine is the difference of pressure of air columns in downcast and upcast shaft.

b. Motive Column:

The pressure due to natural ventilation may be expressed in meters of air column (or) motive column, which is the height of an imaginary column of one square meter in the section that produces a pressure equal to the difference of pressures between the bottoms of downcast and upcast shafts. It is an effective force causing flow.

C. Laws of Mine Air Friction:

The relation between various factors was enunciated by J.J Atkinson in 1854. The frictional resistance of the air depends on the Dimensions on the roadway (area, length, and perimeter), the velocity of air, nature of roadway along with air passes. An account is taken of these factors under the following four laws:

Law 1: The pressure required to overcome friction is directly proportional to the area of rubbing surface i.e.,

$P \propto S$, = perimeter of airway × its length.

Law2: The pressure required to overcome the friction is directly proportional to the square of the velocity of air

$P \propto V2$

Law3: The pressure required to overcome the friction is inversely proportional to the area of crosssection of the airway.

$P \propto a$

Law4: The pressure required to overcome the friction varies with the degree of roughness of the rubbing surface, or the coefficient of friction of the airways,

$P \propto K$

d. Resistance System of Roadways

d.1. Roadways in Series:

A series ventilation circuit is one in which the air is first used in one workplace, then directed to another workplace, and then potentially reused in many other workplaces. It has also been variously described as "cascade" ventilation or "daisy chaining". Where flow occurs in two or more roadways in series, a quantity of air flowing through every roadway is the same (Q), and the pressure spent P is the sum of pressure in individual roadways.

Using the Atkinson equation i.e.,

$P=RQ2$

$RQ2= R1\ Q2+R2\ Q2+R3\ Q2+$----------$RnQ2$ or

$R = R1+ R2+ R3+$----------$+Rn$

d.2. Roadways in Parallel:

The other major system of ventilation circuit design is parallel circuits, also known as "one pass" or "single pass" ventilation. In parallel designs, the air is used in one workplace and then directed to the return. Where airflow occurs in two or more roadways in parallel, pressure difference P is the same across every split, while the air quantities get distributed amongst them depending on their resistances. Thus, the total quantity of air is the sum of the individual quantities of air passing through the splits.

8) VENTILATION SURVEY

A ventilation survey is an organized procedure acquiring data that quantify the distribution of airflow, pressure, and air quality throughout the flow paths of the ventilation system. Better planning of ventilation can be done by analysis and evaluation of data obtained survey in different parts, for the ventilation system to efficient and economic. Generally, ventilation survey is carried out in six different ways i.e.,

A) Quantity Surveying:

The quantity surveying mainly involves to analysis the distribution of airflow in the main roads, galleries, and at the working faces. It also determinates to locate the leakages between intake and returns and to know the efficiency of the fan during fan tests. Quantity of air passing per minute is normally measured by given formula i.e.,

Q = A x V

B) Pressure Surveying:

The purpose of the survey is to determine the frictional pressure drop(p), that corresponds to the airflow(Q), measured in each branch of a survey route. The basic principle of the pressure survey in a mine is Bernoulli's theorem.

C) Qualitative Survey:

The survey involves the determination of firedamp content at different leakage points in the mine and chemical analysis of the air samples. If the firedamp content in the general body of the return air of the ventilation district exceeds 0.75%, the ventilation is inadequate.

D) Hygrometric Survey

Hygrometric survey in mines is normally carried out to check and control the environmental conditions at various parts of the mine to maintain the mine atmosphere (wet-bulb temperature and air velocity) within statutorily permissible limits. It is generally carried out by whirling hygrometers, readings must be taken at all splits, points of leakages, haulages, compressors, etc.,

In Indian underground mines, the relative humidity of mine air in the temperature can normally range as follows:

R.H (%) = 100 – X (D.B.T-W.B. T)

X= 7, for D.B.T > 25

8, for D.B.T, 20-25

9, for D.B.T < 20

According to standards of ventilation in C.M.R 2017, the wet-bulb temperature should not exceed 33.50c whereas dry bulb temperature is about not less than 30.50c if it is, exceeded for every one degree there is to be increasing of air velocity about 1 m/sec.

E) Air Quality Survey

The quantity of air passing through any airway every second, Q is generally given by the expression

Q = U X A (m2/s)

Where, U = Velocity of air passing through that point(m/s)

A = Area of roadway (m2)

The accuracy of the calculation of air quantity is equally influenced by the measurement of air velocity and measurement of the cross-sectional area of the roadway. It is most important to ensure that a standard method is used to carry out area measurements. Normally for better accuracy results, we use the Taping method of measurement.

Taping:
This is the easiest and the most commonly used for measuring cross-sectional areas in mines. Procedure in this method, a tape is stretched over the airway, and with the help of another tape, the perpendicular offsets to the periphery of the airway on either side of the stretched tape are taken at regular intervals of 0.3-0.5 m. The measurements can be plotted with a scale and the area of the resulting diagram determined by a plan meter.

Fixed Point Traverses /Single Point Measurement:
Here, we can measure the air velocity by traversing in two different methods i.e., (moving traverses and fixed-point traverses). In this method, the anemometer is held at a fixed point on the cross-section of the airway, the reading multiplied by a method factor of 0.8 to get the average velocity value.

Usually, readings are taken at the center of the shaft. The method factor varies with a roughness of the side of the airway and the Reynolds number. The method factor is unity at one-seventh of the distance between opposite walls from any wall. An accuracy of 5% can be obtained with single-point measurement.

Instrument Used for Measuring Air Velocity
The vane anemometer is the classic device used to illustrate the mechanical effect of the air; it is simply termed as an anemometer. It is an instrument to determine the distance traveled by air in a given time and used where air velocities between 60m and 1000m3/min. The anemometer is a small windmill-like instrument consists of several radial blades or impellers at 400 to 500 to the direction of airflow and also used a gearing mechanism, a pointer, and a clutch system. A zero-reset lever is also mounted on the instrument. Anemometers are specially designed to measure the air velocity from lower range velocities to higher range velocities are about (10.16 to 50 m/sec or 2,000 to 10,000 fpm).

F) Pressure Survey
Airflow from a region of high pressure to lower pressure, in general, the maximum pressure is found at the top downcast shaft and the minimum pressure is found at top of the up cast shaft. The pressure difference between them causes the flow of air and the traveling of air in mine airways often, km's in length. In those cases, there is to determine the gradual pressure fall from point to point. Determination of Pressure Loss by Gauge & Tube Method:
The pressure losses are determined directly by differential pressure measurement i.e. Gauge and Tube Method. the procedure of gauge and tube method as follows:

1. The pressure difference between the required two points connected by a hose is directly on a manometer.
2. This method gives accurate results but is time consuming as it involves laying and carrying the hose from point to point.
3. This method is generally employed in typical coalmines where very high pressure is not observed.

9) Ventilation Management System
Ventilation management in mines implies the timely delivery of the necessary volume of air to work areas at any given time, ensuring the smooth progress of the mineral extraction process and maintaining safe working conditions for miners. Ventilation management in mines can involve both the development and implementation of measures under topologically and aerodynamically stable conditions, as well as the operational redistribution of airflow across ventilation network workings depending on deviations of monitored parameters from technological standards mandated by safety regulations and mine operation protocols

We can create a ventilation management system based on accurate ventilation parameter and design recommendation of underground mine ventilation system based on type and situation of underground mine. The most important issue of air temperature is a critical consideration in underground mining operations especially in tropical areas where the initial air temperature is high. We can construct the baseline model, is the condition of the initial underground mine ventilation system with a surface dry bulb temperature by using Ventsim software. Then optimization is carried out using the best type of local ventilation system. the model with the best local ventilation system models varies in the cooling system. After that the model with the best local ventilation and cooling system was modeled using CFD to obtain spatio-temporal heat condition data for the observed activities. We need to required data of field measurements will tunnel dimensions (area, A), air velocity (V), dry-bulb temperature (td), and wet-bulb temperature (tw).

Modeling Based on the Activity

The modeling conducted using Ventsim software (Howden, 2018) and uses CFD involves three stage model. first, a baseline model, two-stage model optimization and the last/third stage of model optimization. This modeling was simulated in series order to obtain the optimum condition from each stage. The details of the simulation for each stage are described as follows.

The First Stage

This stage is the optimization model of various types of local ventilation systems which are exhausting (using 1 and 2 auxiliary fans), forcing 1 (using 1 and 2 auxiliary fans), forcing systems with exhaust overlap (using 1 forcing fan with 1 exhausting auxiliary fans near the working face), and exhausting systems with force overlap (using 1 exhausting fan with 1 forcing auxiliary fans near the working face).

The Second Stage

This stage is the optimization model in various installation cooling systems on the best type of local ventilation system from the first stage which are surface cooling, underground, and spot cooler. Mucking and hauling activities have been used as a heat source for this simulation stage to exercise the various cooling systems options.

The Third Stage

This stage is the modeling using CFD to obtained spasio-temporal heat conditions in the working face. Drilling, mucking, and hauling activity have been used as a heat source for this simulation stage to simulate the maximum working temperature condition. This model uses environmental parameter data in the dry season (May – November) as the conservative scenario.

Heat from Mine Location and Mining Activity

The value of each heat source that impacts the model needs to be determined for the input data including from geothermal gradient and mining activity (equipment and human metabolism from drilling, mucking, and hauling activity) (Hartman, 1997). The geothermal gradient or the temperature change per unit depth ($\Delta t/\Delta Z$) used in this simulation is measured at 1.8 ^{0}C per 100 m. Based on field measurements, the temperature of wall rock is 27.6 ^{0}C in the working face. Since the drilling/ mucking activity is done in the working face and stationer the heat source. The input parameters like Inlet Air Velocity (Duct Forcing)(m/s), Outlet Mass, Flow (Duct Exhaust)(kg/s), Duct Inlet Temperature (OC), Tunnel Inlet Temperature (OC), H2O mass fraction (kg/kg), O2 mass fraction(kg/kg), Rock Temperature (OC), will used for boundary conditions in the geometry model CFD for drilling activity.

10) Mucking and Hauling Activities

The heat generated in mucking and hauling activities is shown in Table as the input parameter for modeling using Ventsim in the second stage modeling and ANSYS R1 2023 Fluent software in the third stage modeling. The input data from Tables will used for boundary conditions in the geometry model CFD for mucking and hauling activities.

Table 7 Heat generated during mucking and hauling

Equipment	*Power* (kW)	Efficiency Machine	*Heat* Generated (kW)	*Total Heat* (kW)
Mucking				
LHD	179.00	34%	118.12	122.03
Aux Fan	20.50	90%	2.05	
Worker	1.87	-	1.87	
Hauling				
Mine Truck	89.50	34%	59.06	68.39
Worker	9.33	-	9.33	

Table 8 Input used for heat sources in mucking (LHD) and hauling activity (mine truck) for CFD modeling

Activity	Time (s)
LHD	
Mucking	15
Moving from Development Front to Muckbay	158
Dumping	5
Moving from Muckbay to Development Front	158
Cycle Time (s)	**193**
Mine truck	
Loading	45
Moving from Muckbay to Rampdown Development Entrance	24
Moving to Entrance and Going Back	1048
Moving from Rampdown Development Entrance to Muckbay	24
Cycle Time (s)	**1141**

*Note: table data used for reference only.

11) Heat Distribution Condition Model using CFD

Computational fluid dynamics has been used for modeling the third stage in order to obtain the detailed condition of temperature in the working face area and along the ramp down development. Based on the results of optimization modeling using Ventsim software for stage three, the heat distribution at the working face indicates the average value for each tunnel segment in general conditions, therefore the accurate spatial distribution of temperature can only be obtained if the design input (string model) is discretized as small as possible. In addition, the data generated from Ventsim only provide for steady-state conditions. The transient condition that is spatio-temporal of temperature was needed to determine the locations that have high risk due to the high temperatures during mining activities. The computational fluid dynamic can be used as a tool for heat transfer simulation in transient conditions.

12) Conclusion

The improvement of ventilation system of underground mine for creating ventilation management system. The ventilation management system can be considered structurally composed of a control system and a controlled object. Continuous exchange and processing of information occur between the control system and the controlled object during the management process. The control system must process the information received from the ventilation objects in such a way that the control actions (measures) it generates effectively achieve the management goal under certain limiting conditions imposed by safety regulations. The management task is to ensure normal ventilation of the mineral extraction process and the state of the mine atmosphere regulated by safety regulations for mines and quarries. Quantitative characteristics of gas dynamic processes (mathematical expectation, standard deviation, etc.), minimal energy costs for ventilation, and economic indicators (minimum damage, maximum production) can be adopted as criteria for the effectiveness of mine ventilation management. We can developed the proper mine ventilation management by adopting the software's for accurate modeling and analysis by Ventsim software (Howden, 2018) and Computational fluid dynamics software (CFD).

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