OMER HAITHAM KANAM
and
MAHER OBAID AHMED

A review on underground mine ventilation system

In the field of mines, there are dozens of methods concerned with the optimization of ventilation system in underground mines and how bad ventilation system is playing a major effect on miners and mine's activities. The ventilation system is considered very important because it consumed high energy of mines of total power consumption. This paper is a review of previous studies, which have been done before on design of ventilation system and its optimization methods like, using of software tools to simulate the numerical equations based on the pressure, temperature, flow rate, and other effected parameters, which are recorded by various ways of surveying. It has observed that Ventsim software is widely used because of its flexibility in dynamic simulation based on various parameters included deep, fan position and flow rate.

Keywords: *Ventilation, underground mine, software, atkinson, hardy cross method, Kirchhoff's.*

1.0 Introduction

The design engineers are concerned in creating a suitable environment in underground mines for miners and mining equipment. The most suitable working environment, the good are the productivity, Therefore, the ventilation system is more than important in the mining sector. Techniques are developed during the time to optimize the operating conditions for the ventilation system. Such development includes, the working of fans and its mounting position, the quantity of air required, the distribution of air through the opening, elevation effect, wind resistance, fire detecting, and other individual factors, which are playing a role in improving the efficiency and increase the mine productivity with less incidents.

The software tools were found the most reliable in optimizing the working of ventilation system and in rising the safety factor because it is analyzing the numerical equations for ventilation calculations precisely in different conditions. The programmes simulate the real data available from mines survey.

The objective of this paper is to review previous studies which were focused on the optimization of ventilation system in subsurface mines based on theoretical phenomena, numerical equations, and using software tools in simulation. Dozens of researches were studied the ventilation system inside subsurface mines, due to the risk of work in such places. In the following, some researches which had been done by experts and researchers are summarized.

V. Adjiski et. al., have been employed "ANSYS" software to build a 3D CFD model for calculating the distance from the outlet of the supplementary forcing ventilation system to the growth heading in subsurface mines under, face velocity, dead-zone areas, and the mean angle of air through the heading's volume. Eleven different conditions were tested. The k-epsilon method is used in the numerical simulation inside "ANSYS" because the influencing of the turbulent flow pattern of the air at the headings. The simulated model improved the ventilation system effectiveness and auxiliary forcing as well as, it reduced the energy consumption [1].

An Huaming et. al., had studied the effect of recirculation wind on underground mine ventilation system. The location of recirculation wind was determined using depth first method which states that a wind search starts with one node then followed by all nodes which have connected with each other until the last node which have no connection with other nodes; then it is return to the node that have linked with at least one node, it is also called search strategy. The position of recirculation wind predicted is applied on the Dahongshan copper mine. The obtained data were represented on a graph using Matlab software. The method helped the design engineers to avoid the effect of unidirectional wind on mine ventilation system near the mounted fans [2].

Chen Kaiyan et. al., have suggested a new algorithm called "Improved differential evaluation (IDE) and critical path method (CP) based on the multivariable separate solution strategy (IDECP)". Concisely, the IDE is to take out various sensible solutions on airflow divisions in the ventilation network of subsurface mine, and then to held the best pressure drop regulation solutions by CP method. The new

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Messrs. Omer Haitham Kanam, Department of Mining Engineering and Maher Obaid Ahmed, Department of Petroleum and Refining Engineering, College of Petroleum and Mining Engineering, University of Mosul, 41002, Iraq. E-mail: 1omer.kanam@uomosul.edu.iq / maher.obeed@uomosul.edu.iq

algorithm has been applied to two examples of mine ventilation network with single fan once and multi-fans once another. The results after applying this algorithm have shown a good improvement for the subsurface mine ventilation networks efficiency, interchanges, ruggedness and flexibility. It is recommended to perform multi-examples for further improvement and validation [3].

Euler De Souza, illustrated in his paper, how to optimize the ventilation network in subsurface mines by considering hardy cross method and critical path method. The standard design ventilation networks are based on Kirchhoff's second law and Atkinson equation in addition to airflow, natural ventilation, resistances, air density, air quality, and pressures as data entries. For optimization purpose, a computer programme was used to analyze the complex networks to improve the ventilation circuit and mine operations by predicting the airflow, friction losses, air power losses, and operating point of the fan. His paper showed an important path for excellent ventilation system planning [4].

The effect of ventilation cooling in deep gold mine is evaluated using Comsol software at –652m excavation roadway. Several factors (road section area, inlet air volume, temperature) were investigated with its effect on cooling rate. The consequence shows sharply increasing in cost and the volume is constant when the slop is 0.1 and there is a direct relationship between cooling rate and increasing in road section area [5].

The phenomena of dividing the network branches is related to insert the element which is active into an element which is passive. The one dimensional finite element method is used to perform the analysis of non-linear specifications of the fan by considering a non-linear equations to the ventilation network. The FEM is combined with laminar solution to explain the convective overall heat transfer between air and rocks which based on lyon's solution method. A simulation is carried out by OI Dudar et. al., using "Mine-Climate" software to analyze all the effective parameters like mass flow rate and temperature distribution. The results showed the variation quantity of mass flow rate through a year and clearly showed the effect of natural draught on ventilation system performance [6].

A new equation has been generated from Kirchhoff's first and second laws to compute the air flow sensitivity of local ventilation sub-network areas and to monitor the ventilation process, air distribution, as well as detecting the fire gases. WacBaw Dziurzy nski et. al. have emphasized the use of computer programme "Ventgraph" simulator with the generated equation to calculate the sensitivity of the resistance airflow indicator and the formula of sensitivity of the density indicator. The new formula principle found the airflow resistance when the density of airflow decreased. When the fire exist in subsurface mine, the airflow volume starts to change and the POZAR module option in the "Ventgraph" programme, thus, it is efficient to predict air distribution and fire gases. The developed method is efficient and assist to predict the change in air direction and volume stream of the air flowing in the ventilation system in subsurface mine [7].

The coal mines accidents is predominantly the reason of ventilation system defect. This part has been studied by Shen Fei-min et. al. He refers to fault tree analysis, which explained the accidents from cause to result, to construct a model of evaluation index based on 5 evaluation criteria and 22 evaluation indicators. The model improved the safety of the ventilation index system, as well as, it is improved the ventilation execution, pressure of the air, and the right ventilation system selection [8].

A case study of Donghai mine in China by Feng Wei et. al. build a 3D model for the mine using Ventsim software programme contributed with AutoCAD. There was a complexity in ventilation system management of selecting the defect in air flow in the branches and the laneways. This issue had been solved by display of the direction and quantity of air and other effecting parameters like temperature, pressure drop, and airway resistance. The simulated model observed the modification for the branches and laneways at the point where airway resistance is high, thus the model can simulate the statues of modified branches or laneways at that point and where the recirculation of the airway path is needed with 0.1% default tolerance of air quantity. This study helped the mine engineers to control the faults in ventilation system and take a quick action to recover the problems [9].

In ventilation system, the sensitivity of wind resistance on the network branches approved by Jinzhang Jia et. al.. He established a mathematical model to calculate the sensitivity for each branch by constructing a matrix for that branch. This matrix can be used to realize the sensitivity of wind resistance on the air flow. The model can predict the most effected branch for sensitivity of wind resistance and this is helping to cover any defect in the design of the ventilation network by acknowledging that the system is stable or not [11].

The coal mine ventilation system of Xinglongzhuang has optimized by Aiwei Jiang et. al. using the "Ventsim" software. A 3D model is established in the mentioned software to monitor important parameters such as, temperature, pressure, volume of the air, air distribution quantity and direction, the contribution of roadway with the ventilation system and observed any issue in short time. Due to powerful of the "Ventsim" software tool, the overall optimization of the ventilation system is improved with a very good extent. The re-evaluation of the design system error has been reducing the cost resulting the rise in the productivity thereby saving in the resources like, manpower, financial, and the material are managed by controlling the operating condition of the fan due to the modulation of the seasons [12].

Hypoxia issue has been studied by Zijun Li et. al. for plateau metal mine using CFD technique to resolve the distribution of O_2 mass fraction and the O_2 rising influence in 1m, 3m, and 5m of roadway cut cross from heading face. The study built and applied the model on different high and flow of air duct for the ventilation system to supply oxygen. The results observed difference in distribution of oxygen at the heading face when oxygen supply had different designs. The best results obtained when small holes made on O_2 supply duct and the O_2 effect is optimal at this design [13].

Liang Yuntao et. al., were hypnotized the use of "Ventsim" programme to mitigate and control a combustion issue that may occur in underground mine cause the longwall goaf. Bulianta colliery is a case that researchers have taken to validate the model designed results. The aim is to reduce the pressure difference between surface and ventilation system in underground and this is done choosing a good airway with low resistance to avoid any leakage. The "Ventsim" simulator used a present geometry of the specified mine which drawn in "AutoCad". Three suggestions to mitigate the problem of pressure differential variations that programme gives: firstly, using of exhaust system by locating the fan at the exit point of the ventilation duct; secondly, isolating the longwall panel and this can be supplied more fresh air in the airway and this is done by mounting supplement fan with regulators. Thirdly, is to put more cautions in the place before pressurizing because if the supplement fan fails there could be a large amount of toxic gases flowing and affecting the miners. Added to that, an efficient of booster fan is considered more suitable for longwall operations in planning when the system has fewer disturbances as compared to the second suggestion. The research shows a robust of ventilation system to investigate unrestrained combustion [14].

On the basis of topology theory, Wei Lian-jiang has applied fuzzy logical on the ventilation networks in subsurface mines. He developed a method called "Path Tree Depth-first Growth", which can be used to search all paths of two random nodes. The new method has several multi-features which are convenient, simple, high efficiency, reliable and the affinity is excessively strong, which can be used for ventilation network of non-unidirectional and unidirectional circuit respectively, single source, single terminal ventilation network, multi-source and multi-terminal ventilation network [15].

Luo Wengui et. al., have argued the reliability in calculations of ventilation system networks and branches mathematically. For branches, the degree of reliability depends on different parameters such as, airflow of the fan, density of the air, resistance of the branch with a development of computer programme to calculate the reliability degree. For the networks calculation, it takes the advantages of minimal path between the entrance and exit points of the air and it is based on the disjointed Boolean algebra algorithm. This method includes no mutual boundary between the minimal path fixed by simplification, amplification, absorption and combining operation. The outcomes were intersecting with the needs [16].

A ventilation system was designed manually and programmatically with "Ventsim" software. At the beginning, the manual calculations were performed based on measuring parameters such as, airflow, fan capacity and its location, number of regulators required with its location through the ventilation system then, the GAMS programme was used to modify the Kirchhoff's law of airflow. Finally, the manual calculations and mathematical modification were simulated using "Ventsim" software. The outcomes from the programme had given a precise location for fan and regulators in the ventilation system for the coal mine studied in Western-Razmja by S. Maleki et. al. the total resistance was minified by 14.37% because the programme had eliminated four regulators meaning the efficiency was increased and the ventilation system is more satisfied [17].

Andries J. H. Nel et. al., were claimed a scalable method to optimize the operation of underground mine for the ventilation network and cut down the energy consumption of the ventilation system. The method depends on operational changes of the several parameters such as, wet bulb temperature, volume air flow, mass flow rate, air pressure, diameter of the intake shaft, and energy. Vuma (3D) simulator was conducted to simulate the conditions based on the key performance indicators method. The results were continuously iterative and calibrated according to the set of available data. The obtained results showed that the performance of mine ventilation system increased and the energy consumed by the system was reduced by approximately 23%. The method has a flexibility to apply with the technology of internet of things [18].

A reversal ventilation method is usually dangerous when used to reduce the fire hazardous in the subsurface mine because of the presence of methane gas, but now, a new method is conducted by Grzegorz Pach et. al. to make the reversed method helpful. A numerical simulation technique is applied using "WK-RP" software to calculate the airflow in the ventilation system based on Hardy crossed and Kirchhoff's law methods. The method is not recommended in case of complex system with no branch connections because methane concentration is strictly high in such networks. Since, there are a connection between the branches and the sub-networks in a complex system, this method is applicable because the air flow is fixed when the resistance of regulators changes. This method is reducing the time and give the short rout to escape at the presence of fire [19].

M.A. Semin et.al. have discovered an algorithm to compute the airflow stability during indiscrimination of air resistance through a ventilation system inside Taimyrsky underground mine. In this work, authors proposed two criteria which computed for every branch of the ventilation network:

the guaranteed lower limit of airflow and the deviation ratio of airflow. The resulted information detect the distribution network with minimum air stability and playing a role in the change of the mine ventilation system or part of it. This new algorithm is fast and reliable in calculations of airflow stability of branches and the minimum required number of branches is in between 100 and the software used "AeroSet" is flexible to compute the parameters even if the branches are more than 1000 [20].

The realization of specifications such as information management for mine ventilation, optimization of ventilation system, and 3-D simulation of mine ventilation network were the outcomes of using visual basic, the SQL server database and solid works software. Shen yun used the wind pressure node method integrated with algorithm of iteration by Hardy-Cross. The error limit predicted from the case study of actual node wind volume and actual net hole wind volume were less than 0.00001. The error limit of actual net hole resistance were less than 0.00000008. This algorithm was so efficient in improving the management level, production, and safety of the ventilation system for underground mines [21].

A new algorithm has been written in C^{++} by Mahesh Shriwas, to detect the flow recirculation of air in subsurface coal mine ventilation system. The code depends on the input file including three columns, which "from the node", "to the node", and "the flow rates". This programme is helpful in determining the recirculation of two air paths along mine network and to solve the booster fan circulation [22].

Wang Peng et. al., have elaborated a control system for circulation of ventilation in underground mines. This automatic electrical system was applied in Hongtoushan copper mine to improve the environment of mine at deep level (–287 m) by developing a controlled device to monitor the air quality and mounting a spray system for the cleaning and purifying the circulated air through the roadway. An electrical choke was also mounted to remote the whole system [23].

Curtis Watson et. al., have stated a new method to estimate the roughness profile parameters that uses three dimensional points cloud data obtained by using a mobile Lidar technique. A set of orthogonally sensors were used to scan the environment and to collect the data with the help of some special tool like, multi-functional ventilation meter. Another estimation is held for friction factor which uses both bi-directional method and IBA method. The results showed similarities in the measurement way used in the tunnels of hydropower stations. The friction factor estimation could be calculated from the raw data collected by the measurement tools and there is no real influence on the friction factor estimation at different speed of vehicle carrying a uGPS collected data device [24].

Gao Wei has optimized the ventilation system for underground mines according to ant colony algorithm. This new method is based on the behaviour of ants when they search for food. The ants can communicate with each other through a specific hormone by recognizing the location and density of this hormone then they create their path in order to intercommunion among colony. The method was validated with an application of Handan mine to optimize the ventilation system. The algorithm can solve the excavated roadways combined with the ventilation system optimization and compute the cost of the best ventilation system. This method is suitable for optimization of ventilation network both old and new mines. It can also solve the complicated ventilation system optimization [25].

Zhou Aitao *et.al.*, had asserted a theory of importance of downward ventilation as compared to upward ventilation. Numerical simulation is carried out for the Tangshan coal mine characteristics of gas pressure at stagnation of airflow in the airway and the consequences show, the direction of airflow close to branches is reverse under the downward ventilation conditions in ventilation network and the opposite is true when the upward ventilation considered. Moreover, the discharge of undesirable gases like methane is more difficult when the ventilation system is under downward conditions [26].

2.0 Methodology

In order to design effective ventilation system with minimal defects, first of all, there should be a sequence to follow, starts with surveying of all related parameters using specific tools then a suitable software to simulated the numerical equations and available data.

2.1 SURVEYING

The most important parameters that should ventilation engineer take care of, is the temperature, quantity and pressure. The following instruments are used in mine survey [10]:

- Vane anemometer is used to measure the speed of air with the help of stopwatch to set the time, this instrument needs calibration continuously.
- Inclined tube manometers to measure the differential pressure.
- Pitot-tube to measure the high range of velocity pressure.
- Sling-hygrometer to determine the moist content by measuring relative humidity of the air based on dry and wet bulb temperature.
- Nylon-tubes to measure the 'P' between two points.
- Smoke-tubes to measure the velocity of air flowing at low range.
- Thermometer mercury type to measure the temperatures

2.1.1 Temperature

It is essential to measure the temperature in order to evaluate the specific weight, air cooling power, and humidity. There are two kinds of temperature source, the air temperature and the rock temperature. The air temperature can be measured by a standard thermometer or sling-pyschrometer and for the rocks, temperature can be measured by thermocouple or resistance thermometer including the virgin rock temperature. The following equation determines the virgin rock temperature from a number of readings [10].

$$t_r = \frac{t_{z/2}^2 - t_z t_o}{2t_{z/2} - (t_z + t_o)} \quad \dots (1)$$

where,

t_r is virgin-rock temperature,

t_0 : temperatures measured at rock surface

t_z : temperature measured at depth Z.

$t_{z/2}$: temperature at depth $z/2$ in ^oC.

2.1.2 Air specific weight calculations

This parameter is not measured directly but it is calculated through air properties based on the law of general gases [10].

$$w = \frac{1}{0.287\,T_d}(p_b - 0.378p'_v) \quad \dots (2)$$

Where,

w : air specific weight in kg/m^3

T_d : absolute dry-bulb temperature in Kelvin

p_a : atmospheric pressure in kPa

p'_v : the vapor pressure at dew point in kPa.

2.1.3 Velocity measuring techniques

A part of ventilation survey is measuring the velocity of air. Velocity cannot be measured directly instead an air motion is detected and the velocity is inferred from this effect. As mentioned in 2.1, the most accurate instruments used to measure the velocity are the vane anemometer, smoke-tube, and pitot-tube. Through mine opening, velocity changes due to variation in cross sectional area and the maximum value is when there is a high friction or small sectional area. In calculations, the minimum and maximum values of velocity are not dependent because of error percentage while measuring, instead, the average velocity value is considered in calculations. The optimum measuring of velocity through mine opening or ducts is carrying out by using one of three methods which are [10]:

a. Continues traversing method is to set an imaginary track covered the cross sectional area which must be single, continuous, and nonintersecting. When the instrument of measuring is turning-on, the velocity is detected and the average velocity is calculated by dividing the measured readings upon the time consumed at that point of measurement.
b. In circular cross sectional area of the airway, a multi-alternative circles are constructed and on each circle, four points are measured in the velocity, thus, the total readings are 12, 16, and 20 respectively and the average velocity can be determined. Moreover, the accuracy is increased when the number of points increased too.
c. Fixed point method is to divide the airway cross sectional area into a number of even and equal areas and traversing the instrument slowly for each area. By taking the average velocity for each divided area and the arithmetic average value of average velocities is the desired one.

The mine plan design is an efficient ventilation system literally is shown in the form of flowchart (Fig.1). This flowchart is clearly represent the steps of ventilation system survey starts with instruments preparation and how to calibrate it well, ends with collecting the data and this data will help to solve the numerical equations and simulate it using a suitable software.

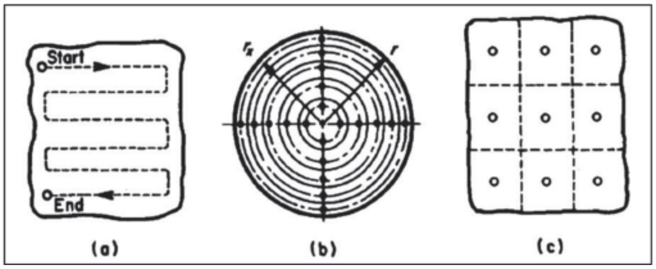

Fig.1 Velocity measurement techniques (a) continuous traversing method (b) fixed point traversing method in circular duct; (c) fixed point traversing method in rectangular duct

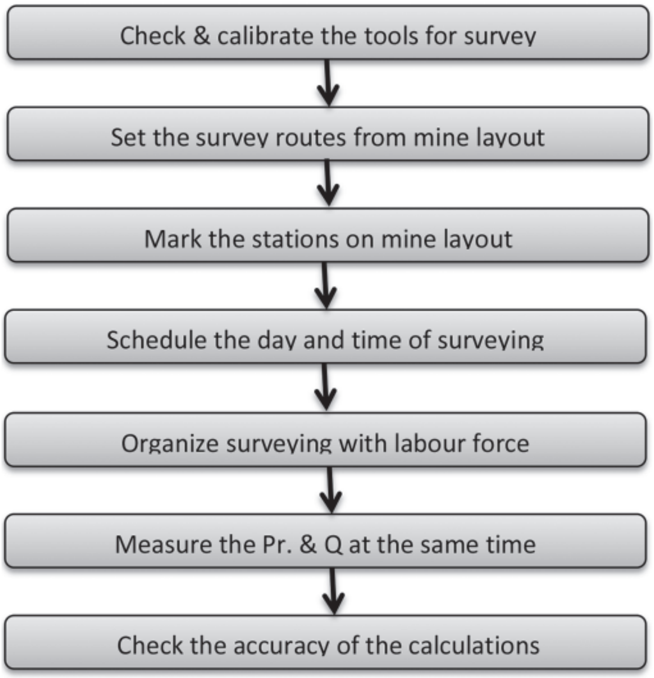

Fig.2 Sequence of ventilation survey

2.2 Design equations and methods

The optimization of air distribution system in underground mine networks is carried out by many researches and so many algorithms have been developed to improve the mine working activities. The basic formulas were used to solve these algorithms are as follow:

1. Atkinson equation

This equation is used to find out the friction loss inside the ventilation system. It is expressed as [1-10],

$$H = \frac{KPLQ^2}{A^3} = RQ^2 \quad \dots (3)$$

where, H is the frictional pressure drop in (Pa); Q is the airflow in (m^3/s); k is the empirical friction factor in ($N.s^2/m^4$); R is the airway resistance in ($N.s^2/m^8$); P is the airway perimeter in (m); L is the airway length in (m); and A is the airway cross-sectional area in (m^2). Atkinson equation is generally presented at standard condition of air density.

2. Kirchhoff's first and second laws

The first law state that the summation of mass flow rates at any junction is equal to zero means, the air volume at entrance of the junction equal the air volume at exit [1].

$$\sum_{i-1}^{b} M_i = 0 \qquad \text{... (4)}$$

where,

$M_i = w_i Q_i$ in (kg/s),

i: represents a particular branch connected to the junction.

b: is the total number of branches connected to that junction.

The second law state that, in any close mesh in the ventilation network, the summation of all energies through air flow is equal to zero [1-7],

$$\Delta\left[\frac{u_i^2}{2}\right] + \Delta zg + W_{fi} = \int_i V dp + F_i \qquad \text{... (5)}$$

where,

$\Delta[ui/2]$ is the change in kinetic energy along the 2 branch (Nm/kg).

Δzi is the change in elevation along the branch (m).

g is the acceleration of gravity (m/s^2).

Wfi is the work input of fans in the branch (Nm/kg).

$f_i VdP$ is the flow work along the branch (Nm/kg).

Fi is the mechanical energy transformed to heat by turbulence within the branch (Nm/kg).

3. Hardy cross method

This method is used to calculate the flow rate in different condition by considering the error changes of air flow and the equation is expressed as [1-10]:

$$Q - Qa + \Delta Q \qquad \text{... (6)}$$

where, ΔQ is the error engaged in the initially supposed airflow quantity. Likewise, ΔH is the identical error in the frictional pressure drop H.

$$\Delta Q_m = \frac{-\left[\sum_{i-1}^{b}\left(R_i Q_{in} 1 Q_{in} 1 - H_{fi}\right) - (NVP)_m\right]}{\sum_{i-1}^{b}\left(2R_i Q_{in} 1 - S_{fi}\right)} \qquad \text{... (7)}$$

where, ΔQ and H_{fi} are the slope and pressure of fan characteristic existed in branch i at proposed flow volume of Q_m and $Q_{in,1}$ is the absolute value of Q_{in} [1-10].

1. Using modified mine ventilation layouts, draw the valent ventilation network. Set all fans, regulators, doors and different ventilation control instruments. State and number the branches and joints. calculate the natural ventilation air density and pressure at each branch. calculate the resistance of branches and do corrections to a standard density of air [1]:

$$R_{i,st} = \frac{W_{st}}{W_{i,o}} R_{i,o} \qquad \text{... (8)}$$

where,

$R_{i,st}$: standardized resistance for branch i.

$R_{i,o}$: Observed branch resistance.

$W_{i,o}$: Observed air density in the branch.

W_{st} : standard density of air (1.2 Kg/m^3).

2. Estimate the airflow volume flowing though each branch of the network and the pressures developed by the fans. When making airflow estimates the following factors should be considered. The Kirchhoff's First Law should be followed at each junction, i.e. the sum of the flow rates into the junction must equal the flow out.

3. Divide the network into a series of meshes. The minimum number of meshes is given by [1],

$$M = B + J - 1 \qquad \text{... (9)}$$

where,

M: minimal number of meshes.

B: number of branches.

J: number of nodes or junctions in ventilation network.

The chosen pattern meshes have to represent the entire network system. In addition to, all meshes must contain no more than one branch which is high resistance and likely, it should not appear in more than one mesh.

4. For each individual mesh, assess the correction factor of mesh by employ Eq.7.

5. Rectify the flow in each individual branch. When rectifying the flow for branches singly forming a mesh, a sign pact for referencing the airflows of the branch surrounding the mesh must be followed. It is proposed to select a clockwise direction enclose each individual mesh to be positive.

6. Recue the process till all values of "Qm become negligibly minimal or are under a prescribed level. At this point, an acceptable balance of airflow will be achieved.

2.3 SOFTWARE PROGRAMMES

The complicated calculations and big data available for an intricacy ventilation network for a mine need to simulate using a suitable software to obtain optimum design and a better performance with little defects in mine process activities. A number of programmes have been used to simulate the ventilation system for underground mines depending on the data obtained from the survey and the basic design equations. Some of them are mentioned in Table 1 with the features of each one.

TABLE 1: A COMPARISON OF VENTILATION SYSTEM OPTIMIZATION AND METHODS USED IN SOME PREVIOUS STUDIES

Author	year	Analysis tool		Algorithm/Method	Problem description and findings
		Software	Manually		
Shen Fei-min	2009	Matlab	Analytical hierarchy process	Fault tree analysis	• Evaluation of index system of ventilation network • Quantitative analysis of fault tree • Improved safety evaluation, rationality, and reliability of mine management system
Wei Lian-jiang	2009	-	topological theory of ventilation network	Path tree depth-first growth	• Difference between theory and application • Automatically simplified the ventilation network • Finds all paths between nodes• Speed up the ventilation analysis
Shen Yun	2011	• Solid work • SQL server • Visual basic	-	• Node wind pressure • Iterative hardy-cross	• The issues are Insufficient function, poorvisualization, and etc. • Solved mine ventilation of information management, disparity of 3d network, and automatically noticed all parameters in network • Optimizing of ventilation system
Feng Wei et. al.	2011	3D ventsim	-	Tracking the recirculation of air- flow	• Complex and hard managing system issue • Improved management system, and reliability of 3D visualizing of system network
Gao Wei	2011	-	Ant colony principle equations	Bionics	• Complication of underground mine ventilation system optimization • Solve scheme optimization • Solve complicated ventilation networks
An Huaming et. al.	2011	Matlab	-	Depth fist search	• Position the recirculation wind of mine ventilation system • Eliminate the recirculation issue for ventilation system
LUO Wengui et. al.	2014	-	Analyzing reliability theory	disjoint boolean algebra	• Issue of mine ventilation system reliability • Find the reliability of the ventilation network and branches • Help with technological transformation, management and design of ventilation network
Mahesh Shriwas et. al.	2014	C++	-	Categories of nodes	• Booster fan recirculation for the ventilation of subsurface mine • the programme detects both single and two recirculating paths
Chen Kaiyan et. al.	2015	Developed programme based on open database connectivity ODBC	Critical path method (CPM) and improved differential evaluation	Finite step iteration	• Issue in distribution of air quantity • Solved the regulations of single & two fans in a ventilation system • Solved the nonlinear complexity • Helped in mine optimization of ventilation network

Author	year	Analysis tool		Algorithm/Method	Problem description and findings
		Software	Manually		
Wac³aw Dziurzy´ nski et. al.	2017	Ventgraph Pozar	Mass balance & Kirchhoff's laws	Changes in airflow	• The problem in ventilation sub-networks sensitivity airflow direction • Evaluated the airflow of sublevels in mine ventilation • Determined the local sensitivity at local airflow
Liang Yuntao et. al.	2017	Ventsim	-	Changes in airflow quantity and pressure loss	• Leakage issue of airflow through a longwall • Isolation of longwall & using of booster fan were proposed to improve the working conditions in underground mine
Andries J. H. Nel et. al.	2018	Vuma (3D) simulator	-	Key Performance Indicator Method	• Optimizing the operation condition • Cutdown energy cost by changing operation parameters • Energy is consumed by 23%
Curtis Watson et. al.	2018		-	Mobile lidar technique	• Estimate roughness parameters to
S. Maleki et. al.	2018	Ventsim and GAMS	Kirchhoff's Lawa	Measuring some parameters such as, airflow, fan position and number of regulators	• Simulate the manual calculations to reduce air resistance • Select the right position for the fan and regulators • Reduce the air resistance by 14.37%
Aiwei Jiang et. al.	2019	Ventsim	-	Establish 3D model of ventilation system	• Evaluate the ventilation system by measuring the thermodynamic parameters through ventilation system • Improve the cost and capacity of ventilation system
M.A. Semin et. al.	2019	Aeroset	-	New algorithm to compute airflow	• Compute the airflow stability due to indistinctive of air resistance • Fast calculations of airflow stability and min. number of branches required.
O. I. Dudar et. al.	2019	Mine-climate	Non-linear equations	1D FEM and Lyon's solution Method and FEM	• Study the convective overall heat transfer and the mass flow rate through ventilation system • Mass flow rate over a year and effect of natural ventilation
V. Adjiski et. al.,	2019	Ansys	-	K-epsilon method	• Calculate the distance between outlet of forcing ventilation system to growth heading under different conditions • Improved the effectiveness, auxiliary forcing, and reduced the energy consumptions
Jinzhang Jia et. al.	2020	-	Mathematical model	Matrix for each branch	• Calculate the sensitivity of wind resistance on ventilation network branches • Select the most effective branch for wind resistance.
Grzegorz Pach et. al.	2020	WK-RP	-	Hardy crossed and Kirchhoff's law methods.	• optimizing reversal ventilation method to reduce fire hazardous • Cutdown escape time and give the shortest rout

3.0 Conclusions

1. This paper has clearly reviewed the most significant methods and softwares used in optimizing the ventilation system of underground mines.
2. As mentioned before, the Kirchhoff's law is the basic phenomena in the design of simple and complex ventilation system in underground mines.
3. Ventsim software is used widely in the simulation because it is most reliable and flexible in the calculations of flow rate, deep, fan position and other individual parameters of subsurface mines as compared to others.
4. It is compulsory to do a survey for several parameters (temperature, pressure, air velocity) which are playing a major role in the simulation of ventilation system process.
5. This review has been interested in the design of underground ventilation system, theoretical background equations, software used and energy consumption because ventilation system has consumed 70% of total mine energy.
6. The most effected and accurate methods in the ventilation system optimization of underground mines are iterative hardy cross, changes in airflow quantity and air flow, finite step iteration and categories of nodes and that is because of considering multi-points each layer of underground mine to analyze them for different parameters and conditions.

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