EXPLORE
International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 3 No. 7, July, 2013

Modelling of Okaba Underground Coal Mine Ventilation System

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ABSTRACT

The design for the pre-ventilation system of the Okaba Coal deposit required 145 m^3/s of air with a main fan pressure of 2.73 kPa, with four booster fans of air volume, 110 m^3/s, 125 m^3/s, 95 m^3/s, 105 m^3/s with fan pressure of 0.63 kPa, 0.87 kPa, 0.47 kPa, 0.50 kPa and with exhaust fan of 70 m^3/s at fan pressure of 0.38 kPa respectively, all required to ventilate the mine. The design is basically on longwall mine as it met the geological condition, engineering properties of the deposit and the design parameters to ensure better safety of miners and offers a great coal recovery. CAD software (AutoCAD) was used in the complete design of the underground coal mine ventilation system for Okaba Coal deposit.

Keywords: *Pre-ventilation, main fan, booster fan, fan pressure, longwall mine, design parameters.*

1. INTRODUCTION

Mining ventilation is an interesting example of a large scale system with high environmental impact. Indeed, one of the first objectives of modern mining industry is to fulfil ecological specifications during the ore extraction and ore crushing, by optimizing the energy consumption or the production of polluting agents. This motivates the development of new control strategies for large scale aerodynamic processes based on appropriate automation and the consideration of the global system (Marx *et al.*, 2001). The approach presented in this research is focused on the mining ventilation process, as 50 % of the energy consumed by ore extraction goes into ventilation (including heating the air). It is clear that investigating automatic control solutions and minimizing the amount of pumped air to save energy consumption (proportional to the cube of airflow quantity) is of great environmental and industrial interest.

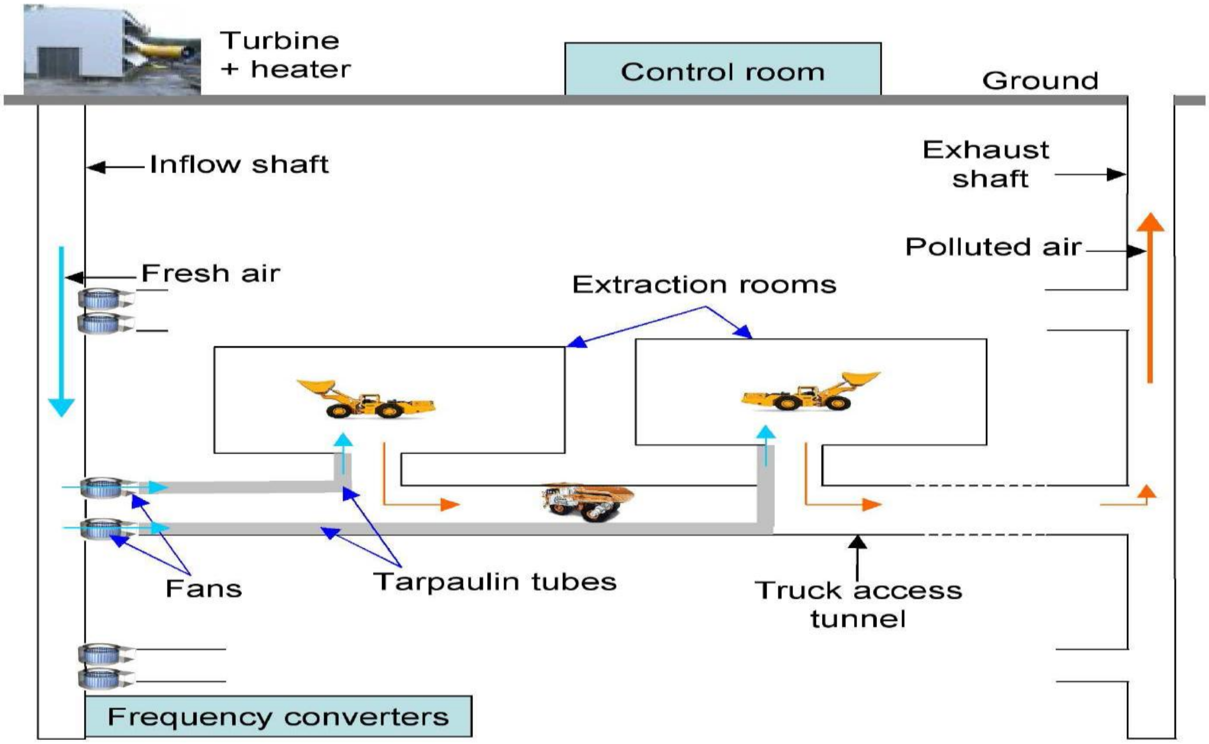

Figure 1: Airflow in an underground mine (After Hinsley, 2005)

The mine ventilation topology is depicted in Figure 1. It is achieved by a turbine and a heater connected on the surface to a deep pit (vertical shaft) that conducts the airflow to the extraction levels. The heater is introduced (in winter time at least) to avoid freezing in the upper part of the shaft and the air is cooled down at high depths (more than 1000 meters) because of the geothermal heating effect (Hinsley, 2005). From the deep pit, fans located at each extraction level pump fresh air to the extraction rooms via tarpaulin tubes. Bad quality air is naturally driven by the pressure gradient and flows from the extraction rooms back to the exhaust ventilation shaft (similar but separate from the inflow ventilation shaft).

1.1 Design Considerations

The basis of effective ventilation of underground mines is the adequacy of the primary ventilation system that is the total volume flow through the mine which is conducted through the major underground workings, normally involving splits into parallel circuits. One of the major constraints on primary ventilation volume which is sometimes not adequately provided for at the design stage is intake air capacity. Whereas high air velocities may be tolerable in return airways and exhaust rises and shafts, (where no personnel are exposed), there is a practical limit to tolerable air velocity in main intakes (shafts and declines) and main development openings where persons travel and work. Dust generation is one problem deriving from intake velocities in excess of 6m/sec. Moreover, high velocities require high pressure gradients and very high power costs to maintain them. A further major consideration with deep and extensive underground mines is the tendency to lean towards series ventilation circuits. Factors which determine total primary volume capacity (and pressure) requirements for a mine include the extent and depth of the mine, the complexity, and the stoping and extraction systems, together with the size of development openings and the equipment used (Head, 2007).

1.2 Mine System and Control Devices

A well designed and properly implemented ventilation system provides beneficial physiological and psychological side effects that enhance employee safety, comfort, health and morale. In planning a ventilation system, the quantity of air it will be necessary to circulate to meet all health and safety standards must be decided at the outset. Once the quantity required has been fixed, the correct size of shafts, number of airways, and fans can be determined. As fresh air enters the system through the intake airshaft(s) or other connections to the surface, it flows along intake airways to the working areas where the majority of the pollutants are added to the air. These include dust and a combination of many other hazards, such as toxic or flammable gases, heat, humidity and radiation (Uchino *et al.*, 2005). The contaminated air passes back through the system along returns airways. In most cases, the concentration of contaminants is not allowed to exceed mandatory threshold limits imposed by law. The return (or contaminated, exhausted) air eventually passes back to the surface via return airshaft(s) or through inclined or level drifts. (Herdeen *et al*, 2006).

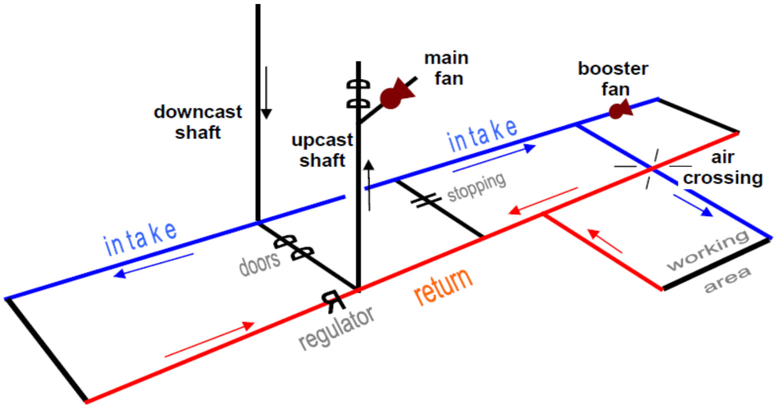

Figure 2: Typical Elements of a Main Ventilation System

2. MATERIALS AND METHOD

2.1 Description of the Study Area

The study area is Okaba in Kogi State of Nigeria, it lies between latitudes $7^0$20’N and longitudes $7^0$25^{1}E and $7^0$45^{1}E. Okaba area consists of lowlands and hills with an average elevation of 274.5m located near the base of the Enugu escarpment. Geologically, Okaba is underlain by Mamu Formation at the northern, northeastern, northwestern and central parts and Ajali Formation at the southern part. The area is drained by many streams that sometimes originate from caves and often flow down the slope. Most of the streams with many tributaries are characterized by dendritic drainage pattern.

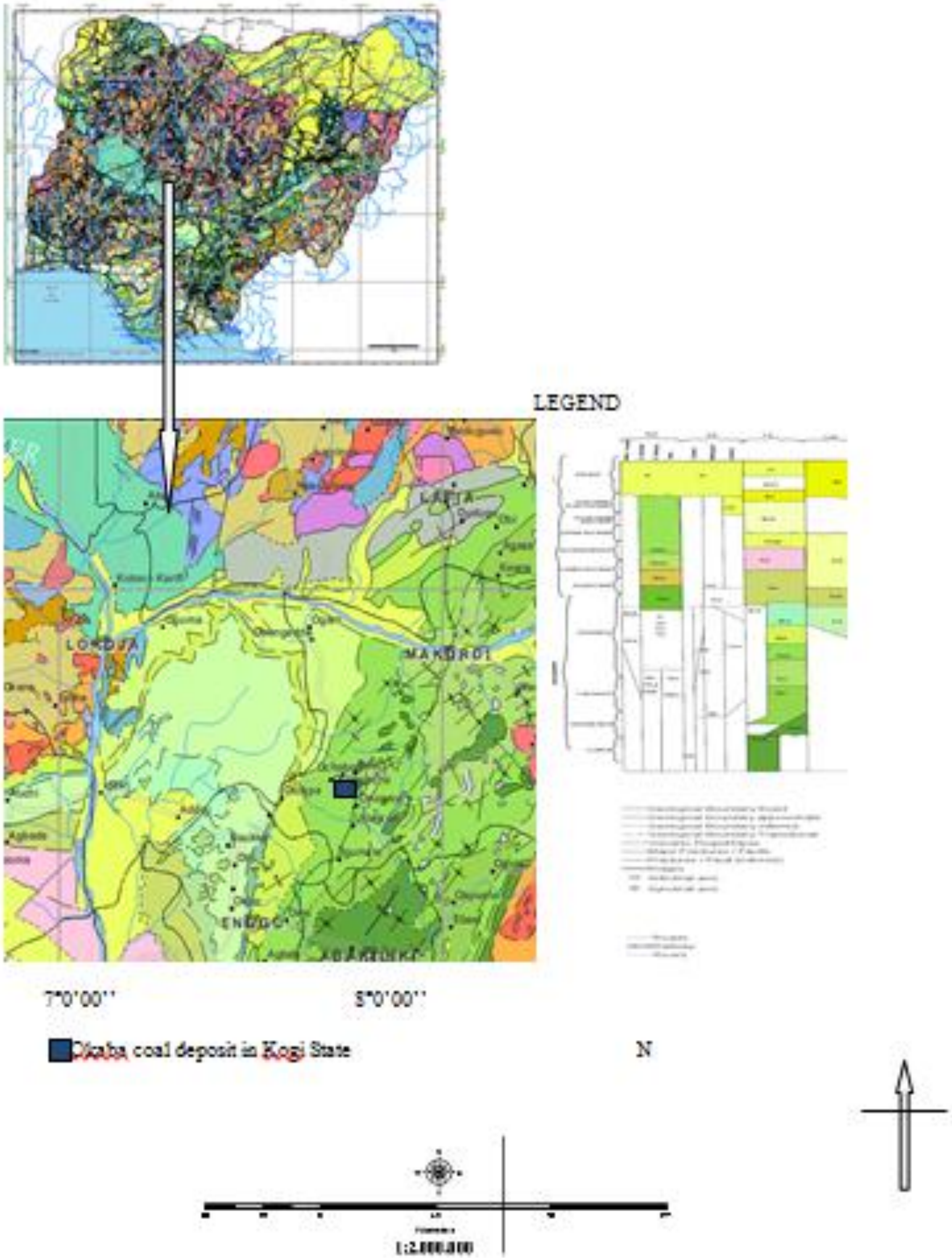

Figure 3: Geological Map of Okaba coal deposit extracted from the Geological Map of Nigeria

2.2 Design of Okaba Underground Coal Mine Ventilation System

Design values for the ventilation system and the resultant engineering properties of the coal deposit were used to design the complete layout of the ventilation system with great attention on the ventilation shaft diameter, diameter of the duct, length of opening roadways, dimensions of panel, number of workers, diesel equipment, poisonous gases and targeted production. The design shows that all the airway types are smooth pipe, the modelled pillar maintained a fixed length while parameters like the pillar width varied in order to generate a factor of safety of 1.6 which is the standard required to safe mining operation in any underground mine. Six fans were installed with one main, one exhaust and the remaining four are booster fans with varying air volume and length of openings basically to determine the mine airflow distribution required for the design with the standard requirement. The Atkinson's equation for head loss and duct resistance for the ventilation designed is determined by the values of O, L,Q,K and A while the air pressure and fan power required by the mine are stated below;

$$H_l = \frac{KLOQ^2}{A^3} \qquad (1)$$

$$R_d = \frac{KlPeri}{A^3} \qquad (2)$$

where R_d is the duct resistance in $\frac{Ns^2}{m^8}$, H_l is the head loss in Pa, K is the frictional constant in Ns^2/m^4, L is the length of the duct in m and O is the perimeter/circumference of the duct in m, A is the cross sectional area of the opening in m^2 and Q is the air volume in m^3/s. The air pressure and the fan power is calculated from the equations below ,

$$P_t = R_d \times Q^2 \text{ (KPa)} \qquad (3)$$

$$Fan\ Power = \frac{P_t \times Q}{\eta} \text{ (Kw)} \qquad (4)$$

Where P_t is the total air pressure, Q is the quantity of air and η is the efficiency of the fan.

3. RESULTS AND DISCUSSION

Table 1 shows the result of estimated design parameters for Okaba underground coal mining ventilation system.

Table 1: Mine Airflow Distribution and Design Paramaters for Proposed Okaba Underground Coal Ventilation Syatem

Fan type	Main fan	Booster fan 1	Booster fan 2	Booster fan 3	Booster fan 4	Exhaust fan
Length(m)	10	4	4	4	4	6
Air volume(m^3/s)	145	110	125	95	105	70
Air pressure(kPa)	2.73	0.63	0.81	0.47	0.57	0.38
Fan power(Kw)	394.70	68.96	101.17	44.41	59.96	26.64
Duct resistance(Ns^2/m^8)	0.130	0.052	0.052	0.052	0.052	0.078
Head loss(Ns^2/m^8)	2722.33	626.68	809.25	339.96	571.00	380.67

The frictional factor for the entry is 0.0028 Ns^2/m^4 (for smooth pipe), the entry cross section was 0.899 m^2, entry perimeter was 3.36 m, the modelled pillar maintained a fixed length, the diameter of the duct was 1.07 m while other parameters like the air volume, length of road way and the pillar width were varied. The design for the pre-ventilation system of the Okaba Coal deposit required 145 m^3/s of air with a main fan pressure of 2.73 kPa, with four booster fans of air volume, 110 m^3/s, 125 m^3/s, 95 m^3/s, 105 m^3/s with fan pressure of 0.63 kPa, 0.87 kPa, 0.47 kPa, 0.50 kPa and with exhaust fan of 70 m^3/s at fan pressure of 0.38 kPa respectively, all required to ventilate the mine.

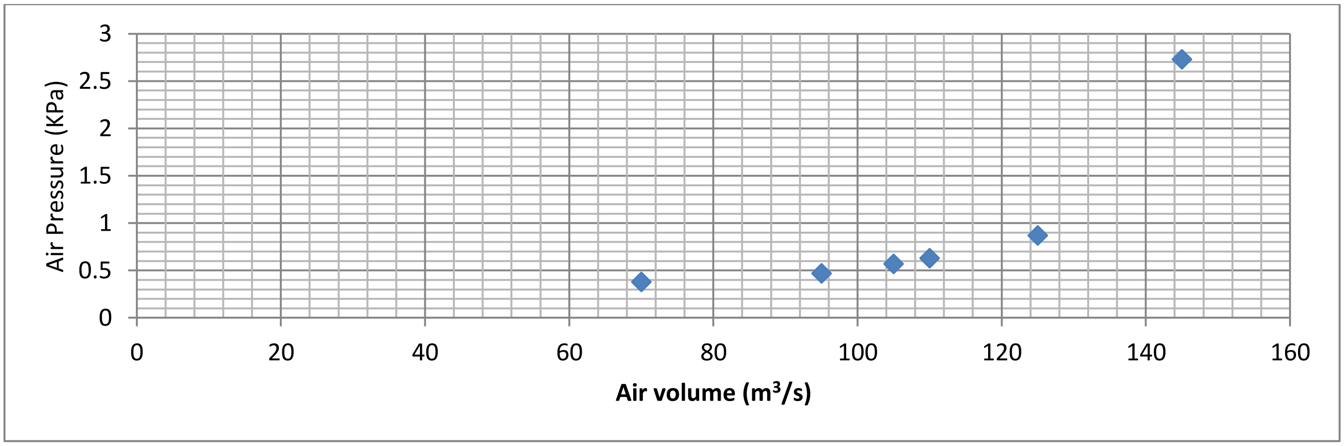

Figure 4: Relationship between Air Pressure and Air Volume

Figure 4 shows the relationship between air pressure (P) and quantity of air (Q) which gives the proportionality of $\frac{P}{Q^2}$ =R where R is the resistance for a particular system with a specific pressure and air quantity. The curve shows that the system resistance in any duct or mine is determined by summation of all the appropriate resistance values which makes the calculation of the pressure of the pressure necessary to cause various quantities of air to flow to be determined. The results of these calculations are then shown graphically to produce the system resistance characteristic. The curve showed a polynomial regression of y = $0.3x^2 – 0.9x + 6.67$ with a R^2 value of 0.946 which indicate a strong relationship between air volume and air pressure.

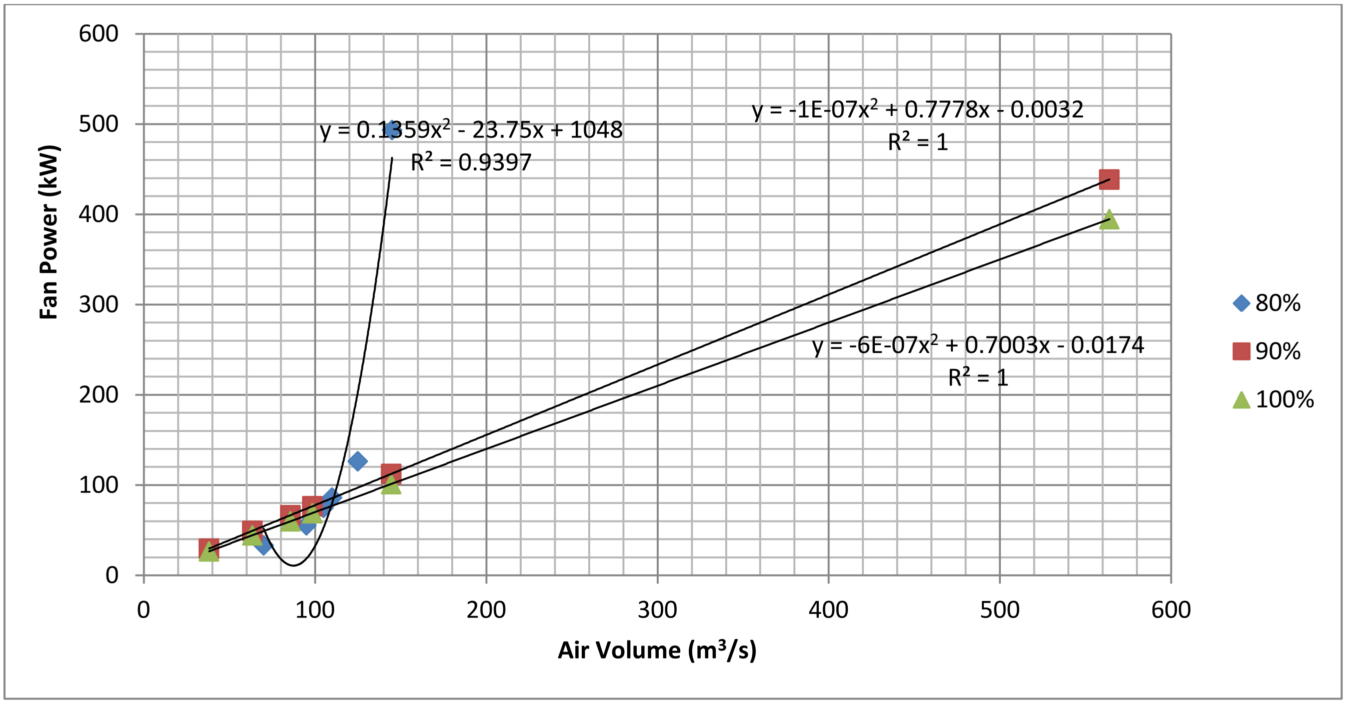

Figure 5: Graph of Air Volume and Fan Power at Different Efficiency

Figure 5 is a curve that showed the fan performance at different efficiency(80 %,90 % and 100 %), the curve for 80 % efficiency of fan gave a polynomial regression of y = $0.135\ x^2 – 23.75\ x + 1048$ with R^2 value of 0.939, the 90 % efficiency gave a polynomial regression of y = $-0.7\ x^2 + 0.777\ x + 0.003$ with R2 value of 1 and the 100 % efficiency of the fan gave a polynomial regression of y = $-0.7\ x^2 + 0.700\ x – 0.017$ with a R^2 value of 1 which indicate a strong relationship between air volume and air pressure. This graph is important because it help determines the cost of power necessary to the fan.

3.1 Okaba Underground Coal Mine Ventilation Design

The main shaft is of 3 m diameter and this is wide enough for the passage of equipment, workers and extracted material to the mine while the ventilation shaft is 1.07 m diameter majorly for housing of the man fan that will be used to send ventilation to the mine. Four booster fans are used to recirculate air to each of the mine face to allow sufficient air to be supplied using flexible duct with 1.07 m diameter. The panel are dimensioned to 2.6 m height, 7 m width and 32 m length which is used in the design data generation as is the one that gave a factor of safety of 1.6 which is the standard for safe mining operation in any underground mine. The system is required to supply 145 m^3/s of air with a main fan pressure of 2.73 kPa to ventilate the mine, the conveyor belt is to be housed at 180 and exist to the surface. As fresh air enters the system through the intake shaft to the surface, it flows along the intake airways to the working areas through the booster fans where the majority of the pollutants may be added to the air such as dust and a combination of many other hazards, such as toxic or flammable gases, heat, humidity and radiation. The contaminated air passes back through the system along returns airways. The return (contaminated) air eventually passes back to the surface via the return shaft.

4. CONCLUSION

The basic principles and answers that were discussed on the research work can be used to a great extent to develop a ventilation system that will be suitable to combat dust and methane inside an underground coal mine.

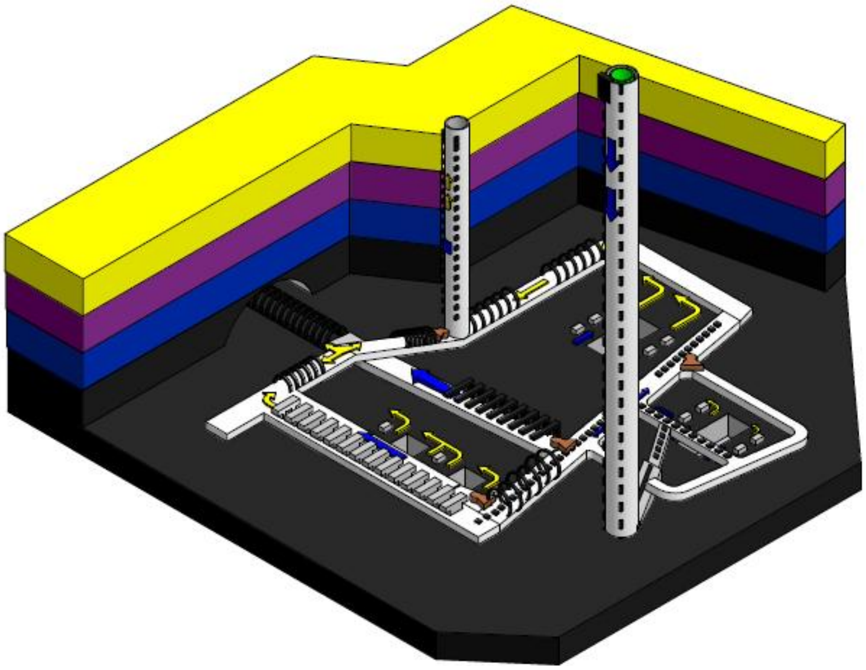

Fig 6: 3D of the Okaba Underground Coal Mine Ventilation System

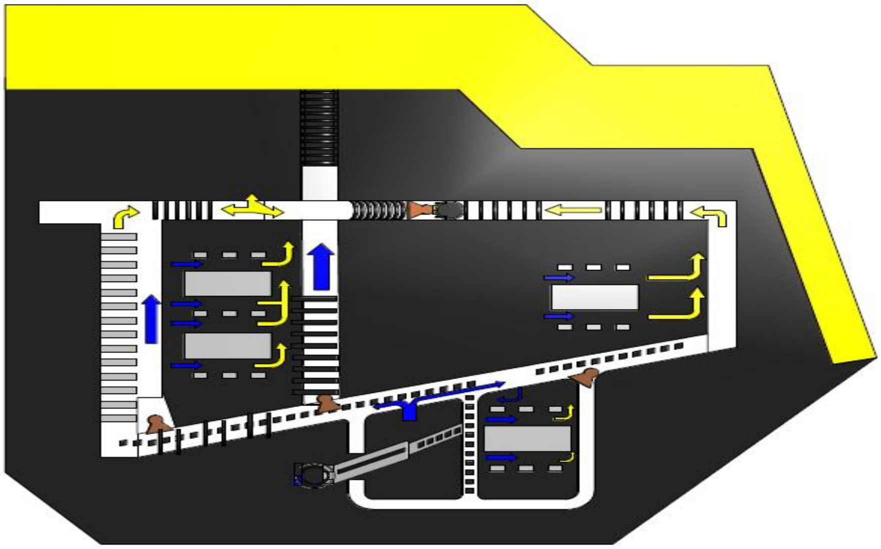

Fig 7: Plan View of the Model

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