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MINE VENTILATION IN A BORD AND PILLAR MINES USING CFD

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ABSTRACT

An underground mine is associated with a proper ventilation system. The ultimate aim is to design a system that is capable of ventilating all working faces, airways and areas underground at minimum costs. In recent years, computational fluid dynamics (CFD) is widely used in mining industry to model the fluid flow behavior in underground mine workings. This paper examines the airflow pattern in mine ventilation system in Bord and Pillar system of mining with the help of two-dimensional CFD modeling. The flow behavior of air is examined between intake and return airways and modified behavior is obtained. The results of this study will assist in understanding the ventilation air behavior and provide a highly effective contaminant removal from the unventilated mine areas. CFD reduces the need of experiments to a large extent and can be used to solve the problems economically in a short time using real life simulation.

Keywords: Mine ventilation, CFD, Bord and Pillar.

1. INTRODUCTION

The basic requirement for the mine ventilation is to provide fresh air for people to breathe and in a state that will not cause any immediate or future ill effects. Because of the processes of mining, if airflow through the workings is not provided, the air would very quickly become stale, contaminated and unfit for human consumption. The ventilation system must therefore be sufficient to deal with the contaminants released during mining. The prime contaminants produced during mining are dust, heat and noxious gases (including water vapour i.e. humidity) and the prime method for dealing with these is an effective ventilation system that supplies fresh air and cool, dilutes gases.

In the 1920's instruments technology advances allowed ventilation surveys to be conducted to measure airflow and pressure drops for airflows for underground ventilation planning. This improved the overall ventilation system and thus the working conditions. Analogous computers were first used to assist in ventilation planning at the University of Nottingham in the early 1950's. However, this was soon replaced by the digital computer in the 1960's. The rapid development of desktop technology in the 1900's will undoubtedly assist the ventilation engineer further.

Shuttleworth [1] provided the first experimental measure of the jets emanating from auxiliary forced ventilation duct into an arched-section roadway. Later Graumann [2] concluded that as one moves away from the outlet of the forced duct the velocity of the free jet decreases while the volume flow in the jet increases, concluding that air is drawn into the jet through entrainment.

Weseley [3] also concluded extensive research into auxiliary ventilation of arched roadways through the use of a 1:2 scale model. Gilles [4] carried the basic scale model tests to demonstrate that dust scrubber system mounted on the machine improve the underground working environment. Tests carried out by Volkwein et al. [5] have shown that a suitable machine-mounted scrubber system can adequately ventilate the face at brattice setbacks of up to 15m. Jayaraman et al. [6] developed a compact, high pressure scrubber system for a continuous miner. Samanta et al. [7] carried out full-scale tests to determine potential dispersion patterns and the transport of dust at the continuous miner face, using a force and machine mounted scrubber fan. Taylor et al. [8] looked in detail at the full-scale airflow patterns near the face with and without the scrubber in operation. Heerden and Sullivan [9] were among the first to employ CFD to investigate ventilation airflow patterns produced around a CM in a development heading. In addition they looked at the movement of dust and methane in the predicted flow fields, although these computational simulations were not validated. Srinivasa et al. [10] used commercial CFD software to predict the airflow patterns and stated that CFD was a useful tool in underground dust dispersion prediction. To this end, recent work by Wala et al. [11] focused on the validation of CFD models against a comprehensive set of data obtained from a series of laboratory scale experiments. The researchers found that the correct choice of software, models and grid was crucial to the generation of reliable numerical results.

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Cannoo [12] demonstrated that recent improvements in CFD modelling, both in terms of the complexity of geometry that can be modelled and the multiphase flow models available, can improve the accuracy of simulations. Taylor et al. [13] developed a test system to measure the airflow profiles at locations between the face and the end of the brattice for different brattice setback distances, intake flow quantities, and entry widths. They found that the entry geometry had a significant effect on airflow patterns. Goodman et al. [14] used a line brattice for a series of laboratory evaluations to examine the impact of brattice setback distance. They showed that increasing brattice setback distance often elevated dust levels, likely due to the reduction of the amount of airflow reaching the face.

2. NUMERICAL MODELLING

Turbulent flow always prevails in mine ventilation. Many mine ventilation problems can be classified as steady state, incompressible turbulent flow without heat transfer.

2.1 Governing Equations

The basic equation to describe the flowing state is partial differential equation, and it's always very hard to be solved, then we turn to discretize the continuous equation by transforming it to algebraic equation, which is easy to solve with mature approaches. The first step for discretization is to divide the zone by grids, which is an important technique, and the form of grid will influence the numerical results. The grid dividing approaches in this paper is finite difference method. Finite difference method is to divide zone to difference grids, replace the solution domain with finite grid nodes, and turn the difference problem to algebraic problem.

The governing equations used by the CFD software package are as follows.

Conservation of mass (continuity equation):

$$\frac{D\rho}{Dt} + \rho\nabla.V_x = 0 \qquad (1)$$

Where,

$\frac{D\rho}{Dt} = \frac{\partial\rho}{\partial t} + V_x\nabla\rho$ is the material derivative.

Conservation of momentum (equation of motion):

$$\rho\frac{DV_x}{Dt} = -\nabla \mathrm{p} - \nabla.\mathrm{T} + \rho \mathrm{f} \qquad (2)$$

Conservation of energy (temperature equation):

$$\rho C_P\frac{DT}{Dt} = \frac{Dp}{Dt} - \nabla.q - \varphi \qquad (3)$$

2.2 Standard *k-ε* model of turbulent equation

Standard k −ε model is the most used method in engineering numerical simulation field.

This model is brought forward by Launder and Spalding, which also is the basic model of turbulent equation model. In this model, an equation about turbulent dissipation rating is introduced based on an equation about turbulent energy, which is.

$$\epsilon = \frac{\mu}{\rho}\left\{\left(\frac{\partial u_i}{\partial x_k}\right)\left(\frac{\partial u_j}{\partial x_k}\right)\right\} \qquad (4)$$

The turbulent viscosity μ_i can be represented by function with k –ε, which is

$$\mu_{i} = \rho C_\mu\frac{k^2}{\varepsilon} \qquad (5)$$

The transport equation of k –ε are

$$\rho\frac{\partial k}{\partial t} + \rho u_i\frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_i}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + G_k - \rho\varepsilon$$

$$\rho\frac{\partial k}{\partial t} + \rho u_i\frac{\partial \varepsilon}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_i}{\sigma_E}\right)\frac{\partial \varepsilon}{\partial x_j}\right] + \frac{C_{1\varepsilon}G_k\varepsilon}{k} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad (6)$$

Where $C_{1\varepsilon}$, $C_{2\varepsilon}$ and C_μ is empirical constant;

G_k is the general item of caused by average gradient.

σ_k and σ_ε is the prandtl number of k and ε.

2.1 Bord and Pillar Mining

Bord and Pillar mining is one of the oldest mining methods. Bord and Pillar is a mining system in which the mined material is extracted across a horizontal plane while leaving "pillars" of untouched material to support the roof overburden leaving open spaces or "room" underground. It is usually used for relatively flat-lying deposits, such as those that follow a particular stratum. One typical bord and pillar structure of coal mine is shown in Figure 1.

2.1 Geometric construction and Grid generation

The geometry specification is important in any kind of CFD simulation. It is desirable to describe the physical boundaries that contain the fluid as accurately as possible, especially for engineering problems, where usually the effect of one or more man-made, or design, objects are to be predicted. Any inaccuracy in the specification of the boundary surfaces may produce a misleading result.

Geometric setup and grid generation used to take a month or longer to perform. Nowadays, the geometry setup and grid generation processes have been made easier, since most of the packages have CAD systems and automatic grid generation modules.

The computational mesh (grid) was generated using the GAMBIT as shown in Figure 2. In this mesh generation 2-D Bord and Pillar is plotted and three heading development is shown. There are two intakes and one return.

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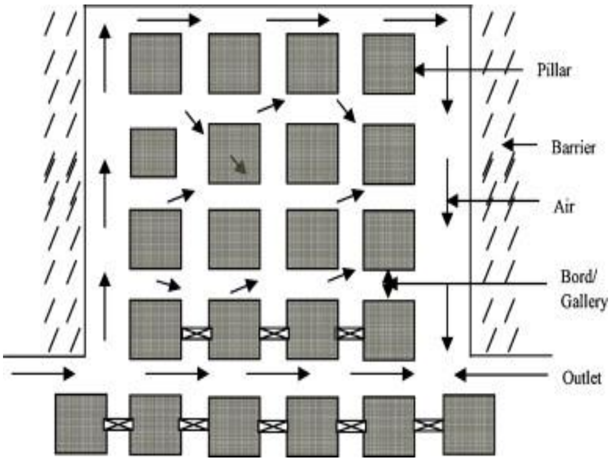

Figure 1: Bord and Pillar structure of coal mine

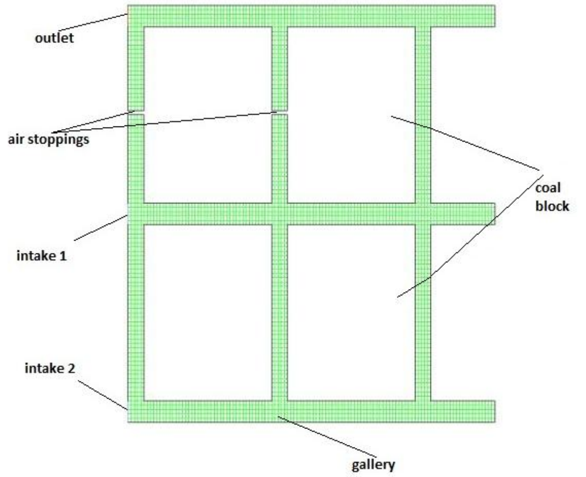

Figure 2: Grid display of 2 × 2 Bord and Pillar structure

2.2 Flow specification and boundary condition

As an example of such specifications, for the analysis discussed below, the models were specified as steady state, turbulent, single phase, and single species flow. Body force and heat transfer effects are small and neglected. The fluid was air with a density of 1.1767 kg/m^3 and a viscosity of 1.5×10^{-5} kg/sm. At the inlet, the velocity component or mass flux, turbulent energy and dissipation rate were specified. At the outlet, pressure was specified as zero. Blockages were defined to eliminate the surplus region, and walls were specified for a non-slip condition.

Coal pillar size=2*3 units,
Gallery size=0.5 unit
Velocity=1 unit/sec,
Gauge Pressure at outlet = 0 Pascal
[1 unit= 8 m]

3. RESULTS AND DISCUSSIONS

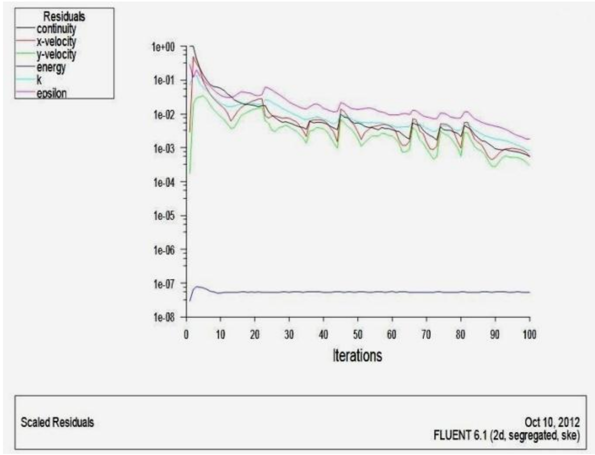

Figure 3: Residuals of iteration of 2 × 2 Bord and Pillar structure

Figure 3 shows the Plotted graph of velocity, energy, k, epsilon for the no. of the iterations for the values obtained from the case study. As the graphs are converging the results obtained from the case are correct.

Figure 4 shows the temperature contour of the 2×2 board and pillar structure. The temperature is almost same at every point in the structure except at the point where air quantity is too less.

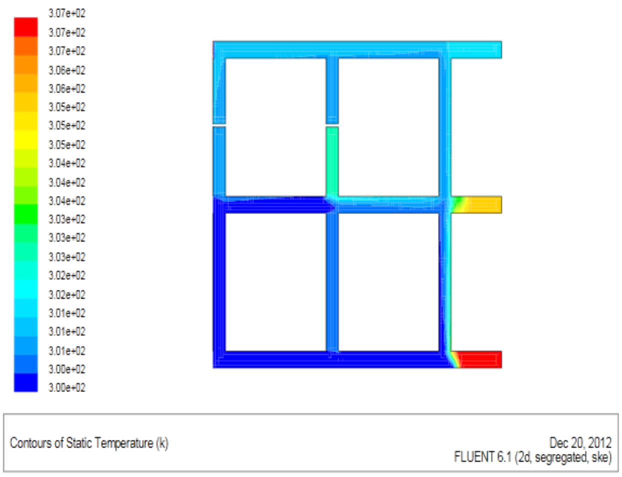

Figure 4: Temperature contour of 2 × 2 Bord and Pillar structure

Figure 5 shows that pressure at the intake side is more than that at the outlet side as can be. The pressure difference takes place exponentially.

The Figure 6 shows the velocity vector of the air. The air is entering from the two intakes and through the galleries finally leaves through the outlet. The air quantity varies at each point depending upon the amount of air reached at that point for this ventilation system. The air quantity is low at the development face so we need to provide an alternative source of air flow at the face to have a safe working environment.

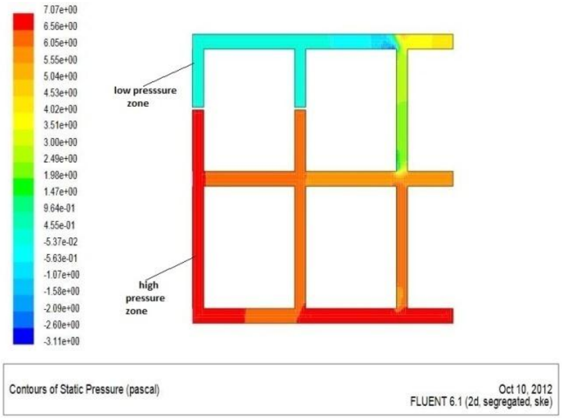

Figure 5: Pressure contour of 2 × 2 Bord and Pillar structure

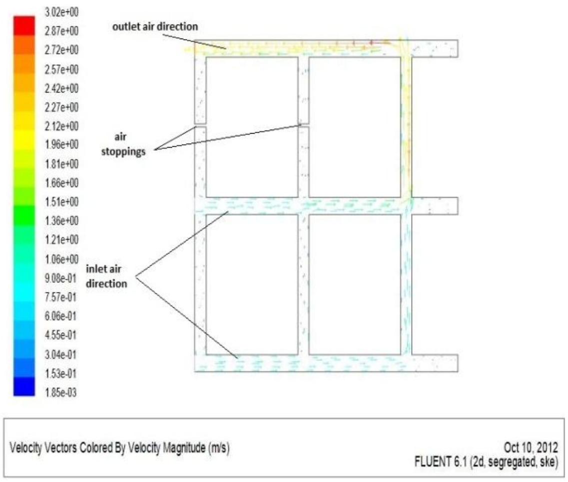

Figure 6: Velocity vector of 2 × 2 Bord and Pillar structure

4. CONCLUSIONS

It is concluded that validated computational flow modelling can improve the fundamental understanding of the airflow patterns. The interpretation of the results produced by these CFD models will improve the planning and operation of ventilation systems, in order to improve the dilution and removal of any gas or dust liberated during the cutting operations.

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NOMENCLATURE

Symbol

T	Temperature	(K)
C	Specific heat	(kJ/kg-K)
ρ	Density	Kg/m^3
∇q	Change in heat	kJ
V	Velocity	(m/s)

Subscripts

p	Constant pressure
x	Velocity in axial direction
μ	Constant viscocity

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