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RESEARCH ON FLOW SHIFT LAW OF POROUS MEDIA IN GOAF BASE ON THE UNSTEADY AIRFLOW THEORY

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Abstract

Based on unsteady flow theory, supported by the theories of mine ventilation, fluid mechanics and infiltration flow through porous media, a mathematical model of fluctuating airflow in the porous media of goafs of mines is established. Features of distribution of flow field in goaf when airflow fluctuating are researched by numerical simulation, and the distribution of flow field is tested with the help of an experiment model which was designed and done by the authors. The results show that the numerical simulation and experiment agree well. This shows that the mathematical model of flow field of porous media in goaf of mine established in the paper can be used to research distribution of flow field in goaf and flow shift law.

Keywords: Unsteady airflow theory, Mathematical model, Numerical simulation, Porous media, Goaf.

1. Introduction

Conventional mine ventilation theory regards the airflow in tunnel as stable flow. Whereas practical research shows that the movement of the airflow in mine is affected by many impersonal factors and airflow condition of its dynamic variation, stable airflow theory still cannot accurately describe the actual flow of mine [1]. Unstable airflow in tunnel is affected by many factors together such as the cross section distribution of mine, hoist equipment of mine lifting and dropping in the tunnel, air fan running unsteadily, dead end tunnelling. Coal resource exploited leading to the increase and distortion of the tunnel length, belt conveyer and tramcar running, personnel treading, damper turning on and the change of fan window area, the change of nature wind pressure and hot pressure action (temperature variation) in tunnel [2], slipping well dropping mine, parvis dripping water as well as network structure form and the tunnel windage matching ratio relation [3] and so on. Those mainly affect wind pressure and the frequent variation of airflow and bring about airflow fluctuating in the tunnel. All of these make the flow field of the goaf be quite unconstant, it's harmful to ventilating safety of mine which can cause serious mine disaster.

Much of the spoil removed during the mining process is left underground. This loosely packed rock known as goaf partially blocks the excavated area, and can be treated as a porous medium. So seeking for a convenient and reliable approach to research the distribution of flow field in goaf and flow shift law is very important and necessary. Establishing mathematical model of porous media about airflow fluctuating in goaf of mine and numerical simulation can solve these problems.

2. Mathematical Model of Flow Field of Goaf

When gas is flowing in goaf, it can be regarded as infiltration flow in porous media, as shown in Fig. 1. There is a difference between losing stock every goaf and the compaction degree of remaining coal and the distance of enter and return wind lane also, so there is more difference between infiltration flow wind speed of goaf everywhere and there is more variation in Reynolds number of goaf [4, 5]. Large amount of research home and abroad shows that there are laminar regions, turbulent regions and transition regions at the same time [6-9]. But people find by the experiment that there is very small range near excavating coal working face in goaf, its flow field are turbulence flow and transition flow as its wind speed of air leak is faster, but other area is small Reynolds number infiltration flow similar. In this area, the following conditions prevail: average diameter is about 0.001 m, average velocity is under 1.2 m/s, coefficient of viscosity is about 1.42110^{-4} m^2/s, so Reynolds number is under 8.4 [10]. Therefore, the laminar flow is the main flow form of flow field of goaf.

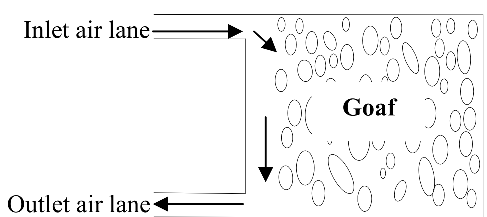


Fig. 1. Gas Flow in Goaf.

Generally, deep airflow velocity in goaf is slow and the flow is laminar flow, airflow rule obeys Darcy law; middle airflow condition in goaf is transition flow and airflow rule of it deviate Darcy law; airflow velocity of goaf approaching the working face brim is faster and the flow is turbulent flow, the airflow rule obeys two times of ventilating resistance rules [11-13]. So the airflow flowing rule of goaf can be described by nonlinearity infiltration flow. The nonlinearity infiltration flow equation is put forward by Bachmat [14]:

$$K' \bullet J' = \frac{\nu}{g}\left(1 + \frac{qD_m\beta}{n\nu}\right)q' \tag{1}$$

where, *K*' is penetration coefficient, two ranks tensors, approximately expressed as scalar to actual goaf K,m^2; *J*' is water power gradient, $J = -\nabla h$ J; ∇ is Harmi operator, expressed by $\nabla = e_i \frac{\partial}{\partial x_i}$; *h* is pressure head, mmH_2O; ν is fluid flow coefficient of kinematic viscosity, m^2/s; *g* is acceleration of gravity, 9.81 m/s^2; *q* is specific discharge m/s; β is geometry figure coefficient; *n* is porosity, dimensionless, $n = 1 - \frac{1}{K_P}$; K_P is expansion coefficient, dimensionless.

From the Dupuit—Forchheimer equation :

$$q' = n \bullet v' \tag{2}$$

Substitute this into Eq. (1), the following expression can be obtained:

$$-\nabla h = \frac{\nu \bullet n}{kg} \bullet \left(1 + \frac{\beta D_m \nu}{\nu}\right)v' \tag{3}$$

If $A = \frac{\nu \bullet n}{kg}$ and $B = \frac{\beta D_m n}{kg}$, expression of Eq. (3) becomes

$$-\nabla h = (A + B\nu)v' \tag{4}$$

Equation (4) is the nonlinearity infiltration flow law of the airflow in goaf, Darcy law and ventilation resistance law are special examples of it.

The stream function is inducted, makes:

$$v_x = \frac{\partial \psi}{\partial y},\ -v_y = \frac{\partial \psi}{\partial x},\ v_n = \frac{\partial \psi}{\partial L} \tag{5}$$

At the same time Eq. (4) is carried through mathematical conversion:

$$(A + Bv)v_x + \frac{\partial h}{\partial x} = 0,\ (A + Bv)v_y + \frac{\partial h}{\partial y} = 0 \tag{6}$$

The following expression can be got by the Galerk integral expression which Galerk method reduces formula in Eq. (6) :

$$\iint_{\Omega}\left[(a+b)\sqrt{\left(\frac{\partial \psi}{\partial x}\right)^2 + \left(\frac{\partial \psi}{\partial y}\right)^2}\right]\left[\frac{\partial \psi}{\partial x}\frac{\partial \delta\psi}{\partial x} + \frac{\partial \psi}{\partial y}\frac{\partial \delta\psi}{\partial y}\right]dxdy =$$

$$= \int_{B1}\left[(a+b)\sqrt{\left(\frac{\partial \psi}{\partial x}\right)^2 + \left(\frac{\partial \psi}{\partial y}\right)^2}\right]\frac{\partial \psi}{\partial n}dL \tag{7}$$

where Ω is the two dimension plane area of goaf.

3. Establishment of Boundary Conditions

Generally there are two kinds of boundary conditions for actual goaf:

1) Pressure distribution of working face boundary :

$$h_o(x, y) = \frac{\partial h}{\partial L} \tag{8}$$

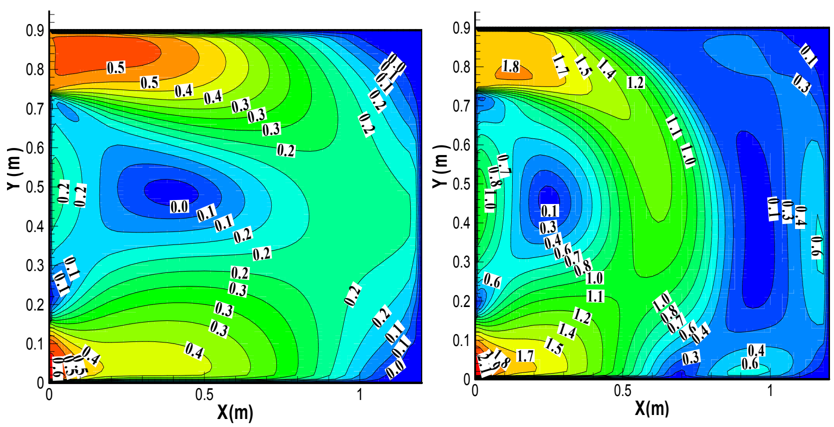
Different pressure distribution represents different ventilation condition according to ventilation resistance law, air capacity and pressure. Different pressure distribution value is obtained by changing air capacity in working face boundary point.

2) Boundary of the velocity distribution of the goaf solid wall, which means there is no air leak, namely:

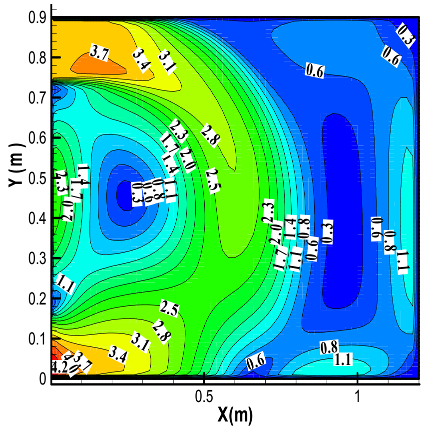
$$V_x = V_y = 0 \tag{9}$$

4. Simulation Results

The geometry dimensions of experimental model are entirely same with numerical stimulation model so as to compare numerical stimulation results with experimental results conveniently. The air velocity value obtained in experiment acts as the velocity of entrance when simulation is carried out. The geometry dimensions of the entrance are 1.2 m × 0.9 m, the width of air inlet and outlet is 0.16 m, the width of porous media section is 1 m. Simulation results are shown in Fig. 2.



(a) *v* = 0.5 m/s **(b) *v* = 1.78 m/s**

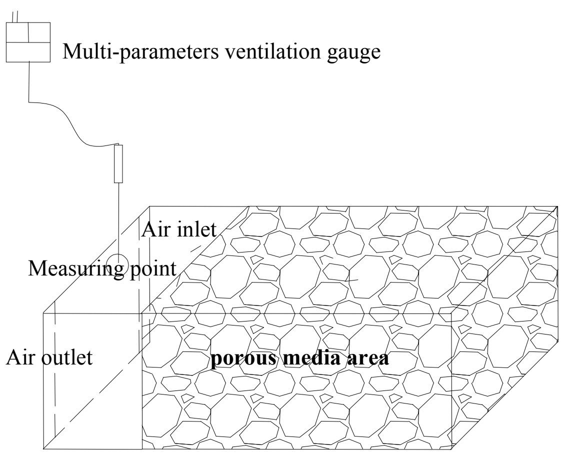


(c) v **= 3.6m/s**

Fig. 2. Velocity Distribution Contour of Unequal Inlet Air Velocity.

5. Experimental Validation

As goaf physical dimension is very wide, it is impossible to experiment according to the physical dimension, a small model is put up in lab. A cuboid outline as the goaf and the porous material which is filled in it as the remained coal collapsed area of goaf. There are two side plackets: one is air inlet and the other is air outlet as airway inlet and outlet of working face, as shown in Fig. 3. Since the air flow of airway inlet is jet flow and it is considered as uniform flow, the air inlet adopts uniform air supply curtain to supply air to guarantee uniform jet flow, as Fig .4 shows.



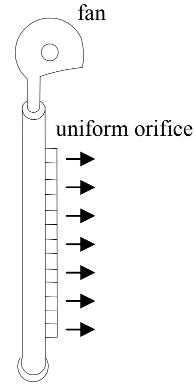


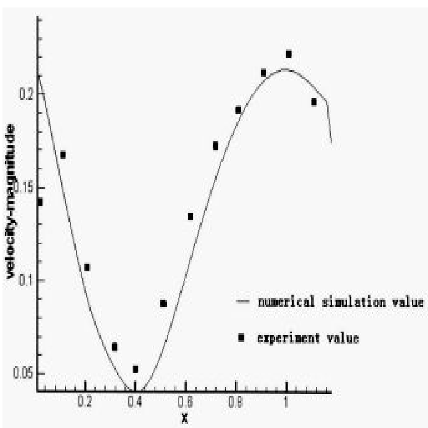
Fig. 3 Sketch of Experimental Device of Goaf.

Fig.4 Sketch of Uniform Air Supply Curtain.

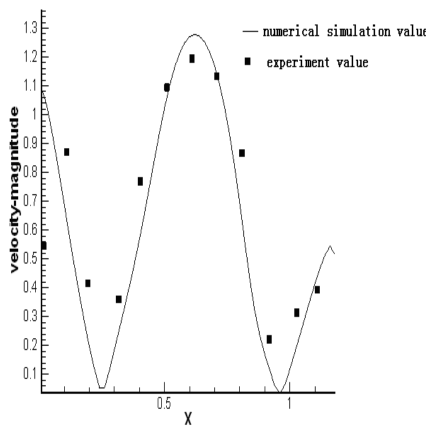
The outline and orifice plate are made by toughened glass, the white froth filled acts as porous medium; the wind column is made by PPR pipe chiseled slot and the interior adds cuniform bar. The velocity is measured by multi-parameters ventilation gauge; using uniform air supply curtain to meet uniform jet flow, the air flow is provided by the blow fan. The geometry dimensions of model are (1200×900×600) mm. There are 12 even spacing orifices in the middle lane of the top of the experimental model, the mean wind velocity of every point is measured.

6. Results Comparison

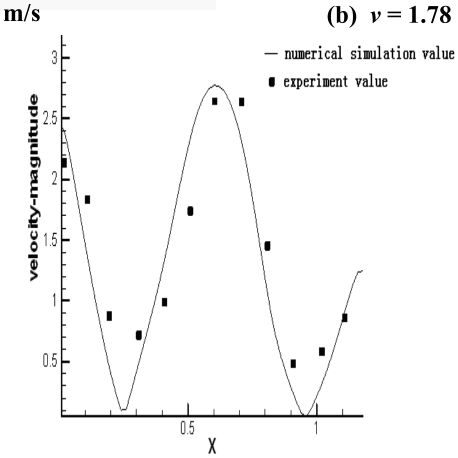
Numerical simulation results and experiment results are contrasted, as shown in Fig. 5. Figure 5 shows that the results of numerical simulation and experiment are coincident. The mathematical model of porous media of unstable flow field in goaf established in this paper can be used to research the distribution of flow field in goaf and it provides a effective method for the fire prevention and cure in goaf.



(a) $v = 0.5$ **m/s**



(b) $v = 1.78$ **m/s**



(c) $v = 3.6$ **m/s**

Fig. 5. Comparison of Experimental and Numerical Simulation Results of Unequal Inlet Air Velocity.

7. Conclusions

- It's hard to determinate flow shift law of porous media in goaf when air flow pulsating. Establishing mathematical model of porous media about airflow fluctuating in goaf of mine and numerical simulation can solve these problems.
- The approach benefits to research flow shift law of porous media in goaf when air flow pulsating, unsteady air flow in mine influence on the flow field of goaf and ventilating safety of the mine.
- According to above research results, some measures should be taken. These can enhance the stability and dependability of ventilating system, broaden and perfect mine ventilating theory, propose the countermeasures of eliminating influence of pulsating air flow on ventilating safety system of mine.

Acknowledgements

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