University of Wollongong
Research Online

Coal Operators' Conference

Faculty of Engineering and Information Sciences

2011

The Efficiency Study of the Push-pull Ventilation System in Underground Mine

Xichen Zhang
1Missouri University of Science and Technology, Rolla MO, USA

Yutao Zhang
1Missouri University of Science and Technology, Rolla MO, USA

Jerry C. Tien
1Missouri University of Science and Technology, Rolla MO, USA

Publication Details

X. Zhang, Y. Zhang and J. C. Tien, The Efficiency Study of the Push-pull Ventilation System in Underground Mine, 11th Underground Coal Operators' Conference, University of Wollongong & the Australasian Institute of Mining and Metallurgy, 2011, 225-230.

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

THE EFFICIENCY STUDY OF THE PUSH-PULL VENTILATION SYSTEM IN UNDERGROUND MINE

Xichen Zhang, Yutao Zhang and Jerry C Tien

ABSTRACT: Auxiliary ventilation refers to the systems that are used to supply fresh air to the working faces in dead end including the use of a push-pull arrangement. There are many advantages of using such a system when compared to other methods. It has been shown that for headings longer than 30 m, auxiliary fans are the only practicable means of delivering the required air quantities. Besides air quantities, air quality is another critical issue for evaluating the ventilation efficiency in underground mines. Forcing and exhausting ducts used in the push-pull system are closely associated with the ventilation efficiency. This paper focuses on the efficiency evaluation for a push-pull ventilation system by using two methods, the dead zone and the mean age of air. By using the CFD technology, the air velocity and air quality are calculated and compared in four different cases. The results of evaluation will be identical by using these two methods. It is concluded that in the push-pull ventilation system, the position of the forcing duct plays a major role on the ventilation efficiency. Also, when the forcing duct position is determined, there must be a particular position of the exhausting duct to provide best ventilation efficiency.

INTRODUCTION

Mine ventilation is critical in all underground mining operations. It provides the miners with fresh air at proper temperature and humidity, and more importantly it removes pollutants out of the mine. However, due to increasing resistance and leakage from stoppings, the main ventilation system may not be capable of ventilating remote or more localized areas underground and auxiliary ventilation is needed to assist the main ventilation system.

An auxiliary ventilation system can usually be classified into three basic types, line brattice, fan and duct systems, and "ductless" air movers. Previous researches have shown that the fan and duct systems are the only practicable means of producing the required airflows for headings with length greater than 30 m (McPherson, 1992). A fan-duct combination can be forcing, exhausting or a combination system of them. Considering that the forcing system will potentially add pollutants to the airstream at the working face, and the exhausting system can cause uncontrolled recirculation, a more common approach is to have a push-pull system, as shown in Figure 1. By comparing the advantages of forcing and exhaust duct, this push-pull ventilation system, especially the forcing system with exhaust overlap, is in practice adopted widely during the process of mechanised advancing because of the following advantages.

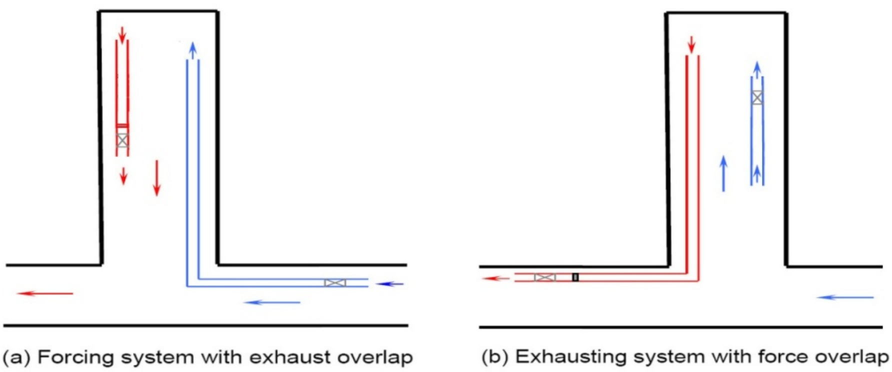


Figure 1 - Overlap systems of auxiliary ventilation (McPherson, 1992)

Firstly, the entire cost of the system for (a) might be cheaper, because the cheaper flexible duct can be used for the long forcing duct, which is also easier to transport and enable leakages to be detected more readily. Secondly, a dust filter or a cooling system can be added in the exhaust duct for (a) in order to

Missouri University of Science and Technology, Rolla MO, USA, xztx5@mail.mst.edu

purify the air and keep a comfortable environment for the miners. Finally, in some emergent cases, the auxiliary funs may stop running, the layout like (a) can make sure that there is still a little fresh air going into the working face (Wang, 2007).

In the push-pull auxiliary ventilation system where the forcing system with exhaust overlap is used, the fresh air is delivered to the working place through the forcing duct, forced to flow through the working area where mixing with the pollutant air takes place, and then exhausted out of the blind heading through the exhaust duct after filtering out the dust by the depurative device at the end of the exhausting duct. Many factors, such as the pollutant air distribution in the working place, selection of fans and ducts, forcing and exhausting device capacities, and duct layout, will all affect the ventilation efficiency. This paper focuses only on the effect of duct layout.

THE EFFECT OF PUSH-PULL SYSTEM LAYOUT

Problem description

In the push-pull ventilation system, airflow behavior through blowing out from a forcing duct into an exhausting duct is influenced heavily by the surroundings. Meanwhile, for the two push-pull ventilation systems in Figure 1, the recirculation or zone with low velocity may exist depending on the ducts layout, as shown in Figure 2 (Niu, *et al.*, 2006; Wang, 2008). Lf and Le represent the distances between the working face and the forcing duct outlet and the exhausting duct inlet, respectively. So, to avoid local recirculation, the position of the forcing duct and exhausting duct must be carefully determined. The effective range (Lr in Figure 2), which is defined as the distance between the duct outlet and the place where the velocity goes down to the required value by the regulation, is critical in placing a vent duct. To meet the minimum airflow requirement on the working face, the distance between the duct inlet or outlet and the working face should be less than the effective range.

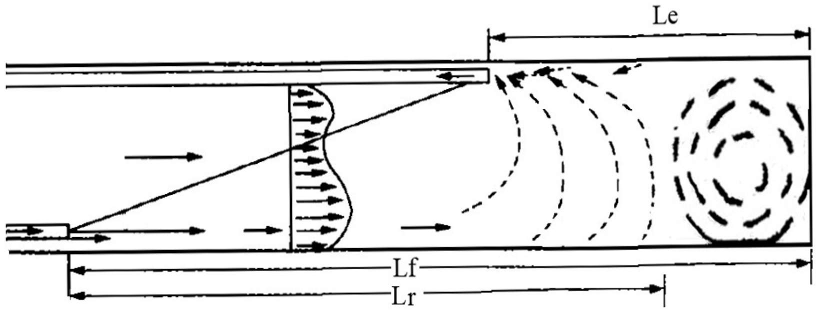


Figure 2 - The air flow distribution in the push-pull ventilation system (Based on Niu, *et al.*, 2006; Wang, 2008)

For a forcing duct, the effective range of a semi-confined jet can be determined by using the formula below (Bai, 2005):

$$\bar{x} = \frac{a \cdot x}{\sqrt{S}} \tag{1}$$

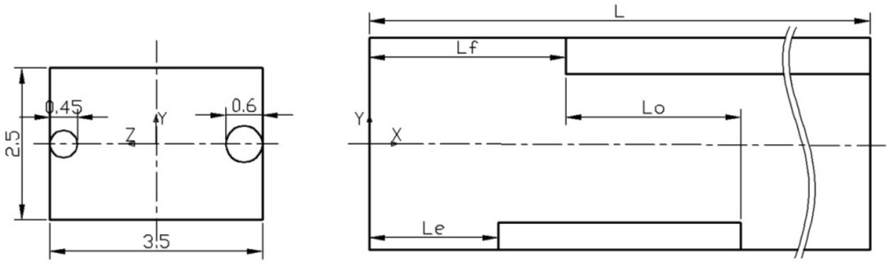
$$\frac{\bar{v}}{v_0} \cdot \frac{\sqrt{S}}{d_0} = 0.177 \cdot (10\bar{x}) \cdot e^{(10.7\bar{x} - 37\bar{x}^2)} \tag{2}$$

Where: $\bar{x}$ is the non-dimensional effective range;
x is the effective range, in m;
a is the turbulent coefficient;
$\bar{v}$ is the average velocity of backward flow, in m/s;
v_0 is the jet velocity in outlet, in m/s;
S is the cross-section area of the roadway, in m^2;
d_0 is the duct diameter, in m.

There is no comparable equation available to determine the effective range for an exhausting duct in a confined space, because the situations are more complicated. Neither theoretical nor experimental equations have been successfully used to determine the effective range. The only approach would be through computer simulation using such package as FLUENT to optimize the exhausting duct location.

Geometric model

Considering a rectangular entry with 2.5 m in height and 3.5 m in width using a push-pull auxiliary ventilation system with 0.6 m diameter forcing duct and a 0.45 m diameter exhausting duct. Both ducts are hung parallel to each rib at half height between the roof and floor. The exhausting duct is 30m in length. The geometry model is built as shown in Figure 3. To avoid the influence of the far end on the flow field, the model length L is set to 100 m. Lo represents the overlap areas.



(a) Front view **(b) Top view**

Figure 3 – Dead-end geometry model

Numerical model

The standard $k - \varepsilon$ model is used to calculate the turbulent flow distribution. The air age, which is defined as the time since gaseous elements enter into a domain through inlet, is introduced as an important index of evaluating the confined space environment (Sandberg, 1981). Since the transport equation for calculating air age is not an available model in FLUENT, the equation is incorporated in the CFD simulation by using user defined functions (UDF) which are developed into a separate code based on the platform of FLUENT and then are compiled into executable functions in the solver. An energy equation is not considered because heat transfer is ignored in this simulation. The air density is also assumed to be constant. The transport equation of air age has the same form with the standard $k - \varepsilon$ model shown below:

$$\frac{\partial}{\partial x_j}(\rho u_j \phi - \Gamma_\phi \frac{\partial \phi}{\partial x_j}) = S_\phi \qquad (3)$$

Where ρ and μ are the density and the velocity of the air, respectively. Universal variable $\emptyset$, the diffusivity coefficient Γ_ϕ, and the source term S_ϕ are defined in Table 1.

Table 1 - Governing equations table

Equation Type	ϕ	Γ_ϕ	S_ϕ
Mass Continuity	1	0	0
X-Momentum	u	μ_{eff}	$-\frac{\partial p}{\partial x}+\frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial x})+\frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial x})+\frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial x})$
Y-Momentum	v	μ_{eff}	$-\frac{\partial p}{\partial y}+\frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial y})+\frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial y})+\frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial y})-\rho g$
Z-Momentum	w	μ_{eff}	$-\frac{\partial p}{\partial z}+\frac{\partial}{\partial x}(\mu_{eff}\frac{\partial u}{\partial z})+\frac{\partial}{\partial y}(\mu_{eff}\frac{\partial v}{\partial z})+\frac{\partial}{\partial z}(\mu_{eff}\frac{\partial w}{\partial z})$
Kinetic Energy	κ	$\mu+\frac{\mu_t}{\sigma_k}$	$G_k-\rho\varepsilon$
Dissipation Rate of Kinetic Energy	ε	$\mu+\frac{\mu_t}{\sigma_\varepsilon}$	$\frac{\varepsilon}{k}(G_k C_1-\rho\varepsilon C_2)$
Air Age	τ_p	$\mu+\frac{\mu_t}{\sigma_\tau}$	ρ

In these equations, u, v, and w are the velocities in x, y, and z direction; k and ε are the turbulence kinetic energy and its rate of dissipation, respectively; $\tau_p$is the average air age; P is the pressure; ρ is the density; G_k represents the generation of turbulence kinetic energy due to the mean velocity gradients; g is the gravity; μ_{eff} is the effective viscosity, equal to the laminar viscosity μ plus turbulent viscosity μ_t, which is calculated with $\mu_t = \frac{C_\mu \rho k^2}{\varepsilon}$; C_1, C_2, C_μ, σ_k, σ_ε and σ_τ are constants in the model.

Boundary conditions

Fresh air is supplied at the entrance to the forcing duct with an average velocity of 12 m/s (or an air quantity of 3.4 m^3/s), delivered to the working face with a temperature of 300 K (27°C). The pollutant air then enters the exhausting duct at a velocity 12 m/s and is delivered out of the exhausting duct. The pressure in the airway outlet is set equal to that of the atmosphere. The boundary condition for the air age equation is set to zero at the forcing duct inlet. No slip velocity is present along the walls and ducts, which means flow velocities are set to zero.

Results and discussion

To simplify the simulation, the distance Lf (Figure 3) between the forcing duct outlet and the face is constant at 10 m based on the effective range equations (1) and (2). Four different cases, in which the distance Le between the exhausting duct inlet and the face varies from 2 m to 5 m, 8 m, and 12 m, are designed and calculated for comparison. The simulation results are summarized and discussed below.

The effect of ducts layout on dead zone

To guarantee a healthy and comfortable environment during operation, mining regulations always set a minimum air velocity in the working place (Wang, 2008; Anon, 2001; Parra, *et al*., 2006); air velocities in the face area are different but varied little. In this paper, the minimum velocity value is set at 0.3 m/s. This value is used to evaluate the ventilation efficiency by using the dead zone method. Dead zones are defined as those regions where velocity is under a minimum value. As mining operations are performed in the vicinity of the working place, this region shows the greatest pollutants' concentration. So, to make sure the environment is suitable for mine workers, air renewal should be ensured at this area. By assessing the dead zones' shape and distribution in this area, it is possible to evaluate air quality of a ventilation system.

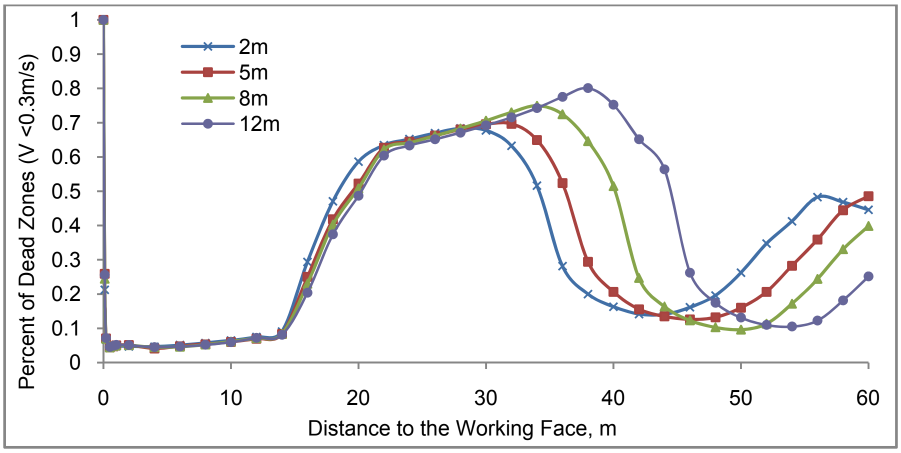


Figure 4 - The dead zones percentages in four cases

Figure 4 shows the dead zones percentages on the cut-planes (normal to X-direction in the model) which are parallel to the working face. In the simulation, the distance between the forcing duct outlet and the working face is constant (i.e. Lf = 15 m). While the distance between the exhaust duct outlet and the working face is variable (i.e. Le = 2, 5, 8, 12 m). The dead zone percentage is defined as the dead zone area divided by the area of the whole section. In all four cases, percentage value follows the same pattern. In the area close to the working face, the percentages are lower than 10% until about 14 m from face, then a sudden increase to the peak before it starts to drop. This sharp increase of the low velocity area is a result of a recirculation region formed in the area between plane 14 m and 21 m. The percentage of dead zone increasing from 10% to 60% means a sharp decrease in ventilation efficiency. Close examination of the data shows that the recirculation region is formed in the overlap area. The range of the region is determined by the duct layout. The forcing duct outlet determines where the recirculation starts, while the exhausting duct inlet determines where the recirculation ends. The recirculation zone in the overlap areas has the worst ventilation in the entire simulation area.

The effect of duct layout on air age

Sometimes, ventilation velocity alone does not tell the whole story since air velocities can be over the required value by the law because of the recirculation, quality of air may not meet statutory requirements. Using "air age" may be appropriate to complement system evaluation. Lots of researches on studying local mean age of air have been done previously (Roos, 1999; Bartak, *et al.*, 2001; Karimipanah and Awbi, 2002). The governing equation of the air age follows the characteristics of the transport equation (Sandberg, 1981). At the flow inlets the air age starts with zero, which is used as a reference or starting point. It increases along the streamlines. If there is recirculation or zone with very low velocity in airflow, the air age will be higher in that region compared to areas outside of the recirculation zone.

Figure 5 shows mean air age on various cross-sections in the entry with the horizontal axis starting at the working face. Generally, as the distance moves away from the working face, the air age trends to increase. The air age increases steadily from the very beginning and faster at 10 m, starting to level off after reaching its peak. Results show that the recirculation region is formed in the overlap area with its range determined by the relative position of both the forcing and exhausting ducts. The forcing duct outlet determines where the recirculation starts, while the exhausting duct inlet determines where the recirculation ends. In addition, the recirculation region in the overlap area has the worst ventilation where the air velocity is low and the polluted air will stay in this region for a long time.

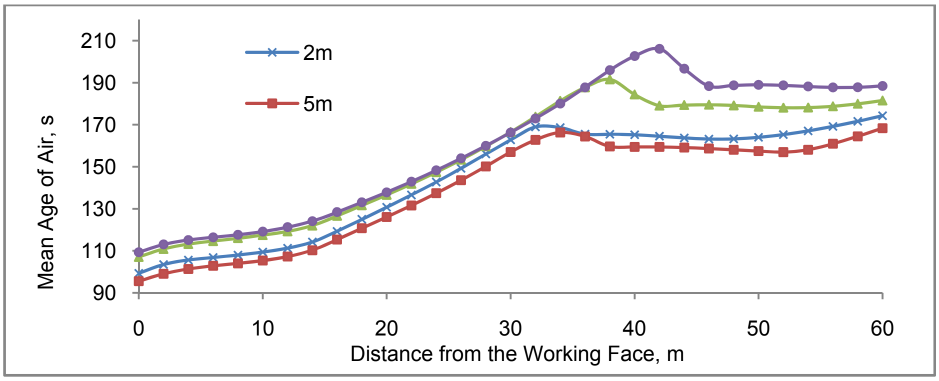


Figure 5 - The mean air age in four cases

Among these four cases, the air age of case 5 m is shortest at every cross-section. Between plane 10m and 34 m, the air age in this region increases from 105 s to its local maximum value of 166 s. Right after its peak, it decreases and then continues to go up at cross-section at 52 m. In this particular model, the 5 m case provides the best ventilation efficiency, followed by 2 m, 8 m, and 12 m.

CONCLUSIONS

The numerical models are used to analyse the ventilation efficiency under four different cases. The ventilation system is evaluated using two different criteria: dead zone analysis based on the velocity distribution and the distribution of local mean ages of air. Both approaches yield similar results.

For a long dead end using a push-pull ventilation system, the recirculation region can be formed in the overlap area, and make the ventilation conditions worse. In the area close to the working face, only the forcing system can determine where the recirculation region starts. The layout of the exhausting system has big influence on where the recirculation ends.

Another finding is that there is a particular distance between the exhausting duct inlet and the working face that can provide the best ventilation efficiency. In this paper, for four different cases, 2 m, 5 m, 8 m, and 12 m, the ventilation efficiencies are almost the same when considering the velocity. However, the 5 m case provides the best ventilation efficiency by considering the air quality.

REFERENCES

Anon, 1999. *Queensland Coal Mining Safety and Health Act 1999*, 251p.

Bai, K S, 2005. *Pump Fan and Fluid Mechanics*, 274p. China Machine Press: Beijing, China.

Bartak, M, Cermak, M, Clarke, J A, Denev, J, Drkal, F, Lain, M D, Mardonald, I A, Majer, M, and Stankov, P, 2001. Experimental and numerical study of local mean age of air, *7th International IBPAS Conference*, pp 773-779 (Rio de Janerio, Brazil).

Karimipanah, T, and Awbi, H B, 2002. Theoretical and experimental investigation of impinging jet ventilation and comparison with wall displacement ventilation, *Building and Environment*, 37(12), pp 1329-1342.

McPherson, M J, 1992. *Subsurface Ventilation and Environmental Engineering*, 905p. Chapman and Hall: London.

Niu, B L, Qiu, H J, and Chen, Y X, 2006. Experimental study of dust removal technology with combined ventilation in heading face in gushuyuan mine, *Mining Safety and Environmental Protection*, 33(6), pp 44-46 (in Chinese).

Parra, M T, Villafruela, J M, Castro, F, and Me'ndez, C, 2006. Numerical and experimental analysis of different ventilation systems in deep mines, *Building and Environment*, 41, pp 87-93.

Roos, A, 1999. On the effectiveness of ventilation, Ph.D. Dissertation, Eindhoven University of Technology, Holland.

Sandberg, M, 1981. What is the ventilation efficiency? *Building and Environment*, 16, pp 123-35.

Wang, D M, 2007. *Mine Ventilation and Safety*, 263p. China University of Mining and Technology Press: Xuzhou, China.

Wang, D M, 2008. *Mine Ventilation and Safety*, 355p. China University of Mining and Technology Press: Xuzhou, China.