Journal of Loss Prevention in the Process Industries 46 (2017) 45–53

Contents lists available at ScienceDirect

Journal of Loss Prevention in the Process Industries

journal homepage: www.elsevier.com/locate/jlp

Unsteady simulation for optimal arrangement of dedusting airduct in coal mine heading face

Guoqing Shi [a, b, *], Maoxi Liu [a], Zhixiong Guo [b, **], Fangkun Hu [a], Deming Wang [a]

[a] *College of Safety Engineering, China University of Mine Technology, Jiangsu, 221008, China*
[b] *Department of Mechanical and Aerospace Engineering, Rutgers, The State University of New Jersey, Piscataway, NJ 08854, USA*

A R T I C L E I N F O

Article history:
Received 2 November 2015
Received in revised form
3 November 2016
Accepted 9 January 2017
Available online 11 January 2017

Keywords:
Dedusting
Airduct
Ventilation
Heading face
Dust explosion
ATEX

A B S T R A C T

To optimize dedusting efficiency in coal mines, a model of dust movement in heading roadway with far-pressing-near-absorption ventilation system was built. The empirical drag force model was applied into the unsteady inter phase coupling modeling of air and dust flow. The Discrete Phase Modeling in Fluent was employed to solve the problem and unstructured grids were utilized to mesh the complex 3-D roadway with different airduct allocations. Results show that the dedusting efficiency with the dedusting fan in the air return side is obviously better than that with the fan in the middle of the heading machine. The dedusting efficiency decreases within creasing distance between air inlet and heading section. When this distance is 2.0mwith airduct in the air return side, it has the best dedusting efficiency; in which the dust concentration in the front of roadway after 60 s of digging and cutting decreases from 1150 mg/m^3 to 365 mg/m^3; the average dust concentration in roadway decreases from 597 mg/m^3 to 144 mg/m^3; and the total dedusting efficiency reaches up to 75.88%.

1. Introduction

Dust has become a serious problem in coal industry worldwide, causing pneumoconiosis in coal workers and coal dust explosions in mines (Wang et al., 2017; Du et al., 2010). The most common dust explosion occurs in underground coal mines. In coal mine tunnel, coal dust explosion is usually caused by gas explosion. Moving at the speed of sound, pressure wave resulting from gas explosion lifts the deposited coal dust in the air. Then gas flame reaches the coal dust causing a dust explosion that is severer than the first one (Beidaghy Dizaji et al., 2014; Bidabadi et al., 2014a, b; Bidabadi et al., 2013; Soltaninejad et al., 2015). In China, over 85% of underground mines face the risk of coal dust explosions, and there were 103 recorded coal dust explosion accidents in China between the years of 1949 and 2007, resulting in 4613 casualties (Zheng et al., 2009). Pneumoconiosis caused by dust threatens human health. According to statistics, pneumoconiosis caused approximately 69,377 deaths among U.S. underground coal mine workers from 1970 to 2004, and over $39B was paid to compensate these workers (Colinet, 2010).

Heading faces in underground coal mines possess the characteristics of highly density of dust and relatively narrow space (Kissell, 2003; Qin et al., 2011). High concentration of dust affects normal operation because it may block workers' sights, leading to accidents. It may also cause dust explosion. How to effectively control coal mine dust has become a key issue (Wang et al., 2015).

Ventilation dedusting technology has been widely used for dust controlling. However, inproper dedusting may increase the risk of dust explosion (ATEX 1999/92/EC, 1999; Going and Lombardo, 2007; Robert Zalosh, 2015). During the dedusting process, local concentration of dust may increase to a level higher than the lower explosion limit. Thus, it is critical to control ignition source to prevent dust explosion. Potential ignition sources in dedusting include static electricity caused by airduct, heat accumulation by running machine, etc.

Ignition sources can be present and active when combustible dusts are processed. These can be related to static electricity build-up and discharge, hot electrical and mechanical parts, sparks generated by electrical and non-electrical equipment, friction effects of components. In order to minimize the occurrence and the effectiveness of these ignition source, the dedusting system design shall be carried out in accordance with international ISO, IEC and EN standards covering ignition source control of ELECTRICAL and

---

* Corresponding author. College of Safety Engineering, China University of Mine Technology, Jiangsu, 221008, China.
** Corresponding author. 98 Brett Road, Piscataway, NJ 08854, USA.
E-mail addresses: shiguoqing2001@163.com (G. Shi), guo@jove.rutgers.edu (Z. Guo).

http://dx.doi.org/10.1016/j.jlp.2017.01.011
0950-4230/© 2017 Published by Elsevier Ltd.

Nomenclature

C_a	Average dust concentration in roadway, kg/m^3
C_D	Drag coefficient
d_P	Diameter of particle,m
$\vec{F}$	Force, N
$\vec{g}$	Vector of gravity, ms-2
L	Distance between the airflow inlet and the heading section, m
L_1	Length of roadway,m
L_2	Distance between pressing airduct and the heading section, m
m_{total}	Total mass of dust produced by heading in roadway, kg
P	Pressure, N/m2
Re	Reynolds number
t	Time,s
$\boldsymbol{u}$	Velocity vector of air, m/s
$\boldsymbol{u}_P$	Velocity vector of particle, m/s
uvw	Velocity components, m/s
V	Volume, m3
W	Width of roadway, m
x, y, z	Coordinates, m
Greek symbols	
μ	Kinetic viscosity of air, m2/s
ρ	Density of air in roadway, kg/m3
ρ_P	Density of particle (skeletal density), kg/m3
η_{total}	Total dedusting efficiency

NON ELECTRICAL equipment.

Airduct ventilation dedusting technology has been popularly adopted for removing dust in coal mine heading face, and its dedusting efficiency is significantly influenced by the location of the dedusting airduct. In order to design optimal processes for dedusting, dust concentration and its distribution for different dedusting airduct allocations should be understood. CFD simulation techniques have the traits of light workload, short time-consumption, and highly repeatability. Compared with field measurement, the results of CFD simulation can reflect the movement process and distribution of dust intuitively and comprehensively. Wang et al. (2006, 2007) established the face model of coal roadway heading and compared the steady state distributions of dust under the condition of forced ventilation and exhaust ventilation. Ren and Balusu (2010) established a three-dimensional (3-D) model of coal face and researched on the movement and distribution of dust in coal face. Wang et al. (2011) modeled a far-pressing-near-absorption ventilation heading face, compared the distribution of steady state under different pressure extraction ratios, and specified the optimal pressure extraction ratio between 1.1 and 1.3. CFD simulation techniques have avoided the limitations of poor lighting underground and difficult observation and been widely applied. Previous simulation of dust movement in heading face mainly assumed steady state, which could reflect the dust distribution status after infinite longtime of working (Hu et al., 2012).

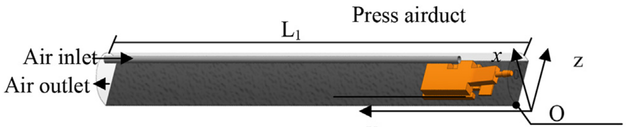
In fact, there is no steady distribution of dust in heading face, since digging and cutting process is always interrupted by working condition and driving procedure. Digging and cutting process will be ceased before the distribution of dust concentration has reached a steady state. Moreover, under complex ventilation conditions like far-pressing-near-absorption ventilation, the airflow could be easily interfered by moving items such as heading machine and other equipment, so that unsteady state physical phenomenon like Karman vortex street flow is more suitable for dust simulation in heading face. Unsteady state simulation can intuitively reflect the movement history of dust and investigate the time development and distribution in addition to the three spatial dimensions (Hu et al., 2013).

In this paper, we take the heading face scene of whole rock in Tangshan Donghuan Coal Mine as an example to establish our simulation model. Unsteady state model of far-pressing-near-absorption ventilation heading face is considered, and solved to investigate the history of movement and distribution of dust during digging and cutting process. This study aims to compare ventilator arrangements for optimal dust prevention in far-pressing-near-absorption heading roadway.

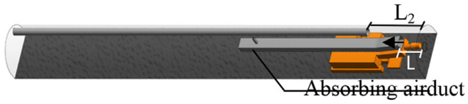
2. Far-pressing-near-absorption ventilation roadway model

2.1. Simulation model and meshing

Fig. 1(a) shows the simulation domain of a heading roadway without dedusting fan. The dimension of the model is similar to the heading face scene of whole rock in Tangshan Donghuan Coal Mine, China. There are two common arrangements for dust-preventing absorbing airduct: 1) the absorbing airduct is located in the middle of roadway, as showed in Fig. 1(b); or 2) the absorbing airduct is located on the air return side of roadway, as shown in Fig. 1(c). We compared the non-dedusting case (Fig. 1(a)) with 6 dedusting models via varying distance, L, between the airflow inlet(Inlet of absorbing airduct) and the heading section. For Fig. 1 (b) arrangement, $L = 2.0$, 3.5, and 5.0 m, respectively; for Fig. 1 (c), $L = 2.0$, 3.0, and 4.0 m, respectively. Other dimensions are defined as: L_1 is the length of roadway and its value is 50 m; the section is semi-arched with the upper semi-circle's radius of 2.75 m and lower rectangle's radius of 1.05 m; the body of heading machine is simplified as a cuboid with outer dimensions of 10 m × 3.6 m × 1.8 m (length × width × height). Distance between the heading machine and the heading section is about 5 m.The pressing airduct with diameter of 0.8 m is simplified as a hollow cylinder that is hanged on the side of roadway. Its distance from road floor is 2.5 m and distance from side wall is 0.2 m. It exits at 7 m away from the section (L_2 in Fig. 1 (b)). The pressing airduct installed in the middle



(a)w/o dedusting fan



(b) absorbing airduct is located in the middle.

(c) absorbing airduct is located on the air return side

Fig. 1. Heading roadway models of different airduct arrangements.