Advanced Materials Research *Online: 2012-02-27*
ISSN: 1662-8985, Vols. 476-478, pp 1297-1304
doi:10.4028/www.scientific.net/AMR.476-478.1297

Research of Ventilation and Dust Removal Technology for Whole Rock Fully-mechanized Excavation Face

Gang ZHOU[1, 2, 3, a], Deming WANG[2, b] , Weimin CHENG[1, 3, c] , Gang PAN[1, d] and Sen CAO[1, e]

[1] College of Resources and Environmental Engineering, Shandong University of Science and Technology, Qingdao, China 266590;

[2] Mining Engineering Post-doctoral Research Station, Faculty of Safety Engineering, China University of Mining and Technology, Xuzhou, China 221116;

[3] Key Laboratory of Mining Disaster Prevention and Control, Ministry of Education, Shandong University of Science and Technology, Qingdao, China 266590

[a] ahsdzhougang@163.com, [b] wdmcumt@163.com, [c] chengmw@163.com,

[d] threven@163.com, [e] caosen19880712@163.com

Keywords: whole rock; fully-mechanized excavation; numerical simulation; closed dust source; wet vibration cyclone fan

Abstract: The whole rock fully-mechanized excavation with big cross section, high rock hardness and strong cutting intensity of fully-mechanized coal winning machine has a higher dust concentration than coal roadway excavation, so ventilation dust removal technology is in need in whole rock face. Based on the dust migration and distribution numerical simulation in whole rock tunnel excavation, optimization design of long pressing and short pumping hybrid ventilation and dust removal system were carried out. Eventually, the comprehensive dust prevention measures with air curtain closing dust source, dust electromotor exhausting dust and retaining curtain capturing dust were realized in this paper, which achieved a good removal efficiency of dust.

Introduction

With continuous improvement of the mine production mechanization degree, blasting driving has been gradually instead by comprehensive digging in rock heading face of large mine with high production and efficiency. With the rapid increase of driving footage of the tunnel, high concentration dust makes a serious threat to safety production in mine and physical and mental health of the miners. So the wet ventilation dust removal system which is suitable for rock heading face should be researched to reduce the dust concentration greatly and make the production safe and clean.

Basic Controlling Equations of the Gas-particle Two-phase Flow Fluid Mechanics

Because of the higher concentration dust in fully mechanized excavation face which belongs to dense flow, Euler-Euler two-fluid flow model was used to construct controlling equations of gas-solid two-phase flow.

Mass conservation equation:

$$\frac{\partial}{\partial t}\left(\varepsilon_i \rho_i\right)+\nabla\cdot\left(\varepsilon_i \rho_i \vec{u}_i\right)=0,\ i=g,s. \tag{1}$$

Where, ε is volume percentage, %; ρ is density, kg/m^3; t is time, s; $\vec{u}$ is velocity, m/s; g and s means gas phase and solid phase separately and their volume percentage must meet the equation:

$$\varepsilon_g+\varepsilon_s=1. \tag{2}$$

Momentum conservation equation:

$$\frac{\partial}{\partial t}\left(\varepsilon_g \rho_g \vec{u}_g\right)+\nabla\cdot\left(\varepsilon_g \rho_g \vec{u}_g \vec{u}_g\right)=-\varepsilon_g \nabla p_g+\nabla\cdot\vec{\tau}_g+\varepsilon_g \rho_g \vec{g}-\beta\left(\vec{u}_g-\vec{u}_s\right). \tag{3}$$

$$\frac{\partial}{\partial t}\left(\varepsilon_s \rho_s \vec{u}_s\right)+\nabla\cdot\left(\varepsilon_s \rho_s \vec{u}_s \vec{u}_s\right)=-\varepsilon_s \nabla p_g-\nabla p_s+\nabla\cdot\vec{\tau}_s+\varepsilon_s \rho_s \vec{g}+\beta\left(\vec{u}_g-\vec{u}_s\right). \tag{4}$$

Where, p is pressure, Pa; τ is stress tensor, N/m^2; $\vec{g}$ is gravitational acceleration, m/s^2; $\beta\left(\vec{u}_g-\vec{u}_s\right)$ means gas-solid drag force.

The expression of drag force function is [1]:

$$\beta=\frac{3}{4}\frac{\varepsilon_s\varepsilon_g}{d_s}\rho_g\left|\vec{u}_r\right|C_{D0}f\left(\varepsilon_g,\mathrm{Re}\right)H_D\,. \tag{5}$$

Where, d_s is the particle size, μm; $\vec{u}_r$ is the real relative velocity of gas and solid two-phrase, m/s; C_{D0} is coefficient of single-particle drag force, Re is Reynolds number of particle group, $f\left(\varepsilon_g,\mathrm{Re}\right)$ is correction coefficient of uniform and multiple particles drag force; H_D is correction coefficient of non-uniform drag force.

The kinetic energy of gas-phrase turbulence and dissipation rate is determined by the $k-\xi$ model, and the expressions are:

$$\rho_g\frac{\partial k}{\partial t}+\rho_g\nabla\cdot\left(\vec{u}_g k\right)=\nabla\left(\frac{\mu_{g,t}}{\sigma_k}\cdot\nabla k\right)+G_k-\rho_g\xi\,. \tag{6}$$

$$\rho_g\frac{\partial \xi}{\partial t}+\rho_g\nabla\cdot\left(\vec{u}_g \xi\right)=\nabla\left(\frac{\mu_{g,t}}{\sigma_\xi}\cdot\nabla \xi\right)+c_1G_k\frac{\xi}{k}-\rho_g c_2\frac{\xi^2}{k}\,. \tag{7}$$

Where, k is kinetic energy of gas-phrase turbulence, m^2/s^2; ξ is dissipation rate of turbulent kinetic energy, m^2/s^3; $\mu_{g,t}$ is viscosity coefficient of gas-phrase turbulence whose expression is $\mu_{g,t}=c_\mu\rho_g k^2/\xi$; G_k means increment of turbulent kinetic energy caused by mean velocity gradient; and c_μ=0.09, c_1=1.14, c_2=1.92, σ_k=1.0 and σ_ξ=1.33 in the equation.

Conservative equation of particle temperature Θ_s [2, 3]:

$$\frac{3}{2}\left[\frac{\partial}{\partial t}\left(\rho_s\varepsilon_s\Theta_s\right)+\nabla\cdot\left(\rho_s\varepsilon_s\vec{u}_s\Theta_s\right)\right]=\frac{\left(-p_s\vec{i}+\vec{\tau}_s\right)}{\nabla\vec{u}_s\nabla\cdot\left(k_{\Theta_s}\nabla\Theta_s\right)}-\gamma_{\Theta_s}+\phi_{gs}\,. \tag{8}$$

Where k_{Θ_s} and γ_{Θ_s} mean diffusion coefficient of particle pulse kinetic energy and collision dissipative coefficient of particle pulse kinetic energy separately, and ϕ_{gs} is particle temperature source caused by gas-phrase.

Numerical Simulation of Dust Transport Law in Full Rock Heading Face

Construction of Physical Geometry Model and the Division of the Grid

Before ventilation and dust removal system was optimized, the quantity of forced-ventilation in full rock heading face in southern return air lane of Tangkou coal mine was 280 m^3/min, and the quantity of withdraw air of water bath type dust removal fan was 320 m^3/min. The specific arrangement is shown in figure 1.

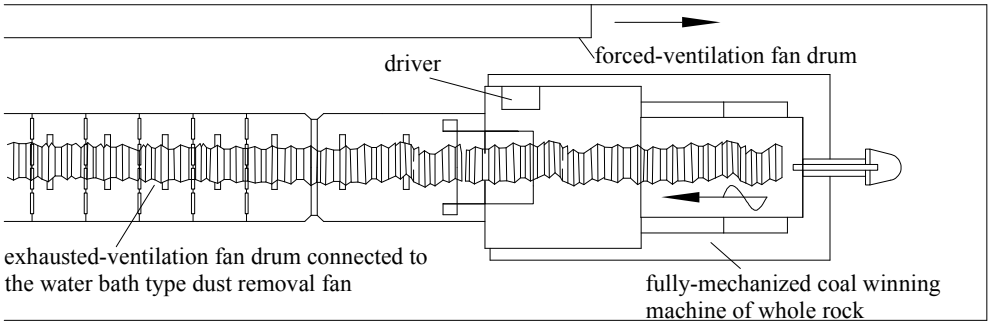


Fig.1 Initial ventilation dust removal system scheme in whole rock fully mechanized face of Tangkou coal mine

For only one dust removal fan was set up at first, certain concentration of dust still diffused to other place in right of the development machine head. So, considering the actual situation, when the physical geometry model was constructed, another dust removal fan was added in right of the lane. The physical model of press-draw combined ventilation system in machine digging face was constructed by using GAMBIT, a self-contained processing software in FLUENT. The model is shown in figure 2.

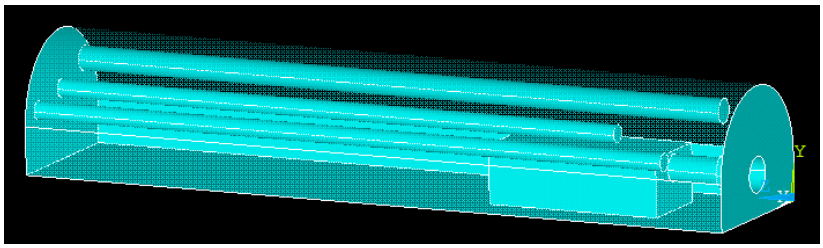


Fig.2 Ventilation system physics geometric model of press-draw hybrid type

The physical model of forcing and exhausting mixed ventilation system in machine digging face was made up of lane, development machine, forced-ventilation fan drum and exhausted-ventilation fan drum. The size of the lane is 25.0×5.44×4.68m, the length of the heading machine is 9.0m, the heading machine is constituted by the machine body, cutting arm and cutting head, and the machine body is a cuboid area with size of 6.0×2.7×1.96m. The length of the cutting arm is 1.8m and the diameter is 0.9m. The cutting head is a cylinder whose length and diameter are both 1.2m and it is next to the roadway wall. The length of the axle wire of the cutting arm and the ground is 1.0m. The press-in type air dryer is a cylinder whose length is 23m and diameter is 0.8m and it is about 2m to the cutting head. The axle wire of air dryer is about 3m to the ground, 0.1m to the nearest tunnel wall, and the quantity of the air that is pressed in is 280 m^3/min. The two press-in type air dryers are all cylinder, the draw-out type air dryer in middle is about 5m to the cutting head and its length is 20m, diameter is 0.6m and the axle wire of it is about 2.36m to the ground; the draw-out type air dryer in side is about 2.5m to the cutting head and its length is 22.5m; diameter is 0.6m and the axle wire is about 1.96m to the ground.

Making a gridding partition on the physical model built by GAMBIT and taking 100 whole hexahedral grids from grids of the model interval size, the divided GAMBIT model grid is shown in figure 3.

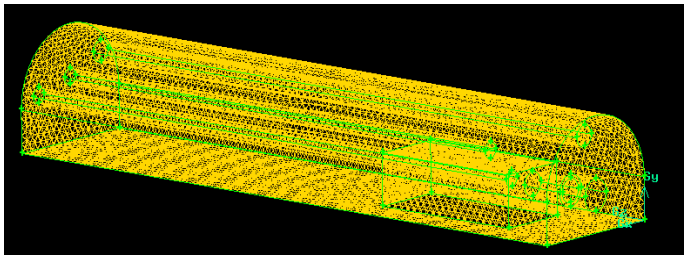


Fig.3 Ventilation system physics geometric model of press-draw hybrid type after the mesh

Boundary Conditions and the Particle Source Parameters

Putting the physical model constructed by GAMBIT into FLUENT and setting the boundary conditions and the particle source parameters of the physical model, which is shown in table 1 [4].

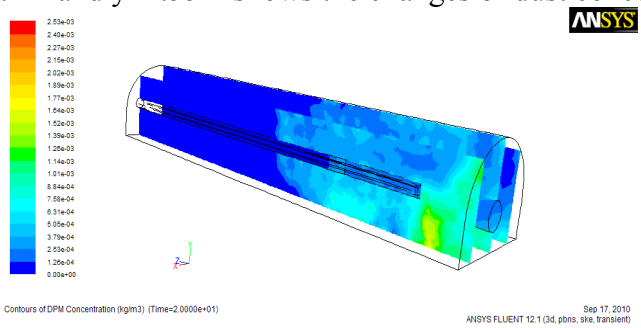
The boundary conditions and the particle source parameters are shown in table 1.

Table 1 Boundary conditions of and main parameters of particle source

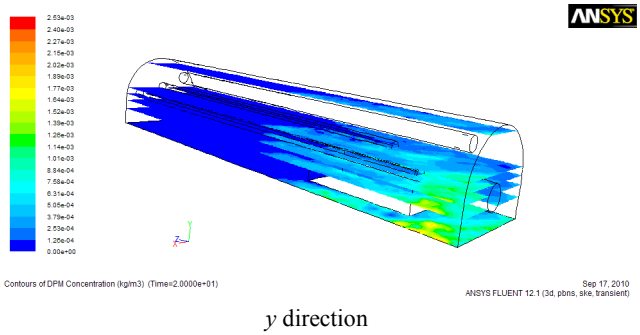
Project	Name	Set of the parameters
boundary conditions	boundary type of index	VELOCITY_INLET
	the wind speed of lane/(m/s)	0.261
	turbulent power energy/(m^2/s^2)	0.3
	turbulent diffusion ratio/(m^2/s^3)	0.3
	boundary type of exit	OUTFLOW
main parameters of dust source	distribution of dust particle size	Distribution of rosin-rammler
	diffuse speed of dust/(kg/s)	0.015
	minimum size of dust/(m)	0.33×10^{-6}
	the max size of dust/(m)	4.317×10^{-5}
	the middle size of dust/(m)	9.62×10^{-6}
	distribution index	2.46
	the initial speed of dust/(m/s)	0
	particle tracking number	2800
	integral time scale constant	0.15
	convergence precision	10^{-3}
	temperature of particle/(m^2/s^2)	0.04
	volume fraction/(%)	7.58×10^{-6}

Simulation Analysis of Dust Diffusion Rule

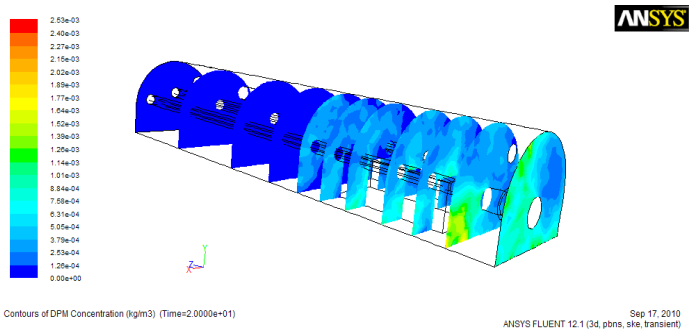
Along the x axis direction 1m, 2.72m, 4.47m, 0m, 1m, along the y axis direction 1.55m, 1.96m, 2.36m, 4m, and along the z axis direction 0m, 2m, 3.5m, 5m, 7m, 8.5m, 10m, 12m, 15m, 20m, 25m, several profiles are set to show the numerical simulation result of dust concentration. The simulation result of dust concentration of z=5.2m and y=1.55m shows the changes of dust concentration.



x direction

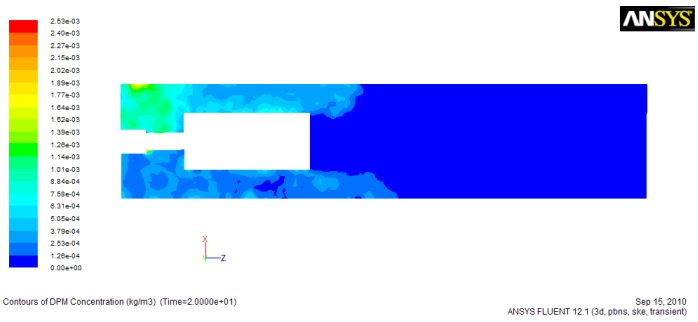


y direction

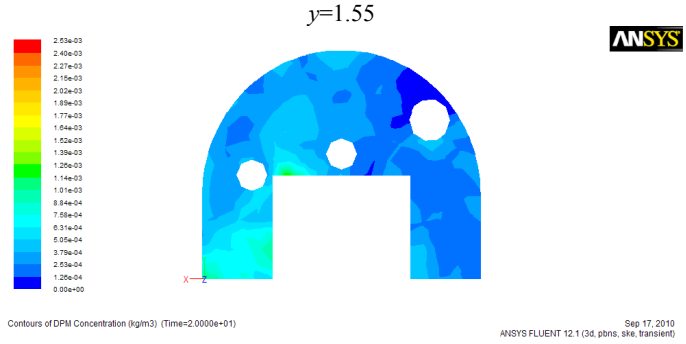


z direction

Fig. 4 Overall trend of dust concentration along different direction in the roadway when the air volume is 320 m^3/min



y=1.55



z=5.2

Fig.5 Dust concentration of where workers breathe when the air volume is 320 m^3 / min

As is shown in figure 4, 5:

(1) Concentration of dust keep falling along *z*, namely from digging head to the end of the lane. From the work face it starts falling fast to less than 231 mg/m^3, and then the dust concentration gradually reduces. (2) Concentration of dust in the area which is 0-2m from digging head is the highest, generally 692 mg/m^3 above. (3) Dust concentration in driver's relative side is more than his other side which shows that most of dust is pressed to the driver's relative side, especially in the 0-2 m regional, and in the scope, the dust concentration is generally in 1040 mg/m^3 above. In this range, most of the dust had been settled, but the dust which can be float by wind begin spreading to other areas, most of the floating dust is in the area where is about 1.5m to the roof. (4) Although the quantity of draw-out air is 320 m^3/min and is more than the pressed-in air which is 280 m^3/min, drawer-type air dryer only absorb a small part of dust, and most of the dust still spread to the other position. It is mainly because the range of the small drawer-type air dryer, which shows that it is difficult to gather and set the production of dust effectively only by using single and hybrid ventilation type. So the comprehensive dust prevention measures must be adopted to reduce the dust concentration.

Dust Removal System by Ventilation Design of Full Rock Heading Face

A Closed Control Dust Device Using Air Curtain

In order to change the ordinary spray nozzle air curtain which has the problems of having a short spray range, covering a small section of roadway, too much noise and other defects effectively, a new type of air curtain air was designed and driven by a 750W explosion-proof motor. The speed of exit is

10-12m/s, the effective range of the air is 3.5-4m, the quantity of air that is draw-out is 50-65 m^3/min, the length of the exit is same to the width of the heading machine which is 2.7m, and the noise is only about 60dB(A) [5, 6]. The new air curtain machine is shown in figure 6.

Fig.6 New wind screen machine that used to closed the dust source

Optimization Design of Dust Removal and Ventilation System in Working Face

Judging from the former numerical simulation results, although a drawer-type dust removal equipment was set in the dig machine center and roadway, the limit of the drawer-type air volume and the position of drawer-type air dryer was not very reasonable. The dust which still had not been captured spread to other area of the roadway, especially the dispersion of high concentration dust in the right side. So, the ventilation dust removal system constructed during the construction of numerical simulation was optimized. The modified ventilation dust removal system is showed in figure 7. At this time, the dust removal by water bath type is changed into a fan vibration twist-action type, and a single piece of air processing changes from 160 m^3/min to 300 m^3/min. Among them the central column drawer-type suck up about the draught of coiled aspiration placed on the turntable rear cover, and another column type cylinder with a flat suction hood is fixed on the digging machine right into the body front.

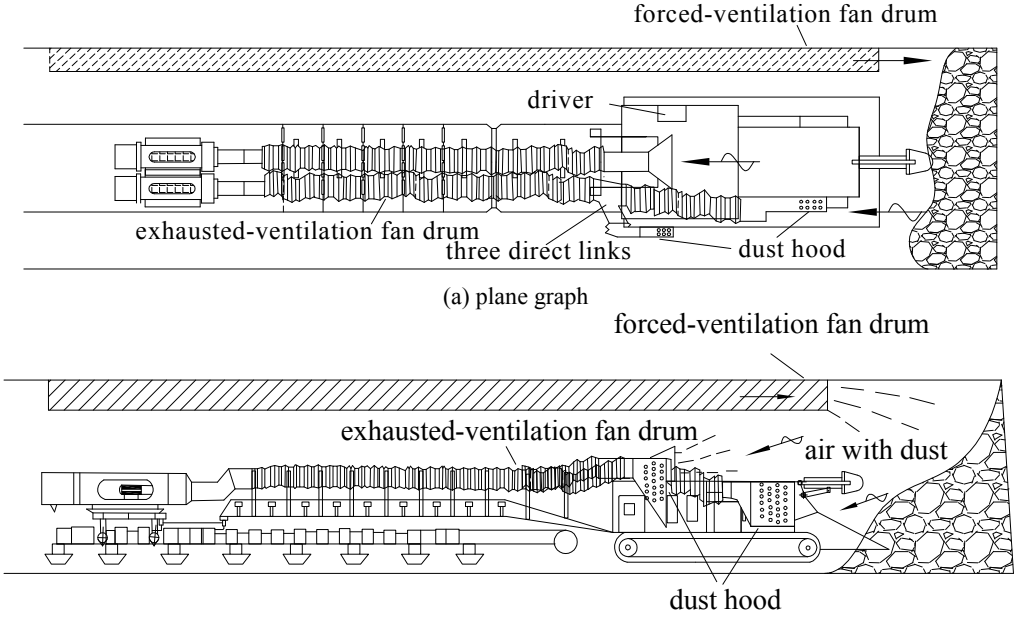


Fig.7 Improved ventilation dust removal system diagram

As is known in figure 7, most of the dust is caught by wet vibration spin dust removal fan at the right of the lane, and the other dust will be caught by the dust removal fan behind the wet vibration spin dust removal fan. This system achieves a good dust cleaning effect.

Field Application

The modified ventilation and dust removal system was put into use in full rock machine digging face in Tangkou coal mine. The situation of dust in every site when different measures were taken is shown in table 2-4.

Table 2 Dust concentration data of each point in the working face when no measures were taken

dust data	point number	1#	2#	3#	4#	5#	6#	average value of man-working area
mudstone	all dust concentration/(mg/m^3)	728.3	392.1	322.3	308.4	236.1	220.7	295.9
	respirable dust concentration/(mg/m^3)	373.9	201.1	167.6	159.3	123.7	111.4	152.6
fine sandstone	all dust concentration /(mg/m^3)	983.1	522.7	437.5	413.5	320.8	296.6	398.2
	respirable dust concentration /(mg/m^3)	555.6	292.1	248.8	231.2	181.2	169.7	224.6
silty sandstone	all dust concentration /(mg/m^3)	1226.5	658.3	548.7	516.4	402.3	369.4	499.0
	respirable dust concentration /(mg/m^3)	716.7	416.5	350.2	329.4	251.5	232.8	316.1

Table 3 Dust concentration data of each point in the working face when the initial dust removal system was used

dust data	point number	1#	2#	3#	4#	5#	6#	average value of man-working area
mudstone	all dust concentration /(mg/m^3)	251.3	124.7	105.1	103.9	81.0	70.8	97.1
	respirable dust concentration /(mg/m^3)	126.0	65.8	57.5	52.7	44.4	39.7	52.0
	dust fall ratio of all dust/%	65.5	68.2	67.4	66.3	65.7	67.9	67.1
	dust fall ratio of respirable dust /%	66.3	67.3	65.7	66.9	64.1	64.4	65.7
fine sandstone	all dust concentration /(mg/m^3)	337.2	166.2	151.4	147.6	106.8	99.1	134.2
	respirable dust concentration /(mg/m^3)	198.9	96.7	82.6	76.1	61.8	57.4	74.9
	dust fall ratio of all dust /%	65.7	68.2	65.4	64.3	66.7	66.6	66.2
	dust fall ratio of respirable dust /%	64.2	66.9	66.8	67.1	65.9	66.2	66.6
silty sandstone	all dust concentration /(mg/m^3)	425.6	207.4	189.3	177.1	143.6	126.3	168.7
	respirable dust concentration /(mg/m^3)	256.6	136.2	114.9	111.3	86.3	78.0	105.3
	dust fall ratio of all dust /%	65.3	68.5	65.5	65.7	64.3	65.8	66.0
	dust fall ratio of respirable dust /%	64.2	67.3	67.2	66.2	65.7	66.5	66.6

Table 4 Dust concentration data of each point in the working face when the improved dust removal system was used

dust data	point number	1#	2#	3#	4#	5#	6#	average value of man-working area
mudstone	all dust concentration /(mg/m^3)	83.8	18	16.8	16.7	13.5	12.8	15.6
	respirable dust concentration /(mg/m^3)	51.2	7.8	7.2	6.7	5.4	5.1	6.4
	dust fall ratio of all dust /%	88.5	95.4	94.8	94.6	94.3	94.2	94.7
	dust fall ratio of respirable dust /%	86.3	96.1	95.7	95.8	95.6	95.4	95.7
fine sandstone	all dust concentration /(mg/m^3)	113.1	22.5	20.1	21.1	17.6	15.7	19.4
	respirable dust concentration /(mg/m^3)	70	9.9	9.2	9	7.6	8.1	8.8
	dust fall ratio of all dust /%	88.5	95.7	95.4	94.9	94.5	94.7	95.0
	dust fall ratio of respirable dust /%	87.4	96.6	96.3	96.1	95.8	95.2	96.0
silty sandstone	all dust concentration /(mg/m^3)	137.4	24.4	23	21.2	18.9	18.1	21.1
	respirable dust concentration /(mg/m^3)	95.3	12.1	11.6	11.2	8.8	8.4	10.4
	dust fall ratio of all dust /%	88.8	96.3	95.8	95.9	95.3	95.1	95.7
	dust fall ratio of respirable dust /%	86.7	97.1	96.7	96.6	96.5	96.4	96.7

Judging from the data above, conclusions can be drawn as followed:

(1) Dust concentration in every site were all a little higher when no measures are taken, the area where the digging machine driver stays is the site where the dust concentration is the highest and it will get to 658.3 mg/m^3 and 416.5 mg/m^3. Even though when the mudstone whose dust concentration is the lowest is dug, the all dust concentration and the respirable dust concentration are 220.7 mg/m^3 and 111.4 mg/m^3, which are far beyond the relevant national standard.

(2) After the traditional dedusting methods were taken, the dust reduction of mudstone, fine sandstone, silty sandstone reduced in a certain degree, and these three kinds of dust were respectively reduced 67.1% and 65.7%, 66.2% and 66.6%, 66.0% and 66.6% in the working place of the working face. Though the dust concentration was decreased at a certain extent, it was still very high and would threaten the health of miners.

(3) After using the modified ventilation and dust removal system, dedusting rate of all dust and respirable dust in 2#-6# working face in full rock machine digging face of south lane decrease to 95.1% and 96.1%, the dedusting effect is obvious and it is a better chose for all rock machine digging face where has little gas or no gas.

Conclusions

(1) Based on the situation that the dust concentration of full rock machine digging face is high and the production process characters, numerical simulation of the dust concentration distribution rule was conducted by constructing basic control equations to fluid mechanics of gas-particle two phase flow, building physical geometry model and ensuring the relevant boundary conditions.

(2) Numerical simulation has been carried out to reseach the distributing rules of dust concentration. From the simulation we can see that enlarge the quantity of air that is drawn in by the dust removal fan and set the dust removal facilities of the other side of the digging machine driver are the effective measures to develop the dust removal efficiency.

(3) The comprehensive dust-reduction measures that contain dust isolation by air, dust fall by dust removal fan and dust extraction by block dust shade are redesigned. The hybrid ventilation dust removal system is developed and its dust removal effect is obvious.

Acknowledgements

This work was financially supported by National Natural Science Foundation (51074100), Natural Science Foundation of Shandong Province (ZR2011EEQ009, ZR2010EM016), Research Project of “SDUST Spring Bud” (2010AZZ199) and Science Research Innovative Group of Shandong University of Science and Technology (2010KYTD106).

References

[1] Gang ZHOU, Weimin CHENG, Lianjun CHEN, et al: Journal of China Coal Society Vol.35 (2010), p. 2094-2099. (In Chinese)

[2] Gang ZHOU: Research of Theory about Dust Prevention by Water-Cloud and Relevant Techniques for Fully-Mechanized Caving Coal Face. Qingdao Shandong: Shandong University of Science and Technology (2009). (In Chinese)

[3] Shengzhu ZHANG, Weimin CHENG, Gang ZHOU, et al, in: Proceedings of the 2008 International Symposium on Safety Science and Technology, edited by Shengcai LI, Yajun WANG, Ying AN, et al, volume 7 of Progress in Safety Science and Technology, section, 20, Science Press USA Inc. (2008).

[4] Gang ZHOU, Weimin CHENG, Lianjun CHEN: *Research and Practice of Key Theory and Technology for Coal Mine Dust Controlling*. (Coal Industry Press, Beijing 2011). (In Chinese)

[5] Weimin CHENG, Wei LIU, Wen NIE, et al: Journal of Shandong University of Science and Technology Vol.29 (2010), p. 77-81. (In Chinese)

[6] Gang ZHOU, Weimin CHENG, Gang WANG, et al: Safety in Coal Mines, Vol.40 (2009), p. 22-24. (In Chinese)