7th International Mines rescue body conference

Study on numerical of the smoke flow regulation and personnel escape during the roadway fire emergency rescue in coal mines

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INTRODUCTION

- Statistics show that every death of dozens of people at home and abroad and even hundreds of major coal mine accidents vicious fire and 90% of them from roadway fire .
- A large number of roadway fire show that 85% to 95% of the casualties are poisoned and suffocated by fire smoke with airflow diffusive transport process.
- The national of industrial informatization statistics show that efficient emergency rescue systems can reduce accident losses to less 6% of the state without emergency rescue systems.
- Productions must be effectively taken to control pollution of toxic gases and import it back to the wind region lane in order to reduce the plume caused by suffocation .So, it will create conditions for fire fighting, rescue and evacuation personnel .

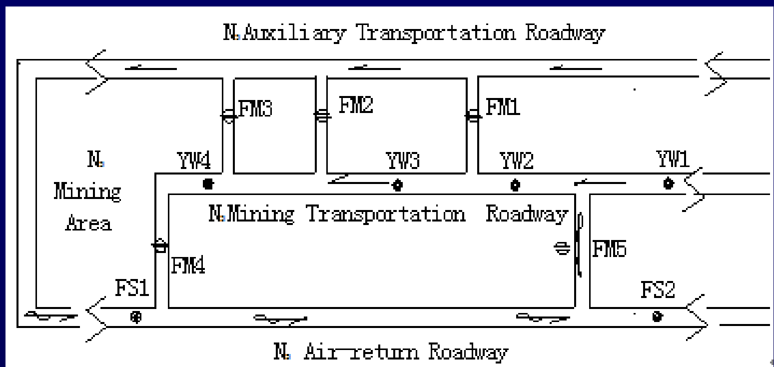
ROADWAY FIRE EMERGENCY RESCUE SYSTEM

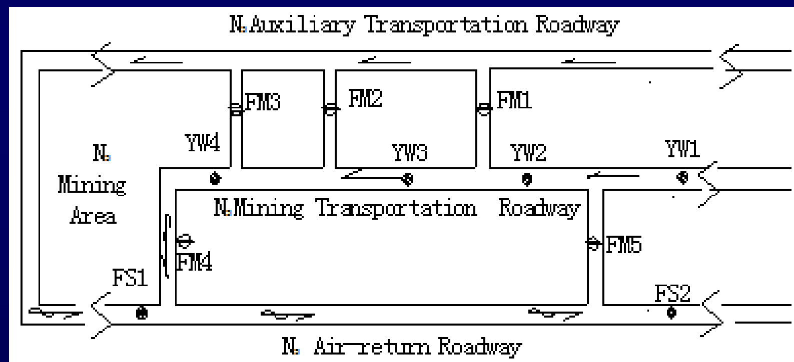
- Wang DM had developed the Mine Fire Rescue Decision Support System (MFRDSS) using DSS technique. The main functions of MFRDSS are simulating mine fire by computer and choosing the best route of rescuing and avoiding disasters as well as recommending the scheme of controlling wind and simulation calculation after the wind control.
- Based on geographic information system (GIS) of the Mine Disaster Emergency Rescue System, a visual emergency rescue system of the mine disaster has been built using the information management systems and GIS to build, by studying coupling between GIS and the technology of coal mining disaster emergency

New Mine fire smoke control model

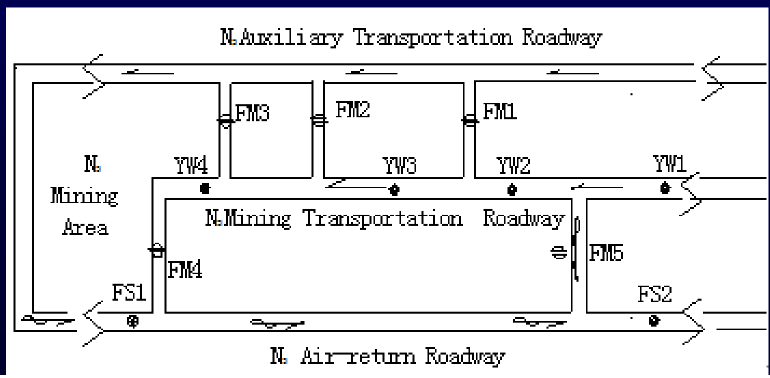
- A remote roadway fire emergency rescue system is developed to adapt to underground disaster, where is no electricity or gas pressure and the airflow control technology is realized in relief process. The system is put into application in N3 mining area.
- The site model of N3mining area airflow control schematic diagram of fire emergency rescue system of belt way

（a）
Normal period





（b）The front-end belt with fire relief system



（c）The back-end belt with fire relief system

New Mine fire smoke control model

- The basic principle of roadway fire emergency rescue system is as follows. Set normally opening throttle FM1, FM2 and FM3 between belt lane and track lane in N3 mining area and locking throttle FM4 and FM5 between belt lane and return air liaison lane. Set two of smoke sensors YW1, YW2, YW3 and YW4 in segmentation and hang just above the tape on both sides to monitor the flue gas conditions in entire roadway in real-time and achieve fire alarm. In normal conditions, when there are cars and people between belt lane and return air liaison lane, FM4 and FM5 will automatically lock. The normally opening throttle will be all closed when emergency rescue system is launched by ground central station in catastrophic conditions. If YW1 and 2 monitor the signal, while in the meantime YW3 and 4 do not, the locking throttle FM5 is opened to put out the fire according to smoke flow. Personnel will run from the mining area track lane. If YW3 and YW4 or all probes monitor the signal in the meantime, the locking throttle FM4 is opened to put out the fire and make personnel run according to smoke flow. Throttle FM4 and FM5 cannot be opened at the same time.

Cataclysm air volume regulation Factors

- Zhou Y, etc. fitted the following empirical formula based on the experimental results:

$$L^*_b=0.0404exp(0.0414Q/u_a) \quad (1)$$

Wherein: L^*_b is a dimensionless length counter, $L^*_b = L / H$; L is the length of the flue gas counter, m; H is height of tunnel, m; Q is fire heat release rate, kW; u_a is the speed of ventilation, m / s.

- Zhou FB, etc. gave the following empirical formula combined with dimensional analysis:

$$L^*_b=0.2369exp(0.00203Q/\rho_a S u_a^3)$$

Wherein: ρa is Merry density, kg/m3; S is the roadway section, m2.

- Vantelon, etc. [29] gave the following empirical formula:

$$L^*_b \propto (gQ/\rho_c c_p T_a u_a^3 H)^3$$

- The study on the critical wind speed did by Wu Y etc showed that the critical increases with heat release rate 1/3 power while heat release rate is low, but when the heat release rate is high, Critical wind speed is almost independent from heat release rate

$$L=p\ LnQD/v3$$

Wherein: L represents the length of the flue gas upstream layer, m; u represents ventilation velocity, m / s; D represents the equivalent diameter of the roadway section, m; Q represents the heat release rate, MW; P is a constant.

The theoretical basis of fire simulation

- Fire Dynamics Simulator (FDS) is based on the fluid dynamics and components combustion theory; mainly solve the basic mass conservation equation, momentum conservation equation, energy conservation equation.

$$\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial u_i \bar{\rho}}{\partial x_i} = 0 \qquad (5)$$

Momentum conservation equation:

$$\frac{\partial u_j u_i \bar{\rho}}{\partial x_j} + \frac{\partial u_i \bar{\rho}}{\partial t} = -\frac{\partial \bar{\rho}}{\partial x_i} + \bar{\rho} g \delta_{ij} + f_i + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\frac{\partial u_k}{\partial x_k}\delta_{ij}\right)\right] - \frac{\partial \tau_{ij}}{\partial x_j} \qquad (6)$$

Energy conservation equation:

$$\frac{\partial h \bar{\rho}}{\partial t} + \frac{\partial u_i h \bar{\rho}}{\partial x_i} = \frac{\partial \bar{\rho}}{\partial t} + q''' - \frac{\partial q_{ri}}{\partial x_i} + \frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right) + \sum_i \frac{\partial}{\partial x_i}\left(\bar{\rho} D_i h_l \frac{\partial Y_l}{\partial x_i}\right) - \frac{\partial \theta_i}{\partial x_i} \qquad (7)$$

Species equation:

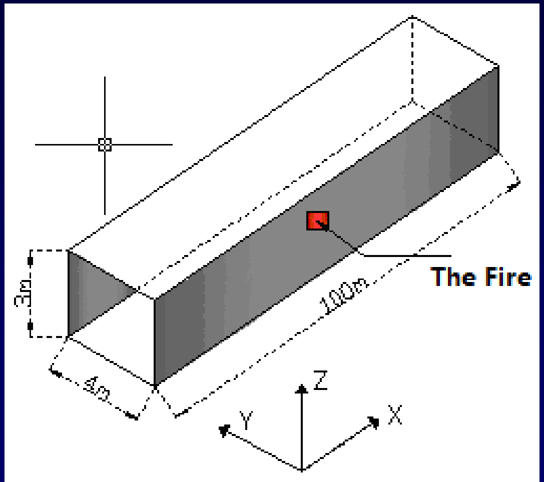
$$\frac{\partial}{\partial t}\left(\bar{\rho} Y_i\right) + \frac{\partial}{\partial x_i}\left(\bar{\rho} u_i Y_i\right) = \frac{\partial}{\partial x_i}\left(\bar{\rho} D_i \frac{\partial Y_i}{\partial x_i}\right) + W_i''' - \frac{\partial \gamma_i}{\partial x_i} \qquad (8)$$

Equation of state:

$$\bar{p} = \bar{\rho} T R \sum \left(Y_l / M_l\right) \qquad (9)$$

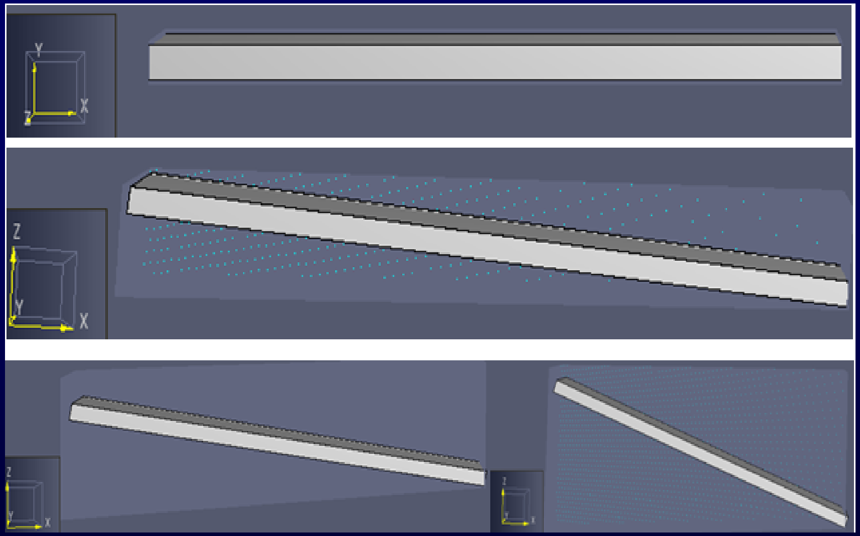
Wherein: $\rho$is gas density, *f* means the amount of large-scale, *k* is thermal conductivity, *vi* is diffusion coefficient, u represents the velocity (u_i means the x-direction component, u_j means the y-direction component), *hl* means the enthalpy combustion components, *δij* means expansion velocity of smoke flow, *Ml* means molecular weight, T means the temperature, γ_l means the mass fraction of component, *h* means the enthalpy, W_l''means components of the reaction rate, *P* means pressure, *q''*means the volumetric heat release rate, *q* means radiant heat flux vector, *t* means the time, *g* means the acceleration of gravity, *R* means the molar gas constant

The establishment of the mathematical and physical model



Basic model

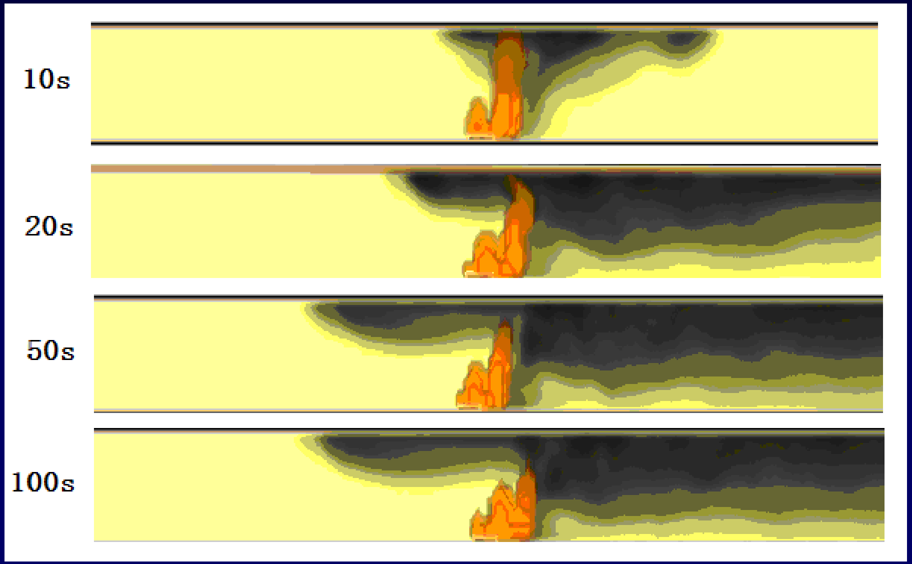
The basic model: with a length of 100m, a width of 4m, and a height of 3m, the minimum mesh size is 0.1m * 0.1m * 0.1m. Fire set point is 50m away from the roadway entrance; the height of fire source is 0.5m.



Model of horizontal **and different inclination angles roadway**

The horizontal roadway model and the actual models of inclined roadway with inclination angles of 5°, 10°, 20° are shown in **the left page**

Results for data simulation



it shows how the smoke flows under 5MW heat releasing rate and a wind speed of 2m/s. The smoke flow roll back distance is 11m and the trend is close

to stable after 50s.

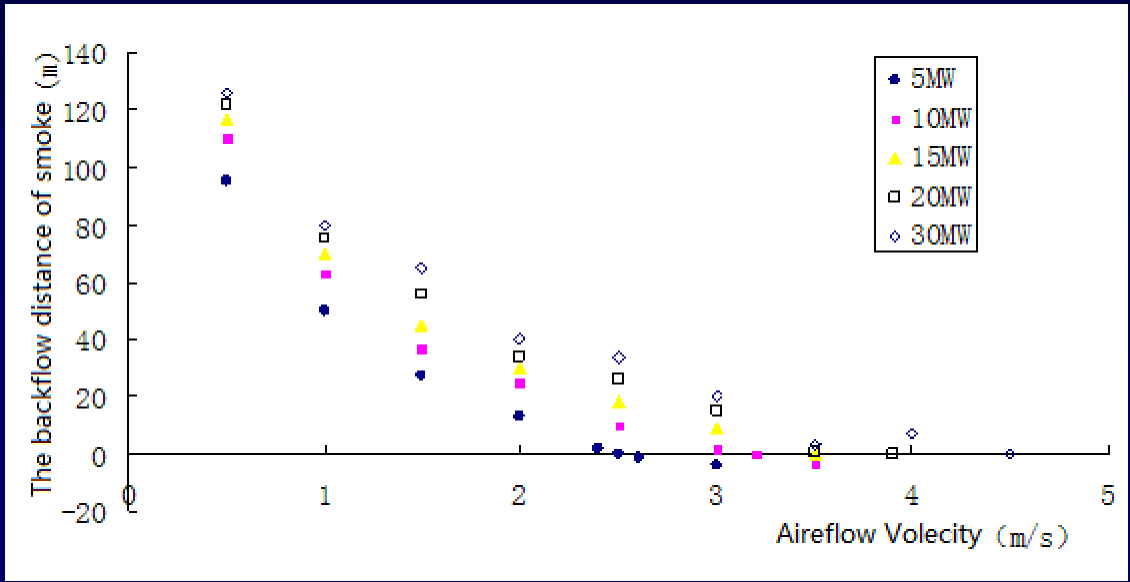
Trend graph of smoke spread in level roadway

Simulation results of critical airflow speed

The smoke roll back distance is 0m under 5MW heat release rate and 2.6m/s wind speed. The fire does not roll back within 50s to 100s. It means that the speed of 2.6m/s does not cause smoke roll back, therefore mark

as critical point

Results for data simulation

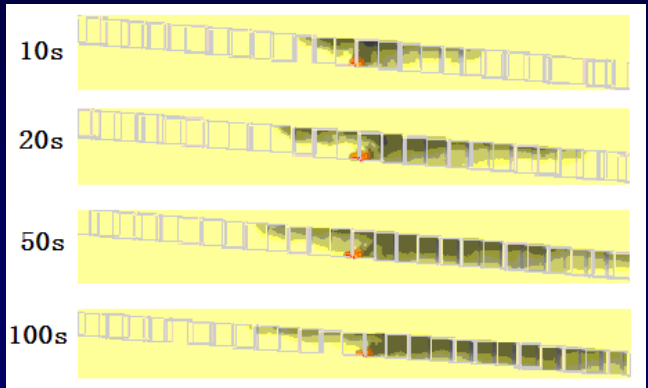


Relationship between smoke backflow distance and airflow speed under different combustibles heat release rate

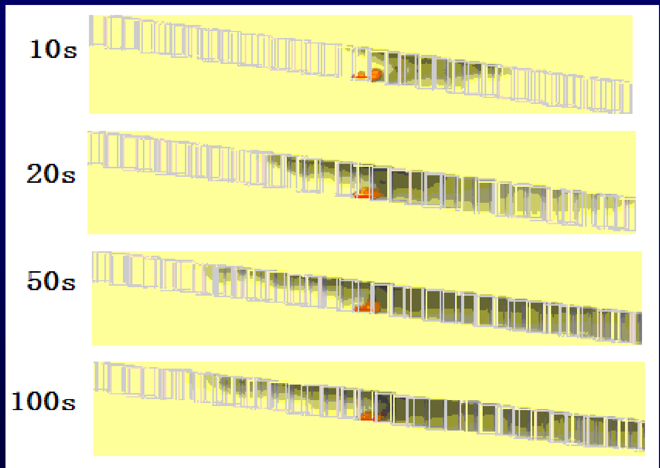
Based on equation (4), the roll back distance is represented as follows:

L=19.43 Ln0.911QD/v3

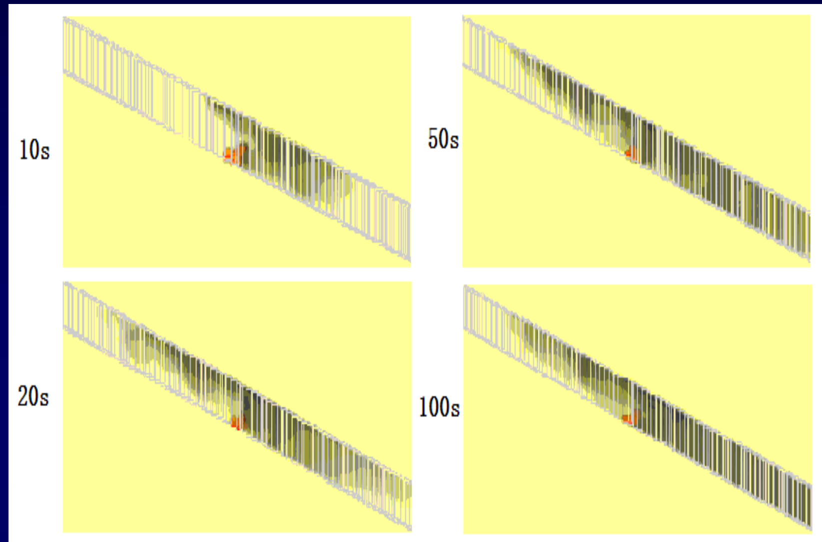
Results for data simulation



（a） 5°



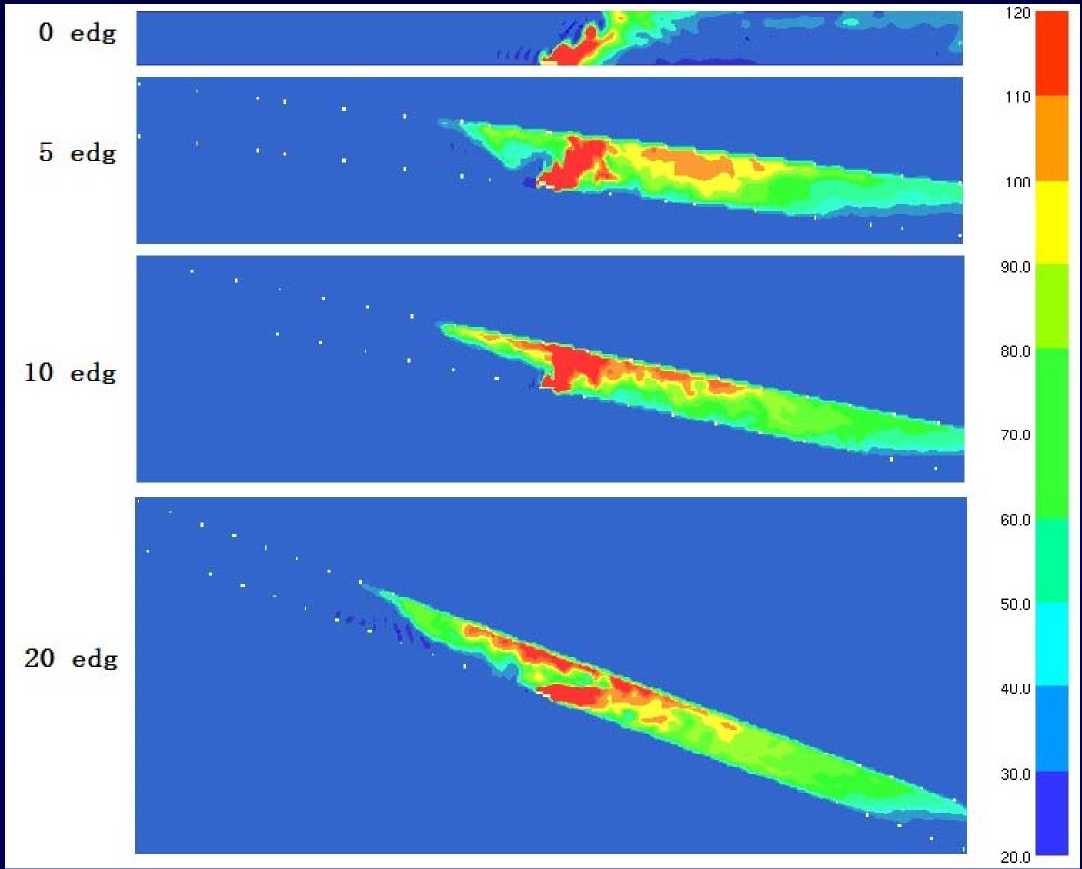
（b） 10°

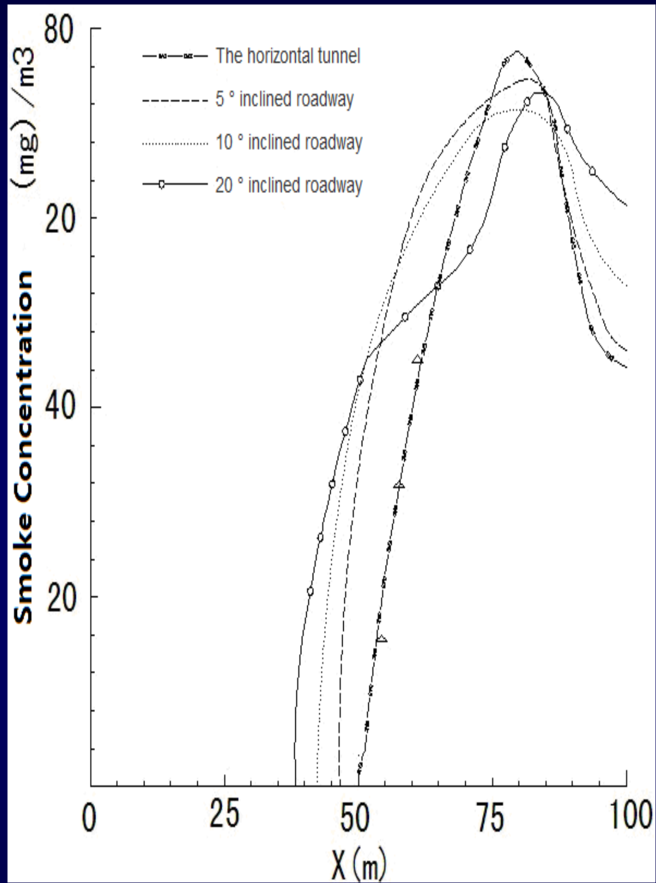


（c） 20°

Trend graph of smoke spread with different dip angles of inclined roadway

Results for data simulation

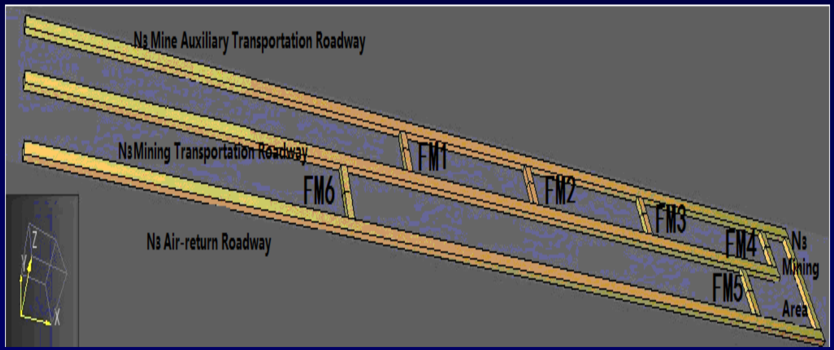




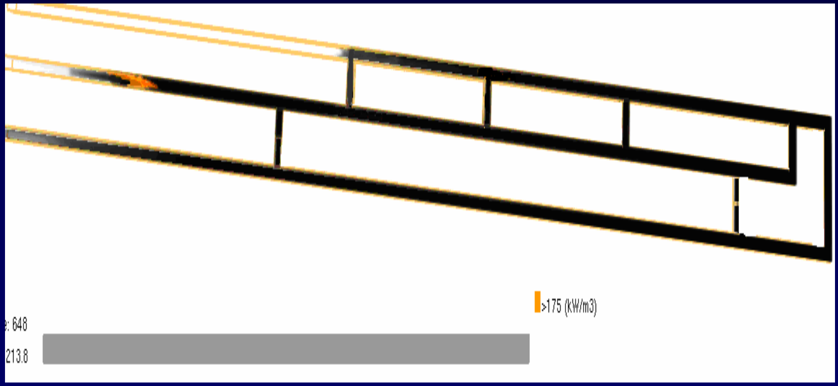
The cross section temperature in different angle

The flue gas concentration profile at the top of roadway

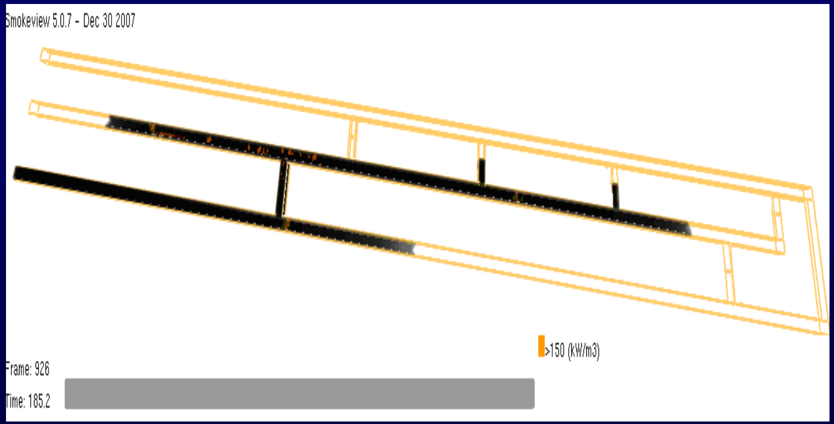
Data simulation of fire smoke flow movement rules in lane network model



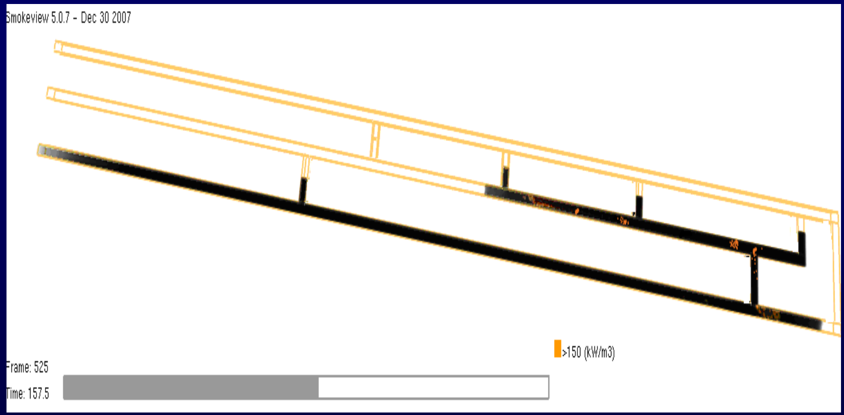
Mathematical-physical model to roadway network



Belt front-end fire without relief system



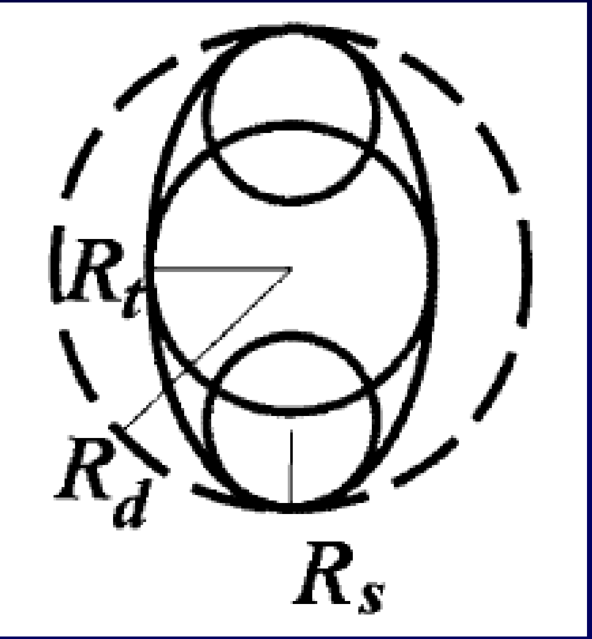
The front-end belt with fire relief system



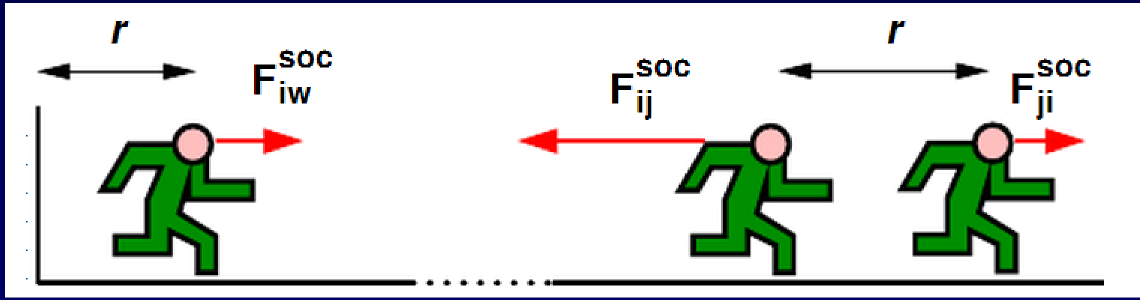
The back-end belt with fire relief system

Analyzes and studies the model of Evac

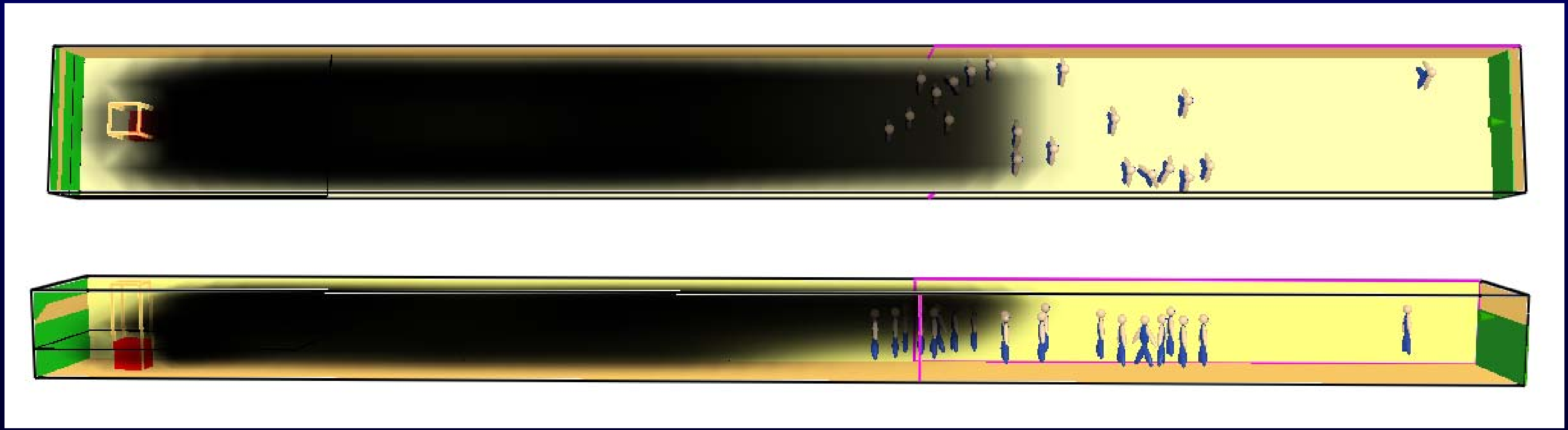
Three round feature sizes



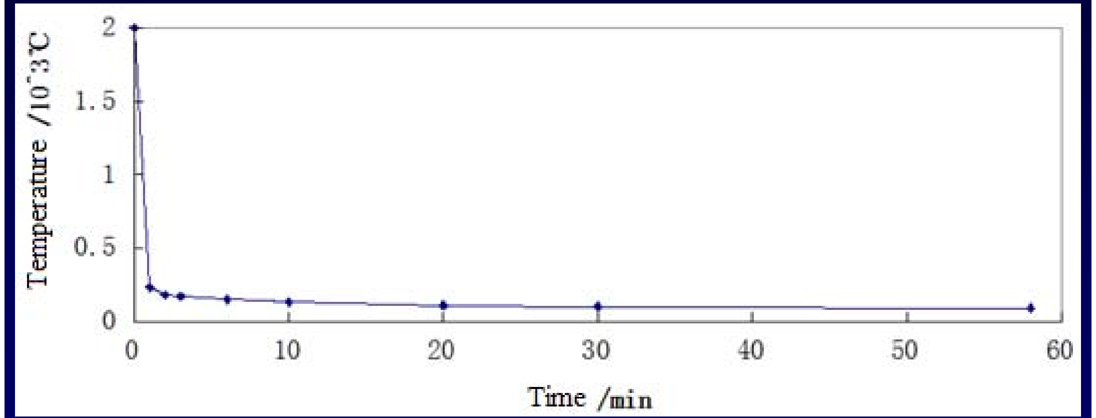
The mechanical model of EVAC in the process of personnel escape



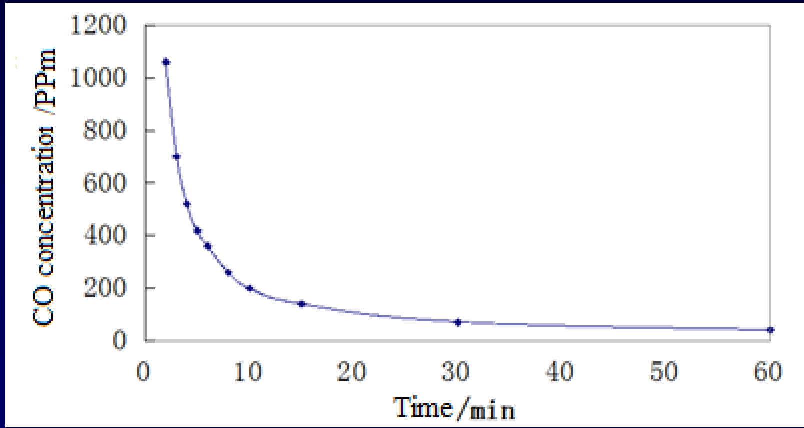
The chart of personnel escape along the flow



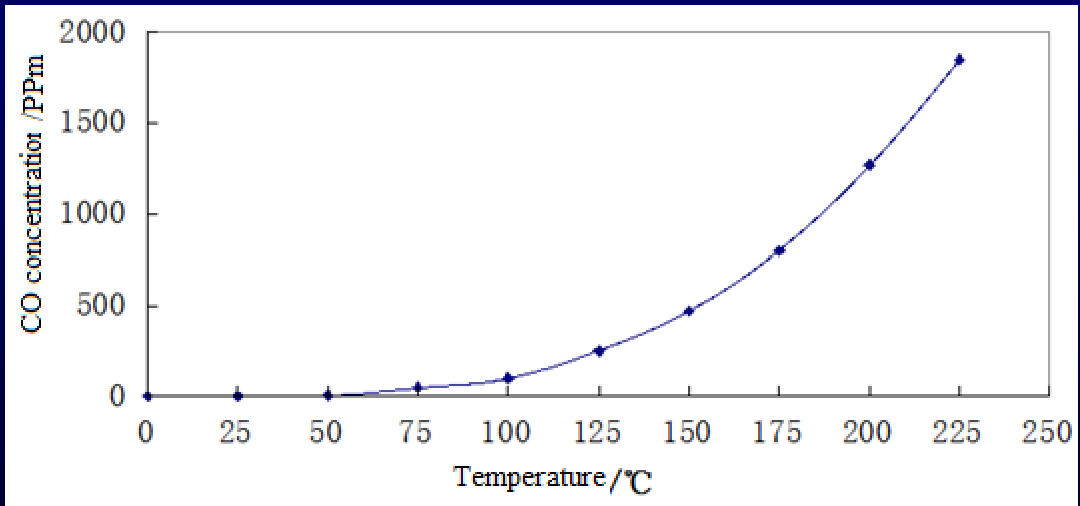
Judgment conditions of **personnel escape**



The relationship between the temperature and extreme patience time

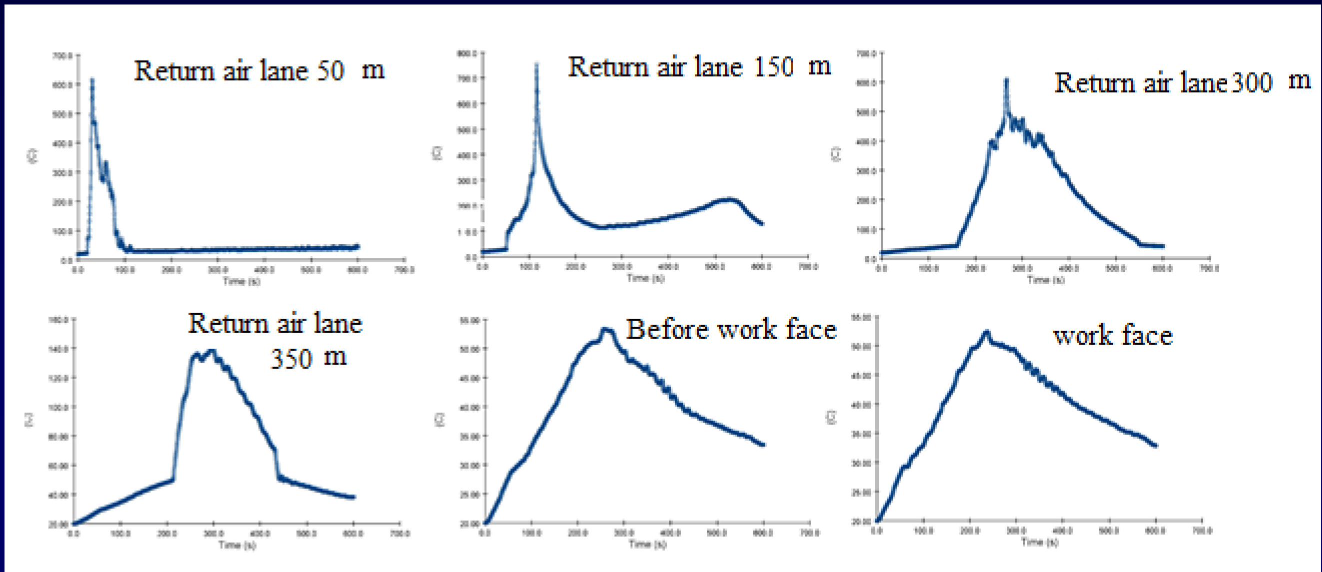


The relationship between the CO concentrition and extreme patience time

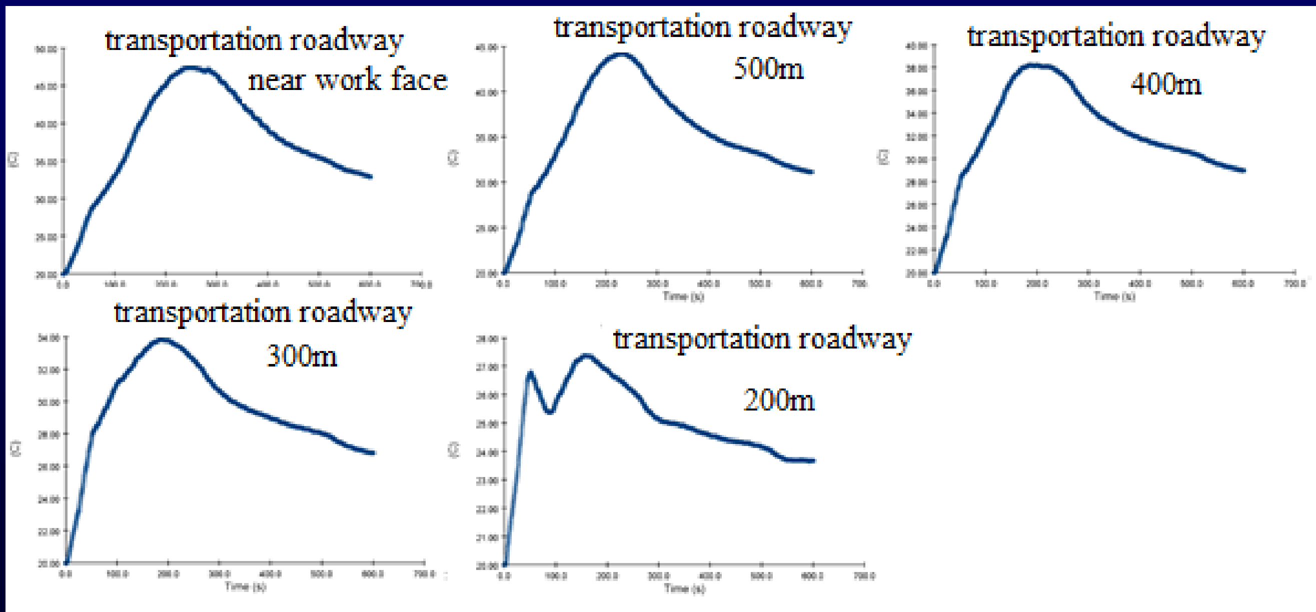


The relationship between the CO concentrition and the temperature in the same extreme patience time

Results for Evac data simulation

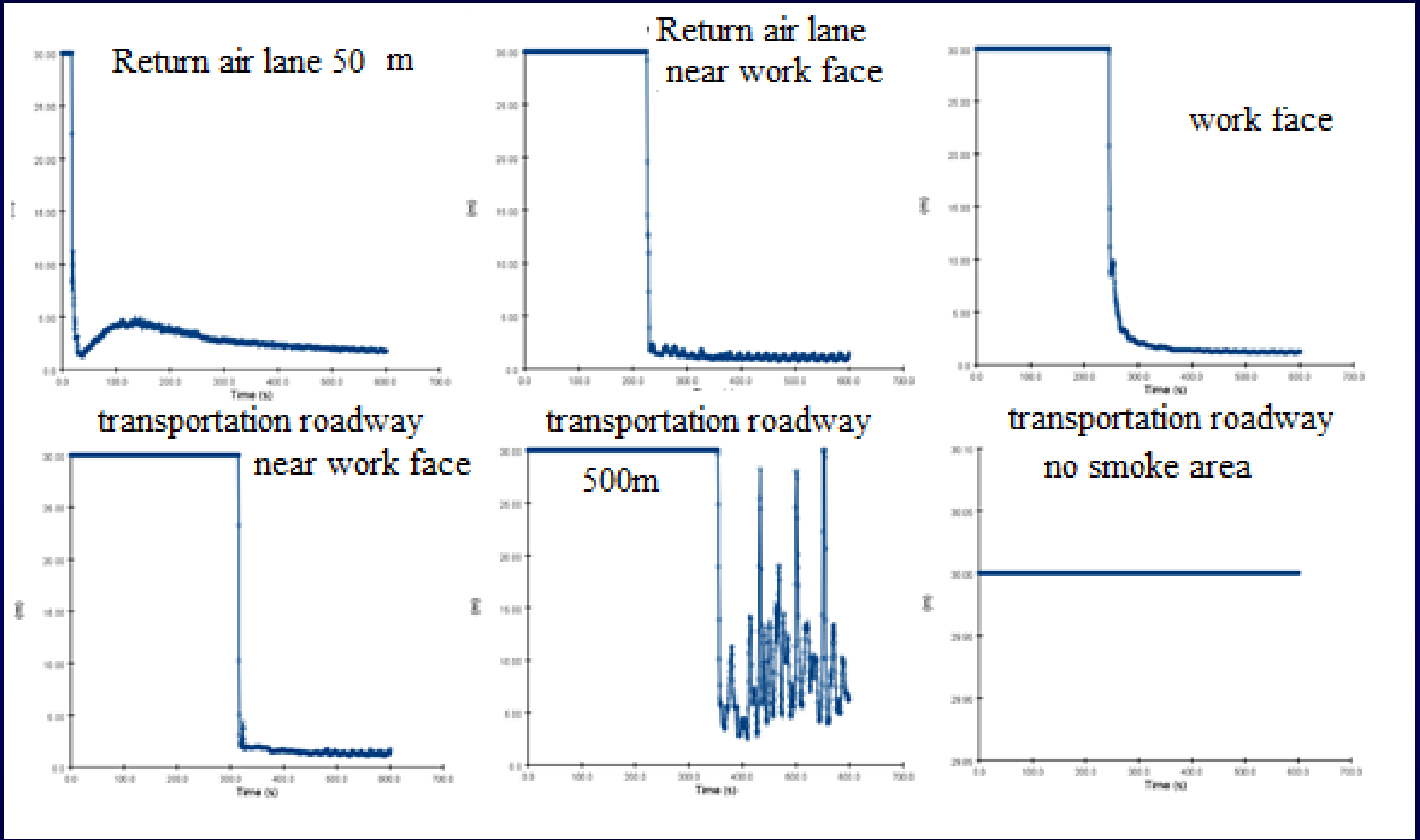


Different measuring point temperature change curve over time in the return air lane



Different measuring point temperature change curve over time in the transportation roadway

Results for Evac data simulation



Different measuring point of CO concentration change curve over time

CONCLUSIONS

1. According to the fire of mine air the smoke flow characteristics in the net, I designed the fire smoke flow regulation and control of emergency rescue system of mine, disaster relief process ventilation system is divided into the smoke flow area. I put through regulating the down hole throttle opening to regulate the smoke flow area and the plume area of air distribution method, improve the emergency rescue system and the coupling between the ventilation system.

2. Analyzing the relationship between the fire heat release rate, wind speed, angle of roadway and smoke flow rolled back distance, using dynamic numerical simulation software FDS fire smoke flow under different conditions to roll back distance is simulated, simulating the relationship between the entry of heat release rate, wind speed, smoke flow rolled back distance, fitting formula is: $L=19.43 Ln0.911QD/v^3$.Simulating the roadway critical wind speed under the condition of different Angle inclined lane of smoke rolled back flow situation, analyzing the enhancement of the Angle influence to roll back distance rule.

CONCLUSIONS

3. Through the establishment of roadway network configuration in the emergency rescue system of physical model, using the dynamic simulation software FDS to simulate fire， simulating belts cable lines under the condition of fire, the distribution regularity of fire spreading, the smoke movement, comparing before and after start the remote emergency rescue system of fire smoke flow motion path to change, demonstrating the emergency rescue system in the mine fire smoke flow control, the practicability and feasibility.

4. FDS+Evac is utilized to study with the combination of simulation of fire development process and the distribution of personnel evacuation. After that, the evacuation network is activated through using EVAC, and the smoke polymer from the fire simulation will affect the movement and decision making of the evacuees.

That's all !

Thanks for everyone !