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Effect of auxiliary ventilations on diesel particulate matter dispersion inside a dead-end entry

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ABSTRACT

Diesel particulate matter (DPM) is considered carcinogenic after prolonged exposure. This paper used computational fluid dynamics (CFD) method to study the effect of four auxiliary ventilation systems on DPM distribution in a dead-end entry with loading operation. The auxiliary ventilation systems considered include: blower fan and tubing; exhaust fan and tubing, jet fan, and push–pull system. A species transport model with buoyancy effect was used to examine the DPM dispersion pattern with unsteady state analysis. During the 200 s of the loading operation, high DPM levels were identified in the face and dead-end entry regions. This study can be used for mining engineer as guidance to design and setup of local ventilation. It can also be used for selection of DPM control strategies and DPM annual training for underground miners.

1. Introduction

For underground M/NM mines, self-propelled diesel equipment that does not require electricity or constant charging batteries is preferred because working faces usually cover extensive areas where these facilities are not available. However, emission from the tailpipe and its subsequent distribution in the underground mine are of growing concerns for miners.

DPM is the particulate by-product of diesel exhaust and it can exist in different modes with different size distributions (5 nm to 10 μm). Due to its very small size and its ability to adsorb very complex (more than 1800 different organic compounds were identified) and potentially toxic hydrocarbons, it can be breathed into the alveolar region of the lungs of miners and cause from acute health problems such as asthma, eye and nose irritation, headaches and nausea [1–3] to long term carcinogenic effects. Also due to the small size, once airborne, it is likely to remain airborne throughout the entire entry, affecting not only the workplace where it is produced but also areas downstream.

For underground M/NM mines, U.S. federal M/NM mine regulations limit a miner's personal exposure to DPM no more than 160 μg/m^3 of total carbon (TC) for an average eight-hour equivalent full shift (effective from May 20, 2008). Till today, there are still mines that cannot meet this regulation limit.

To control DPM hazards, two types of strategies have been commonly used. One is DPM reduction and removal before it is released from the engine tailpipe, which includes proper diesel engine selection and maintenance, use of alternative fuels, and exhaust gas treatment devices [4–8], e.g., diesel particulate filters (DPF). The other is through control measures after DPM is discharged into the environment – mine ventilation, an enclosed equipment cab with filtered breathing air (environmental cab), personal protective equipment, and administrative controls [9,10].

Experience showed that no single strategy can solve all DPM problems and a combination of several measures needs to be implemented in the field to attain compliance. Since none of the strategies are cost free, an effective, efficient, and economical control scheme for operations under different mining conditions is essential in order for a mining company to provide a safe working environment and to meet regulatory criteria. To achieve that, an understanding of DPM behavior in mining environment can be very useful in selecting the control strategies and training the miners. Numerical simulations using CFD can be used for that purpose by visualizing DPM distribution based on laboratory experiments and field studies.

CFD simulations have been successfully used in mining research to detect spontaneous combustion and apply inertisation in gob areas [11,12], study airflow patterns and gas concentrations in continuous miner operations or heading development [13–17], inves-

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tigate scrubber intake designs for longwall dust control [18], estimate a mine's damage status by tracer gas and simulation after a disaster [19] and evaluate transport of mining pollutants in soil, water and air. CFD modeling has been demonstrated as a powerful tool for understanding airflow movement and gas/dust behavior in a complicated three dimensional environment. It can also provide useful information for initial concept testing of new ideas and equipment for environment control.

Simulation of DPM dispersion in underground M/NM mines was carried out by Zheng and Tien [20], in which DPM was considered to behave like a gas. Subsequent study showed that it gave good quantitative agreement with practical accuracy for the DPM distribution and successfully identified the DPM affected areas above the threshold limit [21]. In the present study, DPM emission was also treated as a gas to examine its diffusion inside an underground single dead-end entry.

In this study, the effect of four different auxiliary ventilation systems on DPM distribution inside a single dead-end entry was studied for a loading operation. The ventilation systems considered in this study included: a blower fan with push tubing, an exhaust fan with pull tubing, a jet fan and a combination of blower and exhaust fans with both push and pull tubing (push–pull). This study can be used for mining engineer as guidance to design and setup of local ventilation. The high DPM regions revealed by the simulation can also be used for selection of DPM control strategies and DPM annual training for underground miners.

2. Problem description and CFD modeling

The schematics of a single dead-end entry with four different auxiliary ventilation systems installed are shown in Fig. 1. For all cases, the main entry measured 6 m in width, 5 m in height and 131 m in length, while the dead-end measured 6 m in width, 5 m in height, and 90 m in length. The main entry had of 19.35 m^3/s (41,000 cfm) of fresh air flowing from the left to the right. In Fig. 1a, the push tubing extended into the dead-end entry for about 70 m and about 3.4 m into the main entry. The blower fan at the inlet of the push tubing was set to provide 8.02 m^3/s (17,000 cfm) of fresh air into the face area. In Fig. 1b, the pull tubing extended into the dead-end entry for about 81 m, while 15 m remained in the main entry. The exhaust fan at the outlet of the pull tubing drew the diesel exhaust mixture at a rate of 9.44 m^3/s (20,000 cfm) from the face area and released it into the main entry. The diameter of both the push and pull tubings was 0.8 m.

In Fig. 1c, the jet fan is 2 m in length and 0.6 m in diameter. It provided 8.73 m^3/s (18,500 cfm) of fresh air. For the push–pull system, the pull tubing curved an additional 12 m into the working face as shown in Fig. 1d and all the other parameters are the same with individual blower fan/tubing and exhaust fan/tubing system.

Three-dimensional incompressible unsteady turbulent continuity, momentum, and energy equations, along with standard k–ε turbulent and non-reacting transport equations (2 species, DPM and air) were solved using Ansys Fluent. The Species transport model, available in Fluent, was used to determine the DPM distribution pattern.

Due to the multiple cases covered in this section, all of the boundary conditions are summarized in Table 1. The parameters for the main ventilation and diesel vehicles are derived from previous industrial field study [22]. The detailed meanings of the boundary conditions are presented in other sections and in the Ansys Fluent manual.

In order to achieve accuracy in the simulation results, finer meshes have been generated for the area close to diesel engines where high gradients existed. For all the models, about 1.5 million computational elements (cells) were generated.

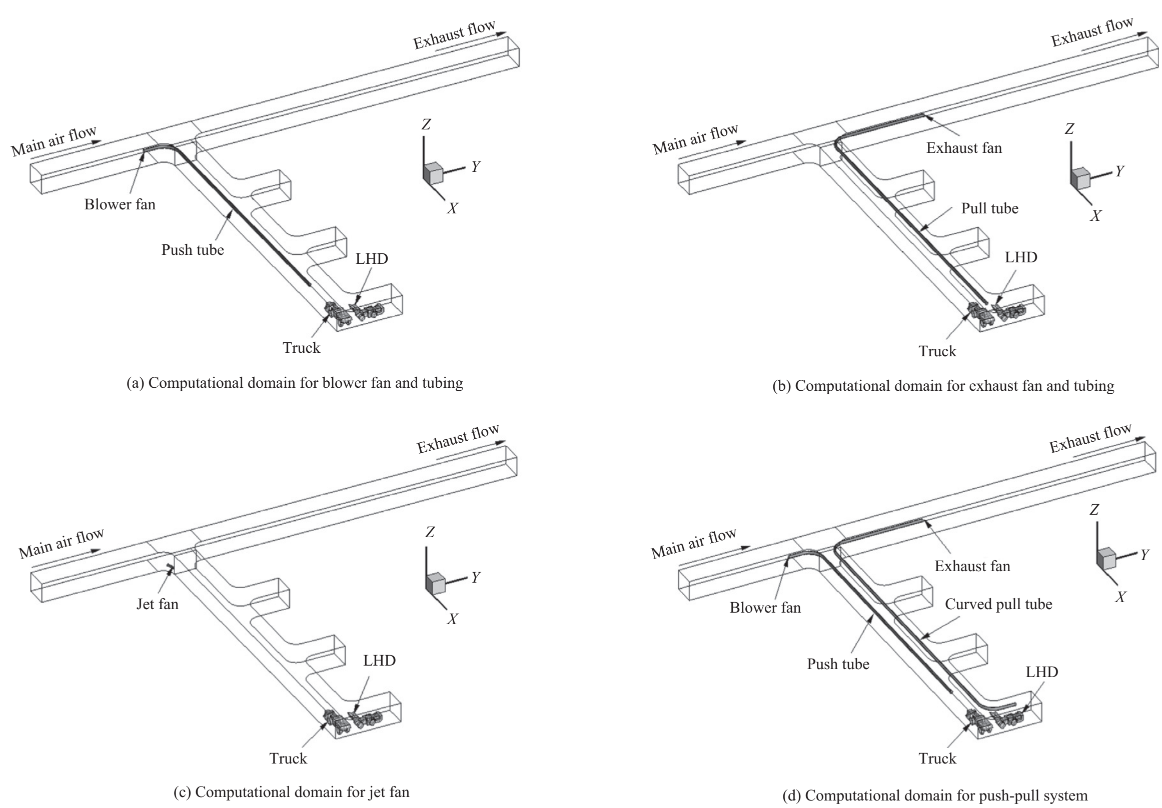

Fig. 1. Schematics of a single dead-end entry with four different auxiliary ventilation systems.