SIMULATING TEMPERATURE INVERSIONS IN SURFACE MINES USING COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

Air temperature inversions affect surface mine environments in the form of accumulation of higher concentrations of pollutants (gases and dust), increased air over pressure and ground vibrations, and prevention of dispersion of gases produced by blasting and equipment operations. In this study, air temperature inversion conditions are simulated in a hypothetical open pit mine model using Computational Fluid Dynamics (CFD) and the effect of the temperature inversion on the dispersion of gas and dust particles in the pit is examined. As expected, it was observed that the gas and dust particles were trapped inside the pit under inversion conditions while they were dispersed in the absence of inversion. Various mitigation techniques that were applied to break the inversion layer were evaluated for their effectiveness in dispersing it. The results and analysis of the inversion dispersion techniques are provided in Part II of this study.

Keywords

Temperature inversions, open pit mine ventilation, computational fluid dynamics (CFD), air over pressure, ground vibrations.

INTRODUCTION

In the United States 85% of minerals are extracted through surface mining methods (Hartman et al. 2002). As the demand for minerals is increasing, production from surface mines is also increasing. This increased production is leading to the development of larger and deeper surface mines. For example, Bingham Canyon Mine located in Utah is now operating at a depth of about 1.25 km from the surface (Hawley et al. 2015).

When a surface mine reaches such depth, depending on the design of pit walls, the diesel equipment used at the mine and the blasting operations can create an air pollution problem due to lack of proper ventilation in the mine. This problem is exacerbated when a temperature inversion exists at the mine. The inversion
layer acts like a lid on top of the pit and traps the pollutants in the mine that would otherwise get dispersed under normal weather conditions. Temperature inversions also create other problems for surface mining operations, such as increased levels of air over pressure and ground vibrations when blasting operations are performed under inversion conditions.

A temperature inversion is defined by an increase in air temperature with height, opposite to what is normally observed. A common type of inversion is the surface-based radiation inversion resulting from the loss of solar input to the earth’s surface after sunset. The surface cools by emitting long-wave radiation, and in turn cools the near-surface layer of the atmosphere, leaving warmer air above. Radiation inversions are a common and important feature of the meteorology and climate of mountain valleys and can also occur in deep bowls with long periods of darkness. Regions such as Alaska and Russia are the main mining locations that are experiencing this dangerous phenomenon. Other atmospheric processes can also lead to inversion formation, but those formed by radiation appear the most relevant to mining operations.

In open pit mines, temperature inversions begin to develop around sunset, when the air over the slopes and pit floor cools in response to the loss of surface heating from solar radiation. Inversion build-up is facilitated by the flow of cold air down the slopes to form a pool of cold air over the bottom of the pit. This results in a layer of cold air near the surface overlaid by a layer of comparatively warm air, creating the temperature inversion. This represents a thermodynamically stable atmospheric stratification which can cause pollutants and gases to be trapped in the pit. The basic characteristics of the typical inversion evolution on clear weather days are fairly well known.

The primary objective of this study was to evaluate the effectiveness of various artificial inversion dispersion techniques proposed by previous researchers. However, to achieve this objective, Part I of this study first focused on the simulation of inversion conditions and its effect on the dispersion of gas and dust particles in a hypothetical open pit mine using Computational Fluid Dynamics (CFD) modeling. Since this is a novel application of CFD modeling, it was necessary to first ensure that the model could simulate an inversion and its effects accurately.

CFD is a branch of Fluid Mechanics that uses numerical techniques to solve and analyze problems that involve fluid flows. It has been proven to be a viable tool for simulating and analyzing the airflows both in surface and underground mines. Several researchers have used this tool for mine ventilation research; of those, the most recent study was a three-dimensional CFD modeling of fugitive dust dispersion in an idealized open pit mine (Bhowmick et al. 2015). The CFD software package SC Tetra was used for our study (Software Cradle 2013).

METHODS

To evaluate the effectiveness of various artificial inversion dispersion techniques, we performed the following tasks: simulation of inversion layer in a hypothetical mine model, simulation of dust particles with and without inversion
conditions, simulation of oxides of nitrogen (NOx) gas dispersion under inversion conditions, and simulation of artificial inversion dispersion techniques in a hypothetical mine model.

As shown in Figure 1, a hypothetical open pit mine model with the dimensions of 2000 m and 3500 m lengths at the bottom and top of the pit, respectively, and 1500 m x 1200 m width and depth, respectively, was created in AutoCAD. For this study, opencast mine dimensions were considered. Though the real world pit geometry consists of irregular terrain and several benches along the pit walls, two inclined walls with 52-degree slope angle and a horizontal pit bottom have been considered for this study.

The west side boundary on top of the pit has been considered as inlet and the east side boundary considered as outlet. The input data for this study were collected from an open pit gold mine located four miles west of Lead, South Dakota, which is situated in the northern Black Hills region. Weather stations were installed at this mine to measure temperature, wind velocity, solar radiation, and wind direction at three different locations in the pit: one at the top of the pit, a second one at the middle of the pit and a third one at the bottom of the pit. Data were recorded every 5 minutes for about 4 months.

The simulations were started with a steady state condition and ran for 24 hours. Unsteady-state analysis (fluid properties change with time) was used for all the simulations. Each cycle used a time step of 1 second, and the model was meshed with 1,000,000 elements. To model thermal buoyancy, we used the Reynolds–averaged Navier-Stokes-based standard Kappa-Epsilon turbulence model. Solar radiation was applied to the model using a solar radiation function that defined the solar heat constant, and the latitude and longitude of the sun’s position. After sunset, a wall heat transfer coefficient was used to simulate the effect of long wave radiation from the surface.
RESULTS

A total of four different scenarios were simulated in a hypothetical open pit mine to analyze the effect of temperature inversions on pollutant dispersion in an open pit mine. The first scenario was the simulation of the formation of a temperature inversion layer. The second and third scenarios were the simulation of dispersion of dust particles under no inversion and inversion conditions. The fourth scenario was the simulation of gas dispersion under temperature inversion conditions. For all four scenarios, the air velocity of 3 m/s was defined at the inlet boundary and simulations were started with a steady state condition; i.e., the air temperature inside the pit was the same everywhere.

In the first case, when solar radiation was applied to the model, the effects of the ground being heated can be seen by a small boundary layer along the exposed ground. As time progresses, the exposure of the ground to solar radiation increases and the ground begins to warm. Usually after sunset the surface of the pit starts cooling down by emitting long wave radiation and the near surface layer of atmosphere cools via conduction. When the surface became cold at night, the layer above the surface became cold and hot air was trapped at the middle of the pit. As shown Figure 2a, a thick hot layer is formed in the middle of the pit between the cold air at the top and bottom. After some time, the hot air moved out of the pit and cold air got trapped inside the pit underneath the hot air, resulting in the formation of the inversion (Figure 2b).

The velocity vectors of the airflow show the air recirculation (Figure 2f). From this figure one can observe that at the top of the pit the air velocity is greater than at the bottom of the pit where the velocities are negligible. The air above the pit is not interacting with the air inside the pit which caused the recirculation inside the pit. This condition causes the concentration of pollutants to increase inside the pit.

In the second scenario, a particle tracking function was used to track the particles in the model. The inlet and the outlet were defined as destruction zones, so that when a particle touches these zones it vanishes. Due to air convection, the particles are flowing towards the wall and outside the pit. Due to the buoyancy effect, most of the particles are flowing out of the pit as time progresses. When no temperature inversion exists in the pit, the simulated dust particles (purple dots in Figure 2c) were dispersed and moved away from the pit bottom. On the other hand, in the third scenario, under temperature inversion conditions, the air inside the pit recirculated without interacting with the air outside the pit. As the inversion layer is acting like a lid on top of the pit, most of the particles are being trapped in the pit (Figure 2d). This condition leads to an increase in the concentration of particles inside the pit which in turn increases the pollution in the working environment.

In the fourth scenario, after the thermal inversion was formed, the gas was released from the bottom of the pit (Figure 2e). After some time, gas started moving upwards by diffusion. But as the thermal inversion layer is present at the top of the pit, there is no upward movement of air above the pit. Due to air recirculation, the gas started moving into the pit. After some time, even though
the concentration of the gas is not high at one specific point, the concentration of gas has been distributed inside the pit. This is a hazardous condition. Due to the thermal inversion layer at the top of the pit, the gas is recirculating only inside the pit.

**DISCUSSION**

The purpose of this study was to investigate the dispersion of gas and dust particles under inversion and no inversion conditions using CFD. From this study, it was observed that CFD can be a very efficient tool for analyzing the airflows...
and temperature inversions in open pit mines. We can conclude that pollutants get trapped inside the pit under temperature inversion conditions, which is an expected result. This gives us confidence that the CFD model is capturing the relevant processes necessary to simulate inversion effects on open-pit mines. An examination of simulated inversion dispersion effects will be presented in Part II of this study.

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LITERATURE CITED


