# Impacts of increasing the airflow rate on load-haul-dump heat spread at an underground mine

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# Impacts of increasing the airflow rate on load-haul-dump heat spread at an underground mine

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**Abstract.** In the mining process, mining companies use various mining equipment to extract valuable materials. One of them is a load-haul-dump (LHD) machine. Although this equipment is very helpful in the production process, it also has drawbacks. This equipment emits heat that can affect air temperature in the mine tunnel and cause a decrease in the comfort of mineworkers, which then impacts the mine productivity. One of the methods that can be carried out to overcome this problem is to increase the amount of airflow by changing the ventilation network. Therefore, this study aims to determine the impacts of increasing airflow on the heat spread of the operated LHD machines. The results of this study are to provide a method for reduced temperature visually and can be used as a recommendation for temperature reduction in the future. To examine the heat spreading, the researchers applied a tunnel model made using CFD software that is ANSYS Fluent and use VentSim software to simulate the network changes. The results indicated that the increase of the airflow rate could reduce the temperature on the work front when the LHD machines are operating and can affect the heat spread.

## 1. Introduction

PT. Cibaliung Sumberdaya (PT. CSD) applies an underground mining method to extract valuable material in the form of gold from the ground. The underground mining method highly requires mine ventilation to deliver and supply fresh air from the surface to meet the respiratory needs of humans and equipment in the mine. Ventilation is also useful for diluting impurity gases and regulating the temperature in the work area so that mineworkers can work comfortably.

In the mining process, PT. CSD uses a variety of mining equipment to assist the process of extracting valuable materials. One of the equipment used is the load-haul-dump (LHD) machine used for the mucking process. These LHD machines are very helpful in the mine production process. However, it also has drawbacks that sufficiently affect the comfort of mineworkers, in which it generates pretty high heat and can potentially increase the temperature in the tunnel. Various ways can be carried out to minimize the temperature increase caused by the operation of the LHD machines. One of them is to increase the airflow to the work front by changing the ventilation network [1,2]. Mine ventilation is an effort to control airflow from the surface into the underground for the need of workers and equipment used. The circulated fresh air can remove dust and toxic gases and lower the temperature. Air is flown into the mine using natural and artificial ventilation [3].

Therefore, this study aims to determine the impact of increasing the airflow to the heat spread of the operated LHD machine. The results of this study are expected to provide a method for reducing temperature visually and can be used as a recommendation for temperature reduction in the future.

## 2. Literature review

### *2.1. Previous research*
This study closely follows previous research on thermal management strategy using CFD [1], which discusses various variables effect on underground mine air temperature including mining machine and airflow rate. This study mostly agrees with its content while also made a model to do a visual observation.

### *2.2. Research location*
The research location of this study is one of the underground mining fronts owned by PT. CSD, namely the XC-13 VT NRTH work front in the Cikoneng block. This work front is at about 200 m depth from the surface and 1700 m from the portal. This work front has a tunnel width of 4.632 m, a height of 5.065 m, a length of 68.9 m, and a horseshoe shape. Furthermore, this work front implements a blow ventilation system that uses a vent duct to channel the air. The source of the air comes from a 37-kW forcing fan installed in another location. This vent duct has a length of 49.94 m and a diameter of 0.7 m [4,5].

### *2.3. The calculation of air requirements*
The calculation of the air demand in the mine refers to the Decree of the Director-General of Minerals and Coal of the Ministry of Energy and Mineral Resources No.185.K/37.04/DJB/2019, which states that the volume of supplied clean air must be calculated based on the largest number of workers at a work location with a minimum requirement of 0.03 $m^3/s$ when the working process occurs and as much as 0.05 $m^3/s$ for each horsepower of operating diesel equipment. On the mining front at PT. CSD, one of the activities carried out is a mucking that uses 1 LHD machine and one worker. The LHD machine with the greatest power in PT. CSD is Tamrock 006 with a power of 202 Hp. By referring to the Decree of the Director-General aforementioned, the total air demand on the work front for mucking activities is as follows.

$$\textit{Air requirement for equipment used} = 202\ Hp\ x\ 0.05\ m^3/s = 10.4\ m^3/s \quad (1)$$

$$\textit{Air requirement for humans (workers)} = 1\ person\ x\ 0.03\ m^3/s = 0.03\ m^3/s \quad (2)$$

$$\textit{Total air requirement} = 10.4\ m^3/s + 0.03\ m^3/s \quad (3)$$

### *2.4. The calculation of the heat generated by diesel equipment*
The internal combustion of diesel equipment has an efficiency of 1/3 compared to electrical equipment [6]. Therefore, diesel equipment generates about three times as much heat as electrical equipment for the same workload. To calculate the heat generated by diesel equipment, we can use the following equation [6,7].

$$q_{ed=}f_m\ x\ f_t\ x\ q_d\ x\ P_d = 34\%\ x\ 36\%\ x\ 2.9\ \frac{kW}{kW}\ X\ 150\ kW = 53.244\ kW \quad (4)$$

The mechanical efficiency of diesel equipment is 34% [6], while the efficiency of using the LHD engine of PT. CSD is 36% [8].

### *2.5. The calculation of heat increases due to diesel equipment*
The heat released by the diesel engine into the mine ventilation air only affects the location where the equipment works [6]. The heat gained due to diesel equipment can be calculated using the following equation [6].

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$$\Delta t_d = \frac{f_m \, x \, f_t \, x \, q_d \, x \, P_d}{\rho_a \, x \, C_e \, x \, Q} = \frac{34\% \, x \, 36\% \, x \, 2.9 \frac{kW}{kW} x \, 150 \, kW}{1.1774 \, kg/m^3 \, x \, 1.0057 \, kJ/kg.°C \, x \, 2.97 \, m^3/s} = 15.139°C \quad (5)$$

Where:

$q_d$ = equivalent energy released by diesel fuel (2.9 kW/kW)
$f_m$ = mechanical efficiency
$P_d$ = the rating in kW of the equipment engine
$ft$ = equipment utilization efficiency
$q_{ed}$ = heat generated by diesel equipment (kW)
$\Delta t_d$ = change in temperature due to diesel equipment (°C)
$\rho_a$ = density of air (kg/m$^3$)
$C_e$ = specific heat of air (kJ/m.°C)
Q = airflow rate (m$^3$/s)

On the calculation above, the ρa and $C_e$ data refer to air properties table at atmospheric pressure for a temperature of 300 °K. Meanwhile, the Q data is the measured airflow rate on the work front [6]. The operation of the LHD machine in the work front can theoretically increase the temperature to 15.139°C for one work cycle of the equipment [6,9], which is 4 hours [4,8].

## 3. Materials and methods

CFD software is used to analyze the impact of increasing airflow on the heat spread of the operated LHD machines. The amount of airflow is changed by modifying the ventilation network using VentSim software. All the data used in this study is secondary data obtained from existing research [4,5,10]. A percent error calculation was conducted for validating the model. Based on the CFD research for mining applications, the percent error of 20% is still acceptable due to limited data and the accuracy of data obtained from the field, so that is normal to have a percent error calculation of up to 20% [11]. The percent error is calculated as follows.

$$\%error = \left[\left(\frac{S-T}{S}\right) x \, 100\%\right] \quad (6)$$

Where:

S = Data generated from simulation
T = Data from theoretical calculation

The CFD software that is used in this research is ANSYS Fluent. The geometry modeling of the tunnel and vent duct follows the work front conditions with the geometry of the simplified LHD Toro 006 shape [12–14]. The specifications of the geometry in this study are presented in Table 1 and Figure 1.

**Table 1.** The data concerning tunnel geometry.

| Geometry | Specification |
|---|---|
| Tunnel Geometry | Length: 68.9 m<br>Width: 4.632 m<br>Height: 5.065 m |
| Vent Duct Geometry | Diameter: 0.7 m<br>Length: 49.94 m<br>Width: 8.608 m |
| LHD Geometry | Width: 1.9 m<br>Height: 1.66 m |

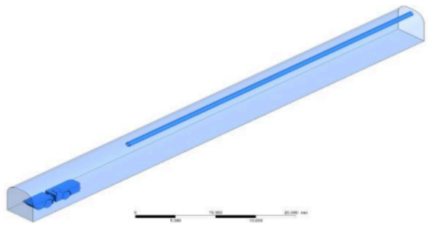


**Figure 1.** The geometry of the work front tunnel.

In addition, the mesh used is a mesh that is automatically generated by the meshing software, which produces a tetrahedral mesh shape. In the boundary setting, the tunnel exit path is chosen as the outflow due to the unknown temperature and pressure at the air outlet through the tunnel [12]. Meanwhile, the air velocity and temperature refer to measured [4,5,10], and the heat flux on the body and exhaust of the LHD machine is one-third of the kW rating of the LHD machine [1] divided by the surface volume.

For the data concerning the solver setting, it is mostly in the default setting. The turbulence model used is the standard k-epsilon turbulent model, which is the most efficient and most widely used in underground mine ventilation airflow modeling using computational fluid dynamics (CFD) [1,11,15–18].

In this research, to accommodate an increasing airflow rate, a ventilation network changes were conducted. The ventilation network changes are simulated using VentSim software.

## 4. Results

### *4.1. Temperature spread in initial conditions*

According to the theoretical calculation results, when the LHD Toro 006 is operated, the air temperature after 4 hours of operation will be 47.472°C. The data of this theoretical calculation are later be used to carry out the percent error calculation to find out whether the model that has been made can be used to reflect the actual tunnel conditions on the work front.

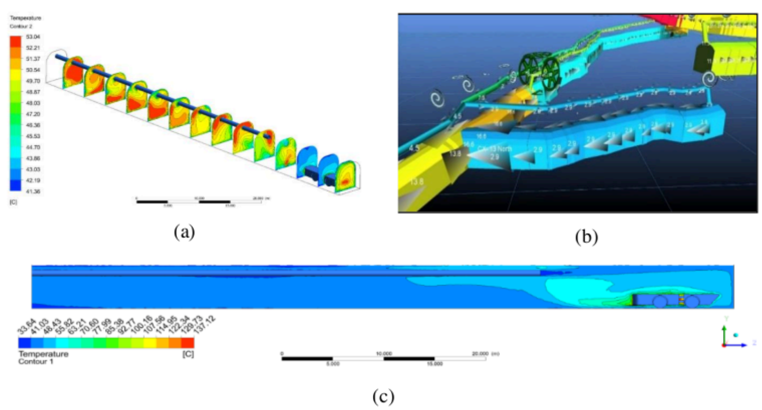


**Figure 2.** The temperature spread on the work front in the initial conditions (a) and (c) and actual ventilation network (b).

Figure 2(a) shows the temperature spread in the initial conditions when the LHD machine is operated. The measurement points are at a distance of 1 m, 5 m, 10 m, to 65 m with multiples of every 5 m from the end of the tunnel. When the LHD machine is operated, the heat is concentrated on its body, especially the rear where the exhaust of the LHD machine is located. The spread of heat rotates following the airflow as the air travels to the tunnel's exit.

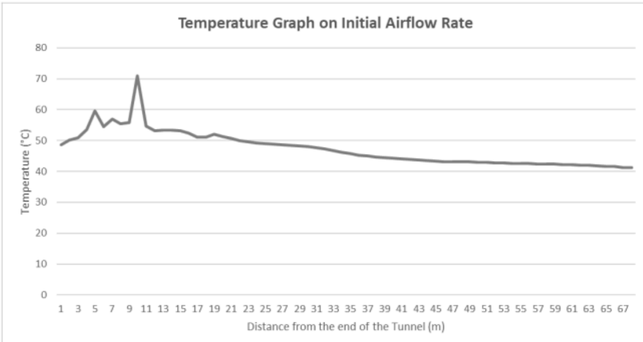



**Figure 3.** Temperature on initial airflow rate.

Figure 3 shows the temperature of the tunnel in every 1 m distance based on when the LHD is operated. The heat distribution is centered at the end of the tunnel where the LHD is operated. The hottest point is at a distance of 8-11 m where the exhaust of the LHD machine is located.

According to the simulation results, the average temperature on the work front is 47.519°C. The percent error ratio is calculated and compared with the theoritical calculation data as follows.

$$\%error=\left[\left(\frac{47.519-47.472}{47.519}\right)x\ 100\%\right]=0.098\%$$

With a percent error value of 0.098%, the model is considered to reflect the actual work front tunnel conditions and can be used to examine the heat spread.

*4.2. Temperature spread when the airflow rate is increased*

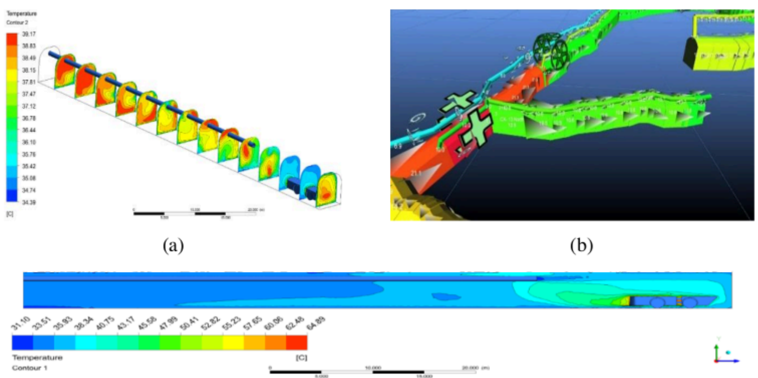
The airflow rate on the ventilation network has changed to reduce the increase in temperature. The airflow is adjusted to the air requirement for the mucking process, which is 10.43 $m^3/s$. Therefore, the theoretical increase in temperature can be calculated as follows.

$$\Delta t_d = \frac{34\%\ x\ 36\%\ x\ 2.9\frac{kW}{kW}\ x\ 150\ kW}{1.1774\ kg/m^3\ x\ 1.0057\ kJ/kg.°C\ x\ 10.43\ m^3/s} = 4.31\ °C$$

When the airflow rate is increased, the air temperature, after the LHD machine operated for 4 hours, theoretically will be 36.643°C. That is very different from the initial conditions, which is 47°C. Changes in the ventilation network can be conducted using the VentSim software. After that, the modeling is carried out.

Using the VentSim software, the ventilation network changes are carried out by cutting the previous vent duct and adding a booster fan close to the work front to force the air. More air is channeled to the work front. After that, the temperature distribution modeling is carried out.

In Figure 4(a), it can be seen the temperature distribution when the airflow rate is increased. The measurement points are the same as the initial condition, namely at a distance of 1 m, 5 m, 10 m to 65 m with multiples of every 5 m from the end of the tunnel. When the airflow rate is increased, the heat spread is similar to the initial conditions, in which the heat is concentrated at the end of the tunnel where the LHD machine is operated. The rear of the LHD machine has the hottest because it is the location of the LHD machine exhaust.



(a) (b)

(c)

**Figure 4.** The temperature spread on the work front when the airflow rate is increased (a) and (c) and changes to the ventilation network (b).

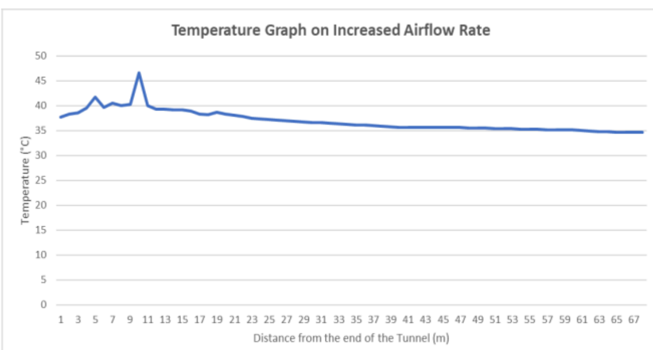



**Figure 5.** The graph of the temperature when the airflow rate increased.

However, when comparing Figure 4(c) to Figure 2(c), when the LHD is operated, the hot air seems not gathered but is carried further away. It is because firmer air can make hot air be carried away faster.

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Figure 5 shows the temperature graph from the model made based on when the LHD is operated at every 1 m distance. It is known that when the airflow rate is increased, the heat distribution is similar to the initial condition, which is centered at the end of the tunnel where the LHD is operated. The hottest point is at a distance of 8-11 m, where the exhaust of the LHD machine is located.

According to the simulation results, the average temperature on the work front is 37.062°C. The percent error ratio is calculated and compared with the theoretical calculation data, which is 36.643℃ with the maximum percent error of 20%. The calculation of the percent error is shown as follows.

$$\%error=\left[\left(\frac{37.062 - 36.64}{37.062}\right) x\ 100\%\right]= 1.13\%$$

With a percent error value of 1.13%, the model reflects the actual work front tunnel conditions when the airflow rate is increased.

## 5. Discussion

From the theoretical calculations and simulations that have been carried out, the increase of the airflow rate impacts the decrease in temperature of the work face. The temperature spread is centered at the end of the tunnel where the LHD machine is operated. The hottest point was at a distance of 8-11 m, where the exhaust of the LHD machine is located. The difference is that the average temperature is lower when the airflow rate is increased.

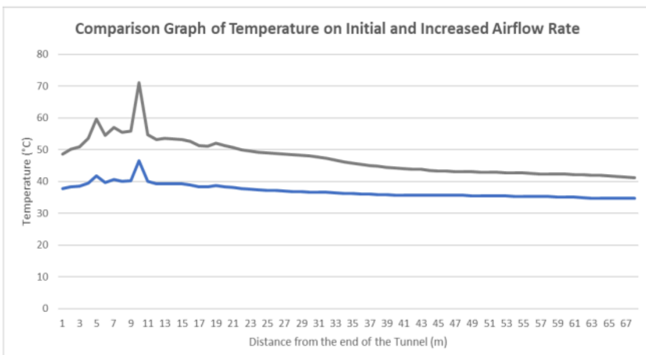


**Figure 6.** The graph of the difference in temperature spread in the initial conditions and when the airflow rate is increased.

## 6. Conclusion

From this study, it can be concluded that, from the simulation results, increasing the airflow rate impacts the decrease of the temperature on the work front when the LHD machine is operated, which is from 47.519°C to 37.062°C. Furthermore, it also affects the temperature spread on the work front because, although temperature spread is similar graphically, it has a much lower temperature. This research has limitations by using secondary data. It would be better if the field data were self-measured. The simulation can be more detailed, even expanded on larger location in an underground mine and more variables as a consideration such as dust, gas content, etc.

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