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Some Effects on the Temperature of the Mine Air at the Heading Face

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Abstract. Currently, with the increase in mining output leading to deeper mining levels, the volume of heading face serving production has also increased. The thermal environment tends to worsen when digging deep due to the geothermal's effect, which increases the air temperature at the heading face. According to QCVN01/2011-BCT, the temperature at the heading face is not allowed to exceed 30^0C. To ensure this, in Vietnam today, mainly forced ventilation method uses local fans to provide a clean amount of air to ensure a favorable environment for workers. With the forced ventilation method, the duct position is usually arranged on the side, and the distance from the duct mouth to the heading face is determined to ensure that $l < 6\sqrt{s}$. In this study, a numerical simulation method by Ansys CFX software is applied to study the influence of several factors such as duct position, air temperature of duct, and roughness characteristics of roadway on the temperature of the mine air at the heading face. The models are set up with six duct positions and four air temperature of duct parameters. Model 1 (y =1.1 m) is better than models 2 to 6 in terms of temperature distribution and the lowest temperature values. Four models have different wind temperatures, and we can see the significant influence of the inlet air temperature of the duct on the thermal environment of the heading face. The results show that with the model T = 297.15K, the temperature value on the roadway length is guaranteed as specified < 303K. The result is a reference for determining the duct position and cool for the high-temperature heading face.

Keywords: Numerical modeling, CFX, Ventilation duct position, Heading face, Temperature of air mine

1. Introduction

With the need to develop the economy, the demand for coal minerals is constantly increasing. In recent years, coal mineral resources in the shallow part of Quang Ninh area are gradually depleting, leading to the trend of deep mining for natural resources with Vietnam's underground coal mines is very necessary. Currently, coal mines in Quang Ninh, Vietnam are prepared and exploited to the following levels: Mao Khe -400, Ha Lam -350, Khe Cham 2-4, -500; Mong Duong -400; This leads to an increase in the amount of preparatory excavation work and preparation at such depths, which means that the temperature of soil, rock, and coal will also gradually increase above 30^0C along with the use of modern machinery and equipment. The air in the excavators also increases. As a result, the thermal environment deteriorates, affecting the working conditions of workers. Advance this to create favorable working conditions on wind speed, temperature, humidity, dust for mines as standard. At coal mines, the main method of local ventilation is the forced ventilation method. With the layout of the side ducts, the location depends on transport equipment with a distance of $L<6\sqrt{s}$ for the roadway. There are many research works on working environment conditions in heading face in the general and thermal environment in particular. In general, the deterioration of the thermal environment in the heading face is mainly due to geothermal effects on machinery, equipment and inlet wind temperature. According to Agus, P.S et al., the three-dimensional blind heading model for studying the effects of the airflow velocity, the rock temperature and heat dissipation from mining equipment on the air temperature in the underground mine [1]. The heat transfer between the surrounding rock and the airflow in the underground mine is varied, including conduction heat from the rock to the airflow, thermal convection between the wall and the airflow, heat radiation from the wall to the airstream, and also includes heat transfer between the rock and the water, water and airflow [2, 3]. Len et al. stated that the high temperature of deep underground space is essentially influenced by the thermal characteristics of the surrounding rock [4]. QUAN Truong Tien et al. shows that the surface temperature affects the mine air temperature [5]. The mine temperature is affected by the geothermal, climate and heat radiation from mining equipment [6]. Other research indicated that mine air's important heat source effects are the heat from the rock, etc. [7]. In addition, many mathematical models have been proposed in the mine ventilation area, from one-dimensional heat transfer models to computational ventilation dynamics (CFD) models. In Vietnam, there are many typical studies on air temperature in underground mines. Dao Van Chi et al. [8] and Nguyen Van Quang et al. [9] analyzed the main factors that affect air temperature in the underground mine, such as the temperature of the surrounding rock, heat of equipment, and airflow. However, this analysis and assessment is only qualitative and has not determined specific values. To improve microclimate conditions in underground mines, the authors proposed solutions to improve ventilation efficiency to ensure the velocity moves in the roadway and the mine air's temperature and humidity within the allowable limits [10, 11, 12]. Another study, determination of reasonable working mode for main fan to ensure the required air flow for heading face [13].However, in specific geological conditions with specific area characteristics, the influence of factors on air temperature in the heading face is also different. In this paper, the author builds a numerical model showing the influence of duct position, inlet wind temperature, and especially taking into account the roughness of the roadway affecting the thermal environment in the heading face. From there, it can be used as a reference to choose the position of the duct, select the inlet temperature to ensure favorable environmental conditions, and save cooling costs when used. Thus, in addition to the influence of the heat source, the input temperature is critical, directly affecting the thermal conditions and the roughness of the heading face, increasing the heat exchange time between the rock and the air. The article builds 6 models with duct height (y = 1.1 m; 1.7 m; 2.0 m; 2.3 m; 2.6 m; 3.1 m) near the side of wall and 4 models with inlet air temperature (t_{duct} = 297.15K; 299.15K; 301.15K; 302.15K) vary with a 2 cm wall roughness.

2. Modeling

The simulation was based on the basic parameters of the roadway level -250 seam L7 of Mong Duong coal mine: the length of roadway L > 40 m; the height of the roadway y = 3.5 m, the width of the roadway b = 4.5 m). The -250 level transport road uses the forced ventilation method with the following parameters (ϕ_{duct} = 0.6 m, h_{duct} = 2.3, v = 9 m/s). From that, the article builds six positions of duct models (height of duct y = 1.1 m; 1.7 m; 2.0 m; 2.3 m; 2.6 m; 3.1m). 4 models of inlet wind temperature (t_{duct} = 297.15K; 299.15K; 301.15K; 302.15K). The position of the duct is arranged in Figure 1.

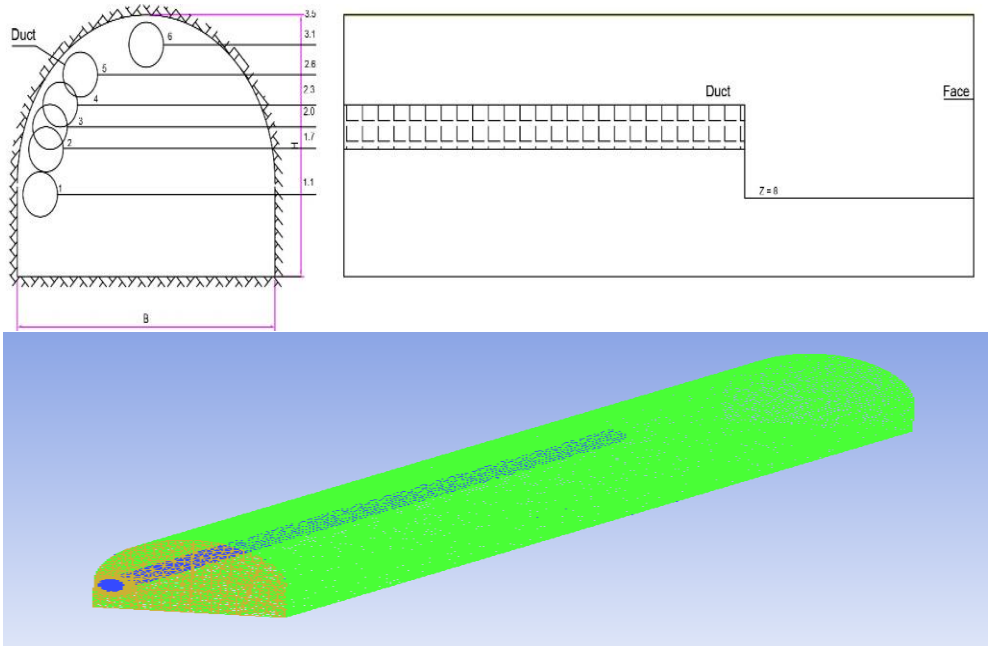

Fig. 1. Position of an air duct on heading face.

3. Computational model

3.1 Numerical model

The article uses numerical simulation (CFD) with geometric modeling and meshing done in ICEM-CFD software with the same geometric size as above, meshing with pipes of 0.03 and roadway of 0.3, the number of elements $2.2x10^6$ – $2.6x10^6$ divide the boundary condition into two classes. The numerical simulations were carried out in ANSYS CFX. The turbulence model is K-Ɛ.

3.2 Mathematical model

Numerical fluid mechanics is a method of simulations of phenomena related to the flow of gases, heat, and mass transfer. This paper uses this method to determine the influence of the parameters (duct position, inlet temperature) on the temperature distribution in the working area. Conservation equations for mass, momentum, and energy are expressed as:

- The continuity equation

$$\frac{\partial p}{\partial t}+\frac{\partial(pu)}{\partial x}+\frac{\partial(pv)}{\partial y}+\frac{\partial(pw)}{\partial z}=0 \quad (1)$$

where: u,v,w is direction velocity (m/s); p is density (kg/m^3); t is time (s).

- The momentum equation

$$\frac{\partial}{\partial t}(pv)+\nabla.(vv)=-\nabla p+\nabla\mathcal{T}+pg+F \quad (2)$$

where: p is static pressure (pa) $\mathcal{T}$ is stress tensor (pa), gravitationnal body force (m/s^2); F is external body force (N).

- The energy equation

$$\frac{\partial}{\partial t}(pE)+\nabla.(\overrightarrow{v}(pE+v))=\nabla\left(k_{eff}\nabla T\right)+S_h \quad (3)$$

where: E is energy (J), T is temperature (K); k_{eff} is effective thermal conductivity; S_h is source term.

3.3 Boundary conditions

The boundary conditions and computational model settings for this study are presented in Table 1.

Tab. 1. Model parameters.

Real parameter	Model parameters	Real parameter	Model parameters
inlet air duct	Inlet	Temperature of air duct	302.15K
Velocity of air duct	9 m/s	Temperature off-air road	302.15K
Outlet	Outlet	Temperature of rock	305.15K
		Wall roughness	2 cm

4. Numerical simulation

4.1 Check the fit of the model

Measurement data, through field measurement with the temperature measuring equipment of the mine model "Kestrel -300", the measurement position is length from the face (z = 1 m, 2 m, 4 m, 10 m, 15 m, 20 m, 25 m, 30 m, 35 m) measure many positions on the cross-section to get the average result. Table 2. shows the measurement data result.

Tab. 2. Measurement and simulation data results.

Distance to face (m)	Measurement data (^{0}K)	Simulation data (^{0}K)	errors (^{0}K)
1	303.4	303.506	0.1
2	303.6	303.57	0.03
4	303.9	303.678	0.22
10	303.9	303.878	0.02
15	304	303.837	0.16
20	304.3	304.017	0.28
25	304.6	304.332	0.27
30	304.6	304.587	0.06
35	304.7	304.596	0.1

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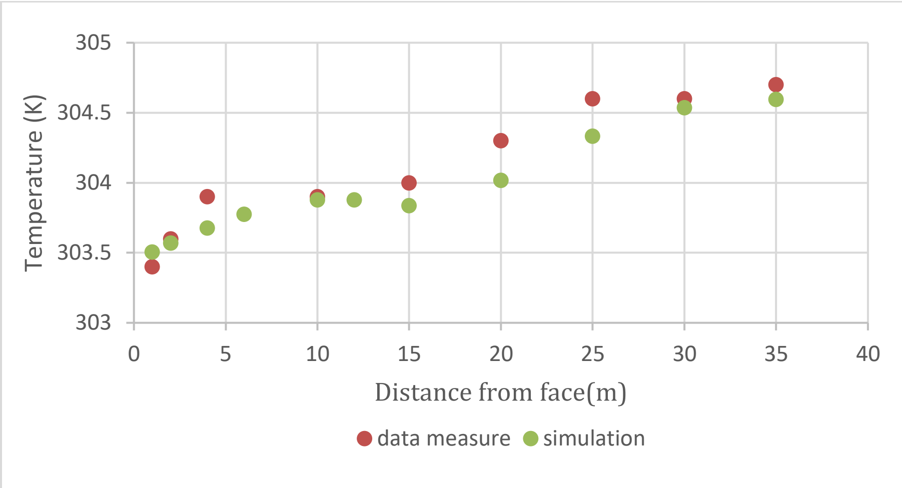

Fig. 2. Measurement and simulation results.

Figure 2 shows the numerical simulation results of the model (y = 2.3 m), and the field measurements show minor deviations, but they do not affect its accuracy. Therefore, the results of numerical simulations have a reference value.

4.2 Model with the variable position of the duct

From the software results, the article determines the average temperature of the cross-section on the roadway, then builds a graph with the average temperature value at the cross-sections with six models (y = 1.1 m; 1.7 m; 2.0 m; 2.3 m; 2.6 m; 3.1 m). The results are shown on the graphs corresponding to each model.

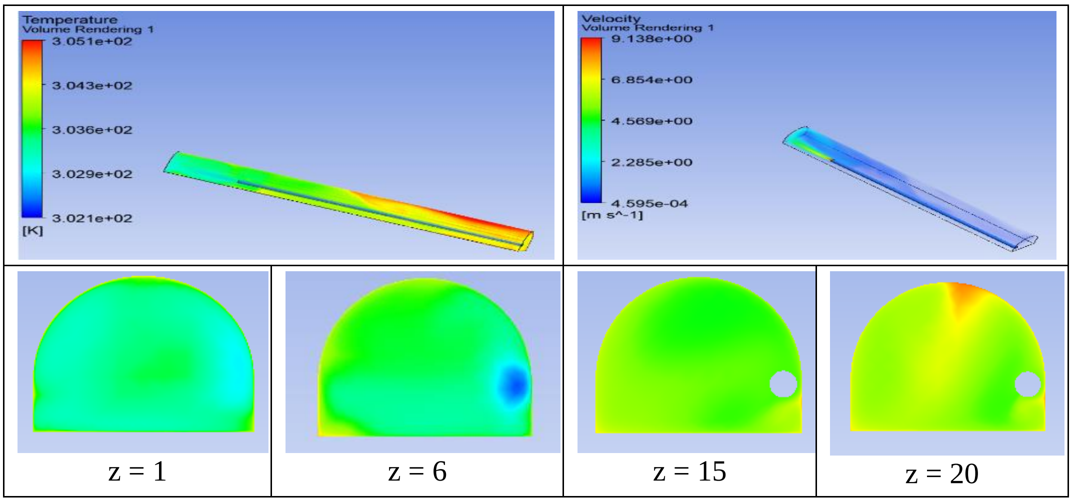

Fig. 3. Temperature distribution on the section and velocity on the road (y = 1.1 m).

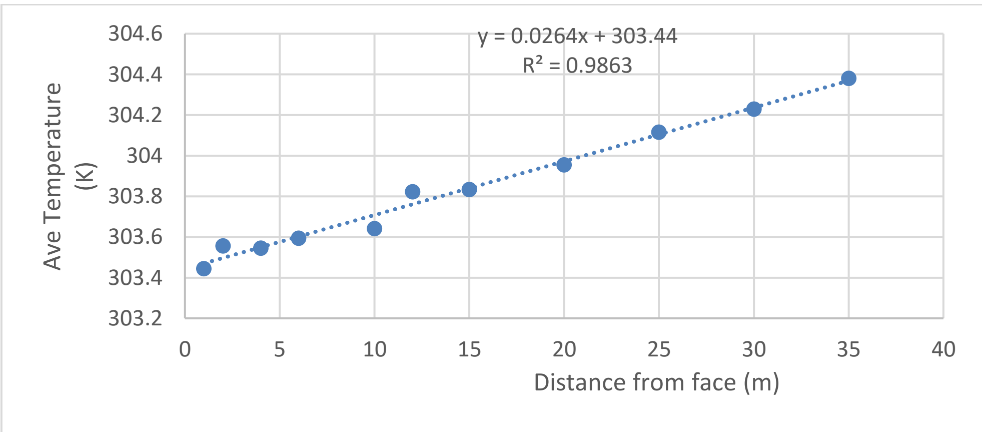

Fig. 4. Relationship between temperature and distance to face (y =1.1 m).

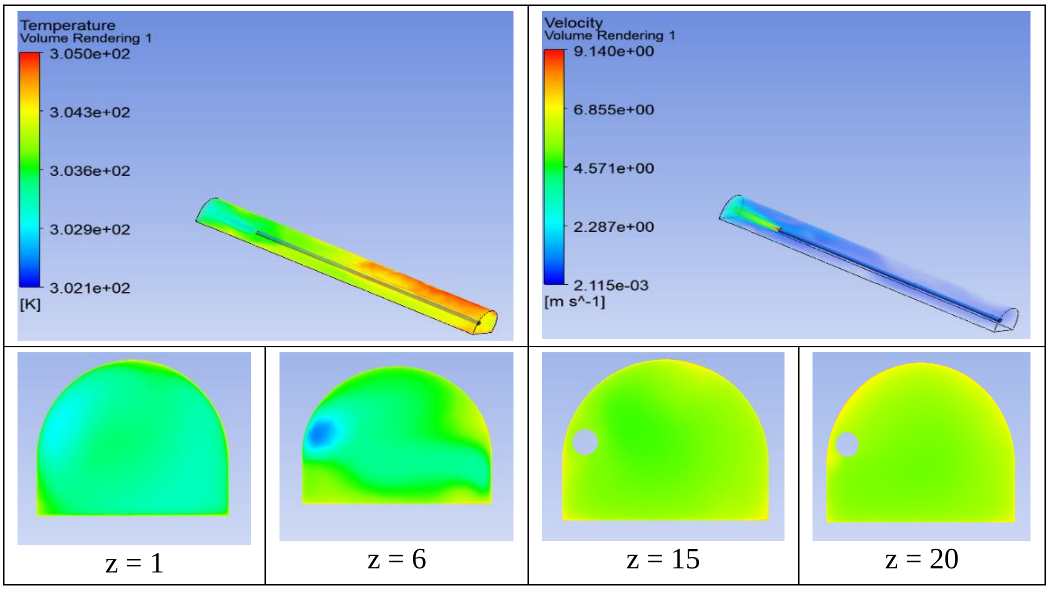

Fig. 5. Temperature distribution on the section and velocity on the road (y = 1.7 m).

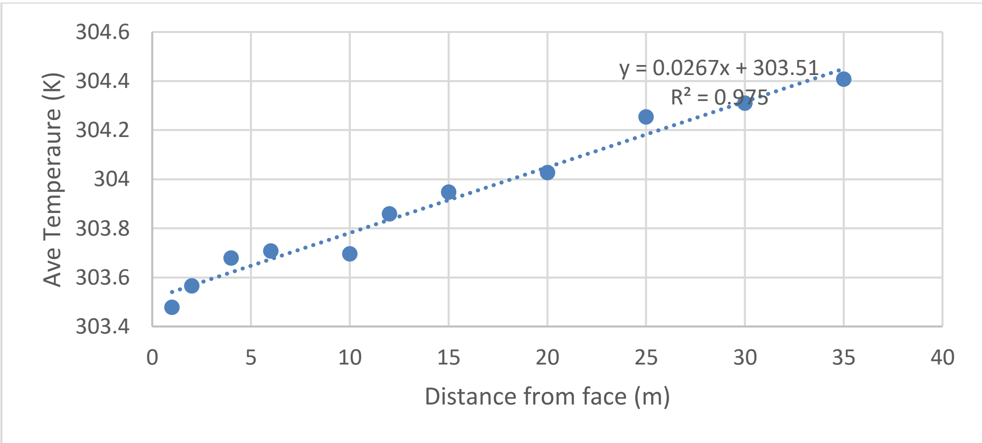

Fig. 6. Relationship between temperature and distance to face (y = 1.7 m).

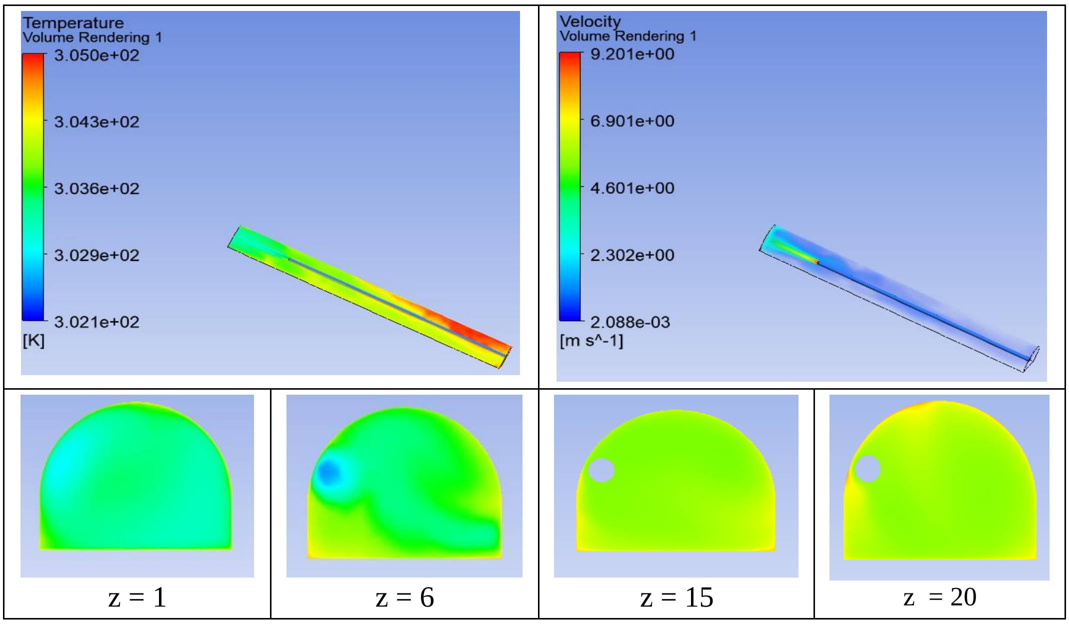

Fig. 7. Temperature distribution on section and velocity on the road (y = 2.0 m).

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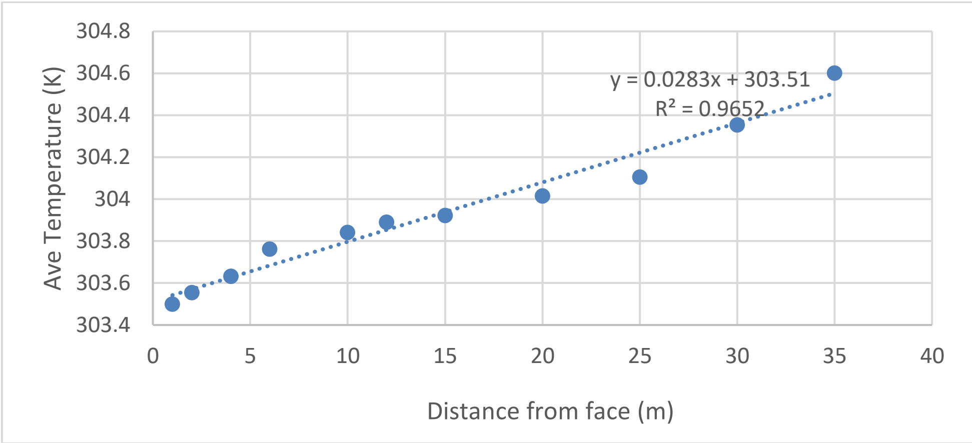

Fig. 8. Relationship between temperature and distance to face (y = 2.0 m).

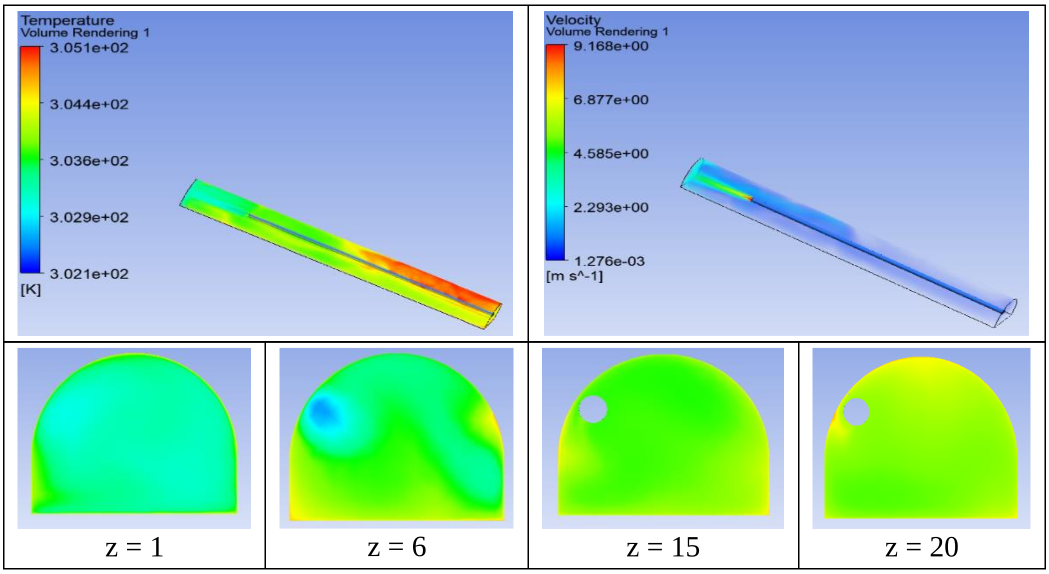

Fig. 9. Temperature distribution on cross-section of road (y =2.3 m).

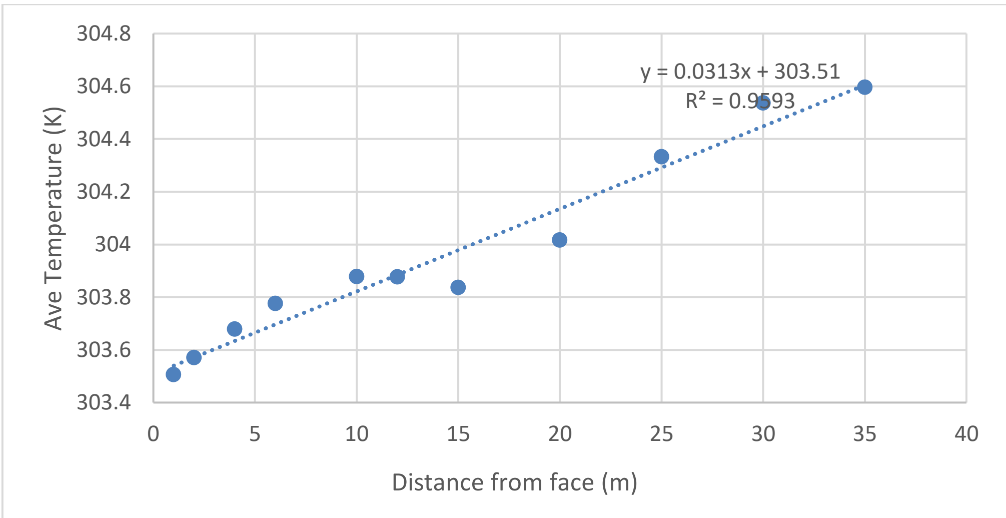

Fig. 10. Relationship between temperature and distance to face (y = 2.3 m).

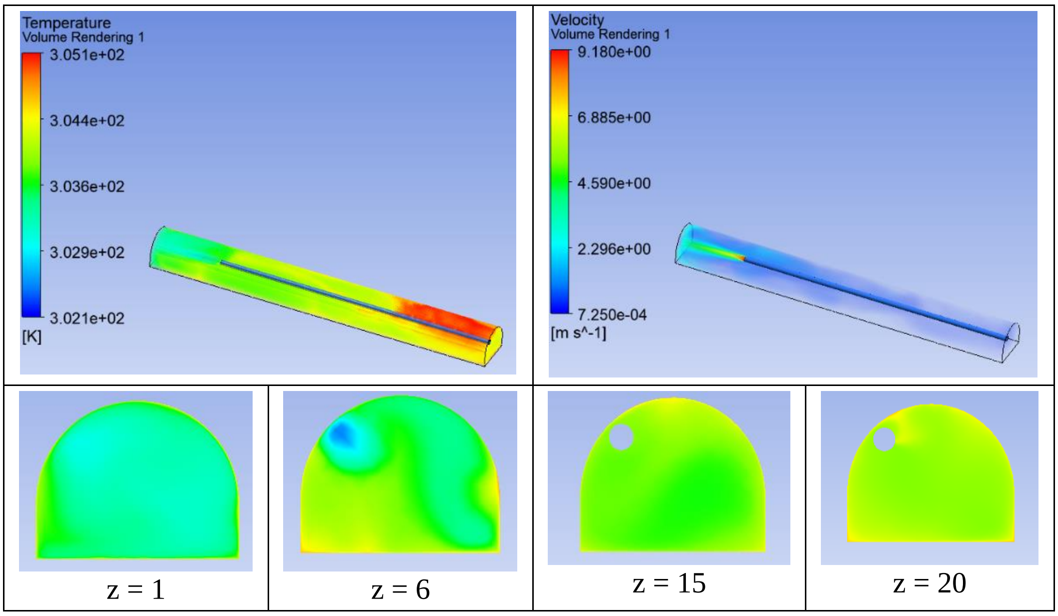

Fig. 11. Temperature distribution on cross-section of road (y = 2.6 m).

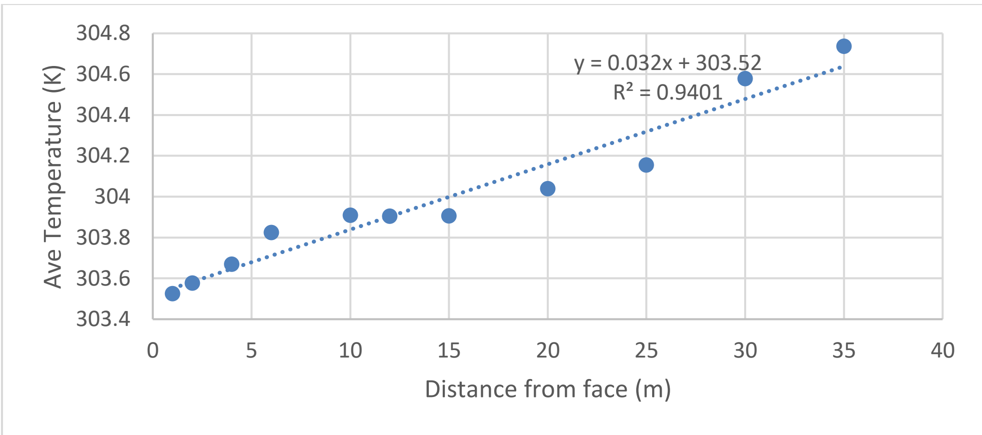

Fig.12. Relationship between temperature and distance to face (y = 2.6 m).

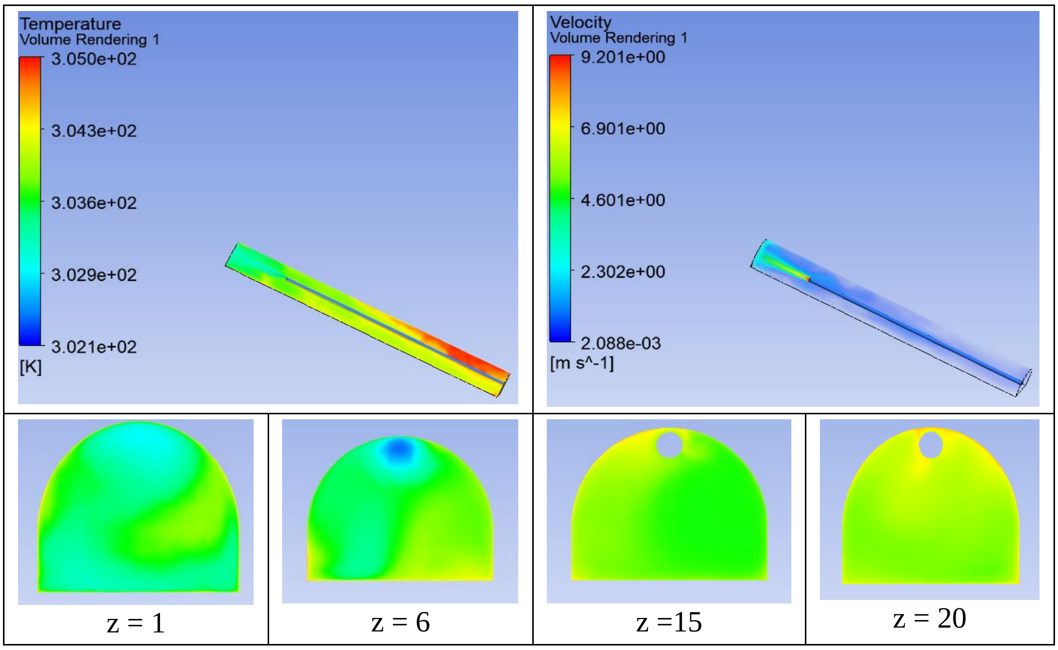

Fig. 13. Temperature distribution on cross-section of road (y = 3.1 m).

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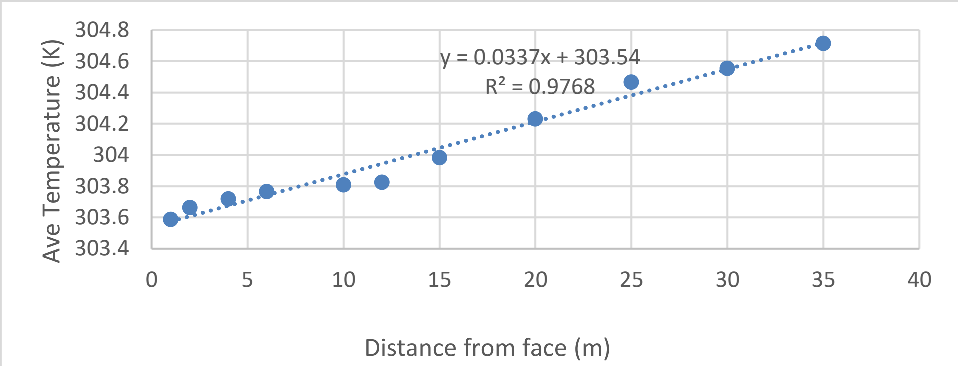

Fig. 14. Relationship between temperature and distance to face (y = 3.1 m).

4.3 Model with variable wind temperature in the air duct

For the heading road with a high-temperature environment and heat generation sources, the inlet wind temperature dramatically affects the thermal environment of the working area. Thus, the article built four models with temperature parameters.

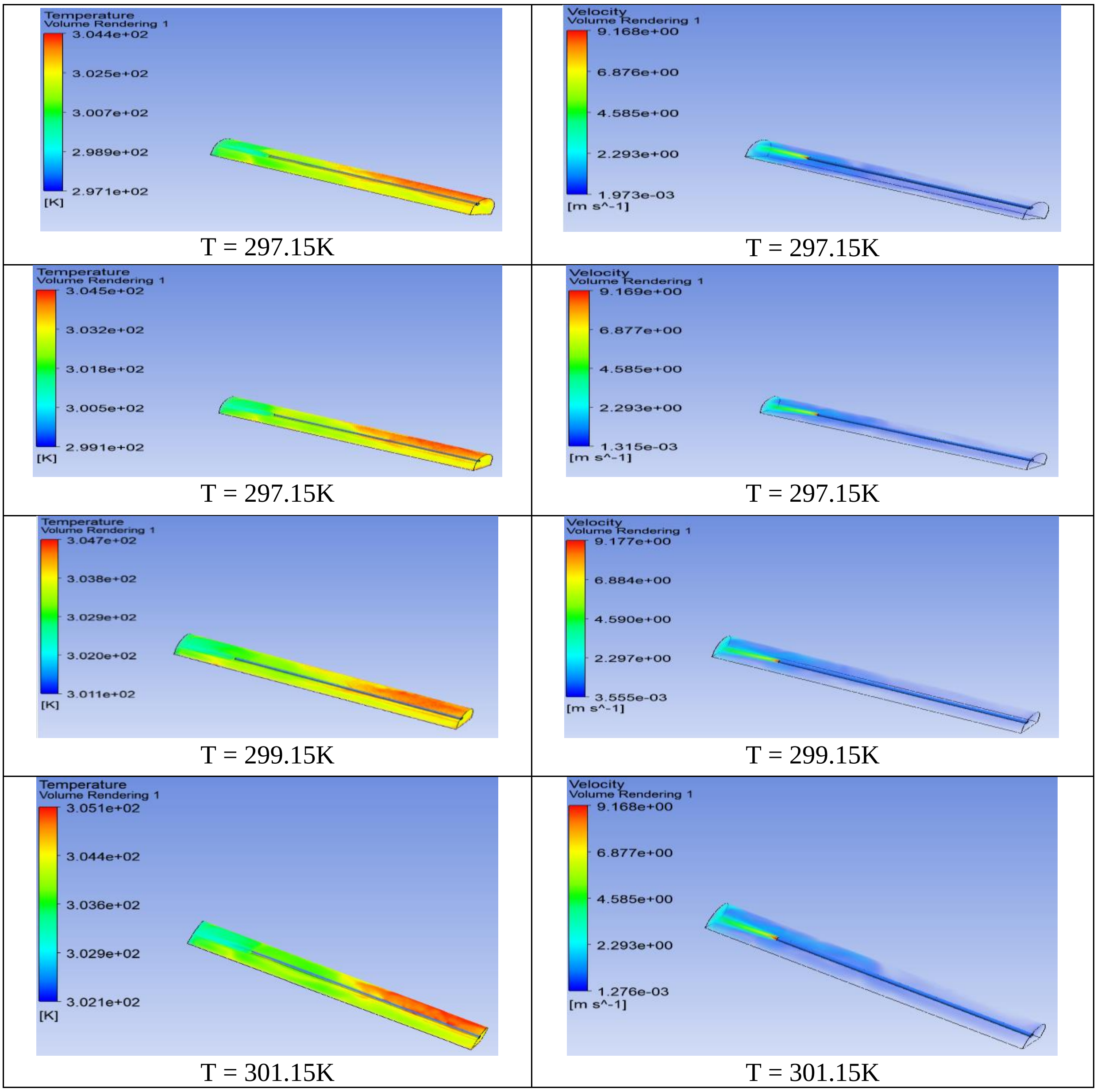

Fig. 15. Distribution of temperature and velocity fields with different wind temperatures.

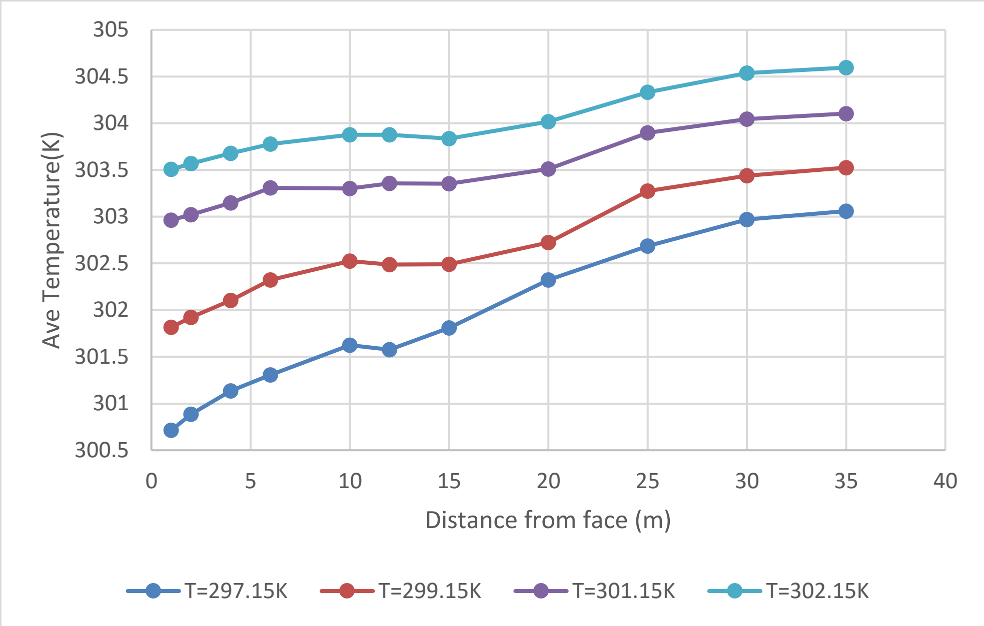

Fig. 16. Result of change of air temperature of road with inlet air temperature.

5. Results and discussions

Currently, with the increase in mining output leading to deeper mining levels, the volume of heading face serving production has also increased. The thermal environment tends to deteriorate when digging deep due to the geothermal's effect, which increases the air temperature at the heading face. This study evaluates and analyzes the influence of duct position and inlet temperature on air temperature in the heading face with a roughness of the roadway.

The simulation results of six models show that the temperature distribution on the cross-section was uneven and affects the comfort of the working environment. The air temperature near the wall is the highest because rock temperature and roughness increase the heat transfer time. As the distance from the mining face increased, the average temperature of the section increased almost linearly. The air temperature in front of the duct is lower than the behind, due to the influence of the duct's airflow. Therefore, the temperature in the roadway increases gradually due to the heat transfer of the surrounding rock and the airflow. Model 1(y = 1.1 m) gives the most favorable temperature environment from 0-20 m in front of the face with average temperature t_{tb}< 304K in which model 6 (y = 3.1 m) average temperature t_{tb} < 304.2K is larger than other models. Fig. 4, 6, 8, 10, 12, and fig.14 shows that the thermal environment condition increases gradually from model 1 to model 6. With model 1, the temperature is distributed on the cross-sections more evenly than the remaining models. The environmental conditions in the working area are the best compared to the remaining positions.

The effect of inlet wind temperature on the thermal environment in the heading face is shown in Fig. 15,16. Model T = 297.15K with a longer roadway are below 303K of 35 m. Model T = 299.15K with a longer roadway are below 303K of 20 m. Model T = 297.15K and T = 299.15K with thermal environment was better than model T = 301.15K and T = 302.15K. Among them, the roadway air temperature of Model T = 297.15K was the best. Besides, the other two models did not meet the standards (T = 301.15K and T = 302.15K). Model T = 297.15K shows that the temperature value in the face area is the most comfortable from the measurement. Therefore, it has been found that the inlet air temperature is the biggest factor that affects mine temperature.

This study confirms the influence of geothermal, equipment, airflow, air temperature on the temperature field. However, this study shows the factors that affect the air temperature in the heading face, such as the duct's position and the inlet air temperature, and the roadway's roughness. Numerical modeling can represent the analysis of the temperature field with different conditions. The paper's findings provide a systematic understanding of the thermal environment, from which more effective thermal control strategies can be further developed.

6. Conclusions

This paper has studied six models of ventilation ducts on the heading face, four models with wind temperature, and analyzed the thermal environment of each model, combined with numerical simulation, to achieve a high-temperature environment more comfortable mining. Model 1 outperforms models 2 to 6 in terms of temperature distribution and lowest temperature values compared to the remaining models. Therefore, a layout like model 1 reduces costs when using the equipment cooler. From the model results of four models with different wind temperatures, we can see the significant influence of the inlet wind temperature on the thermal environment of the heading face. The results show that with the model T = 297. 15K, the temperature value on the entire length of the roadway is guaranteed according to the regulations. As for model T = 299.15K, temperature conditions to ensure the standards only allowed within about 20 m from heading face. The rest of the models do not guarantee the standard requirements. Thus, creating a comfortable environment through ventilation is not enough. Therefore, with a high-temperature heading face, it is necessary to use cooling devices to reduce the temperature of the heading face to create a comfortable working environment for employees.

7. Acknowledgments

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