The Key Factors Analysis of Palisades Temperature in Deep Open-pit Mine

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Abstract. In order to study the key factors of palisades temperature field in a deep open-pit mine in the natural environment, the influence of natural factors on the palisades temperature in a deep open-pit mine were analysed based on the principle of heat transfer. Four typical places with different ways of solar radiation were selected to carry out the field test. The results show that solar radiation, atmospheric temperature, and wind speed are three main factors affecting the temperature of palisades and that the direct sunlight plays a leading role. The time period of the sun shining directly on the shady slope of the palisades is short because of blocking effect, whose temperature changes in a smaller scale. At the same time, the sun slope of the palisades suffers from the solar radiation for a long time, whose temperature changes in a larger scale, and the variation is similar to the air temperature.

1. Introduction

In recent years, with the intensification of open pit mining expansion, the pollution level of the harmful gas and dust occurring in the process of mining has been on the rise [1]. These pollutants not only endanger the safety and health of the miners, and halt production due to low visibility also bring great economic losses to the mine [2]. On the cloudless night, it is easy to form the inversion layer with the strongly effective radiation from the ground cooling quickly. The inversion layer will hinder the vertical movement of airflow below, and also inhibit the spread of air pollution and water vapor condensation [3-5]. Therefore, to study the key factors of palisades temperature in a deep open pit mine not only can provide theoretical basis on studying the distributed regularity of temperature field systematically, and is a big issue for studying formation and dissipation of the pollutant in the open pit, optimizing the open-pit mine working environment, ensuring safety in production and enhancing productivity.

2. Field Experiments

2.1. The Experiment of Mine General Situation

Experiments mine is located at 118 degrees, 32 minutes to 36 minutes east longitude and 40 degrees, 6 minutes to 9 minutes north latitude, with the geological structure of zone of subsidence in Hebei which consist mainly of gneiss.

The area is the warm temperate zone half moist monsoon climatic region and the year dominant wind direction is northwest. The field experiments in the mine implemented from April 20 to 23, 2015, testing

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continuous changes of the palisades temperature, air temperature, relative humidity and wind speed in four typical position of mining boundary state.

2.2. Measuring Point Distribution and Test Methods

Under the premise of ensuring mine production and testers safety, we selected four points in four directions of the mine on the wall respectively. The four points were named 1, 2, 3 and 4 as shown in Figure 1. The absolute altitude of the four measuring points were respectively-88m, -88m, -77m, and -77m. At the same time, we put a temperature recorder to measure the local atmospheric temperature in the mine command center and adjust the instrument recording time intervals for 2 minutes continuous measuring 24 hour. The experimental instruments used in the test were puxicoo RC - 4 temperature recorder and Taiwan Hengxin AZ9671 wind temperature and humidity recorder.

3. The influence of Environment on the Palisades Temperature

According to the thermal conduction theory, the three basic modes of heat transfer are thermal radiation, thermal conduction and thermal convection [6]. Actually, the natural environment would affect firstly and essentially these three basic modes, and further affect palisades temperature. Therefore, the key factors influencing the variation of the palisades temperature are in fact the factors that the natural environment influencing the thermal radiation, thermal conduction and thermal convection. The palisades temperature is affected by various natural factors due to long time exposing in air, which is vividly shown in Figure 2.

Figure 1. Measuring point distribution

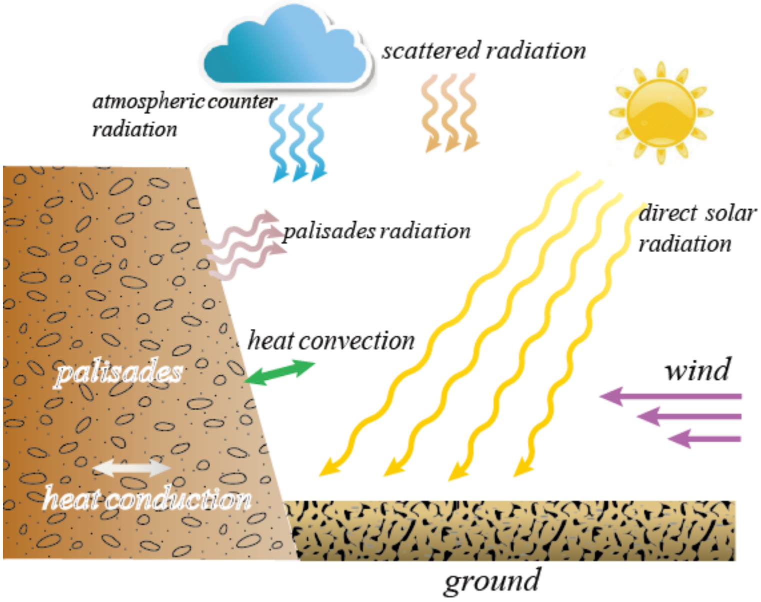

Figure 2. The influence of environment on the palisades temperature First.

When the solar radiation reaches the palisades, most of the solar energy is absorbed by rocks and translated into heat, and the rest energy is reflected to the air. The proportion of absorption to reflection of the solar radiation energy is affected by several factors such as clouds, the features of the surface of the palisades, rain or snow. Second, the difference of temperatures between the palisades and the air will also lead to heat transfer thanks to the thermal conduction and the thermal convection on the surface in contact with the palisades and the atmosphere. This heat transfer can be affected deeply by the wind.

The difference between the palisades radiation and atmospheric counter radiation is called the palisades effective radiation, which is affected by the temperature of palisades and the surrounding air, the relative humidity of the atmosphere and the condition of the clouds.

3.1. Thermal Radiation

For the palisades of the iron ore, solar radiation makes the palisades to obtain heat, is the most important source of heat radiation [7], so solar radiation is one of the factors that affect rock temperature changes [8,9]. As shown in Figure 3, there is an inclination of the palisades and the horizontal plane because the slopes of the open pit are sloping. The intensity of scattered radiation and direct solar radiation which the palisades received could be deduced according to the solar radiation intensity in the horizontal plane, as shown in Table 1.

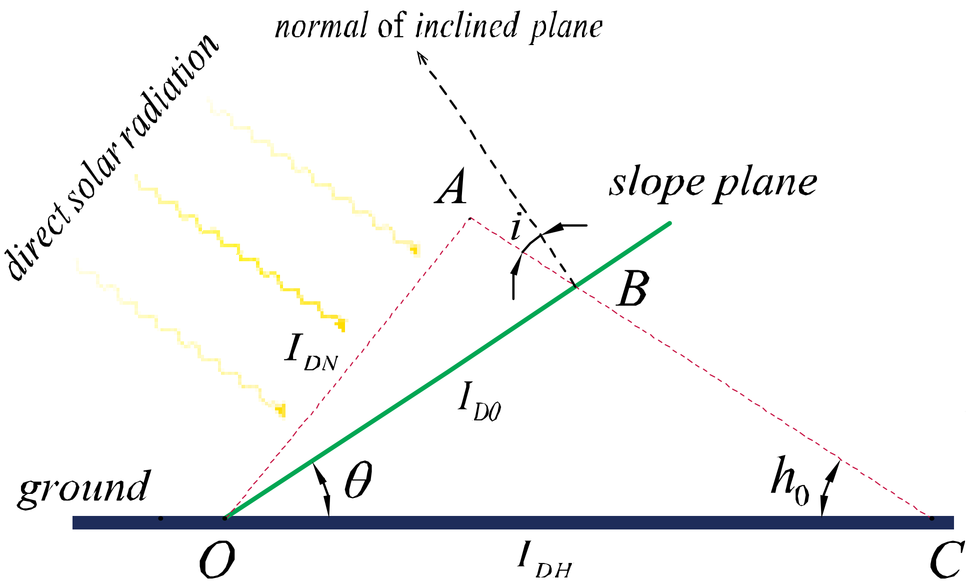

Figure 3. The calculation diagram of the intensity of solar radiation in a slope surface.

Table 1. Related physical quantities with respect to the intensity of solar radiation on the slope rock face

Physical Quantities	Symbols	Expressions
Solar elevation angle	h_0	$h_0 = \arcsin\left[\sin\psi\sin\sigma + \cos\psi\cos\sigma\cos(15t+\lambda-300)\right]$
The direct solar radiation intensity on the horizontal plane	I_{DH}	$I_{DH} = I_{DN}\sin(h_0) = \frac{A\sin(h_0)}{\exp\left[B\sin(h_0)\right]}$
The intensity of scattered radiation received on the horizontal plane	I_{dH}	$I_{dH} = CI_{DN}$
The solar radiation intensity received by the rock face	I_θ	$I_\theta = I_{D\theta} + I_{d\theta}$
The direct solar radiation intensity on the inclined plane	$I_{D\theta}$	$I_{D\theta} = I_{DH}\frac{\cos i}{\sin(h_0)} = I_{DN}\sin(h_0)\frac{\cos i}{\sin(h_0)} = I_{DN}\cos i$
The intensity of solar radiation scattered on an inclined plane	$I_{d\theta}$	$I_{d\theta} = I_{dH}\cos^2\frac{\theta}{2}$
The description of related parameters		h_0 is the angle between the direction of the sunlight and the horizontal ground; ψ is the Local latitude; λ is the local longitude; t is the observation time corresponding to Beijing time zone; σ is the solar elevation angle; A is the solar radiation under zero air mass; B is the atmospheric extinction coefficient; C is the scattering factor; θ is the angle between the rock face and the horizontal ground; i is the angle between the direction of the sunlight and the normal direction of the rock face.

3.2. Thermal Conduction

Thermal conduction follows the basic law of heat conduction that is Fourier law:

$$q = -\lambda \cdot (dT/dx) \tag{1}$$

Where q is the density of heat flux, W/m^2; T is the thermodynamic temperature, K; x is the normal coordinate on the isothermal surface, m; λ is the thermal conductivity, W/(m • K), which is related to the type of material and temperature [10]. For the rock in a certain thermal conductivity, the main factor affecting the heat transfer is the temperature difference between the atmosphere and the palisades. Therefore, the atmospheric temperature is one of the factors that influence the palisades temperature.

3.3. Thermal Convection

The palisades exposed to the atmospheric environment is contact with the atmosphere directly [11]. A convective heat transfer system is formed between the atmosphere and the ground surface. Therefore, the temperature is closely related to the temperature distribution of the palisades.

The basic formula followed by the thermal convection is the Newton cooling formula:

$$q = h \cdot (t_w - t_f) \tag{2}$$

Where t_w and t_f is respectively the temperature of the palisades and fluid (wind), K; h is the convective heat transfer coefficient, $W/(m^2 \cdot K)$.

The convective heat transfer coefficient plays an important role in the heat exchange of the palisades. The main factors affecting the convective heat transfer are the wind speed, and the second is the smoothness of the palisades surface. Joergus [12] proposed that when the wind speed is 5 m/s, convective heat transfer coefficient can be calculated by $h = 1.161(5.8 + 4v)$. Therefore, the wind speed is one of the factors that affect the palisades temperature [13].

Temperature, solar radiation, and wind speed have an impact on the heat exchange between the palisades and the atmosphere. The influence of cloud, precipitation, snowfall and other environmental factors on the temperature of the palisades is very limited, and there is a certain correlation between air temperature and solar radiation. These influence of these factors can be partly reflected by the temperature and solar radiation.

To sum up, solar radiation, atmospheric temperature and wind speed are the main factors that influence the temperature of palisades. The heat transfer modes of palisades include thermal radiation, thermal convection and thermal conduction.

4. The measurement of the three factors

The typical diurnal variation process of the intensity of solar radiation (Figure 4(a)), the wind speed around the rock face at point No.1 (Figure 4(b)), the temperatures of each measuring point (Figure 4(c)), the local atmospheric temperatures outside the deep open-pit mine which was named point No.5 (Figure 4(c)) were measured, which showed that the change of solar radiation could have an immediate effect on the temperatures of the rock face and that the variation of the temperatures of rock face was similar to that of the local atmospheric temperature.

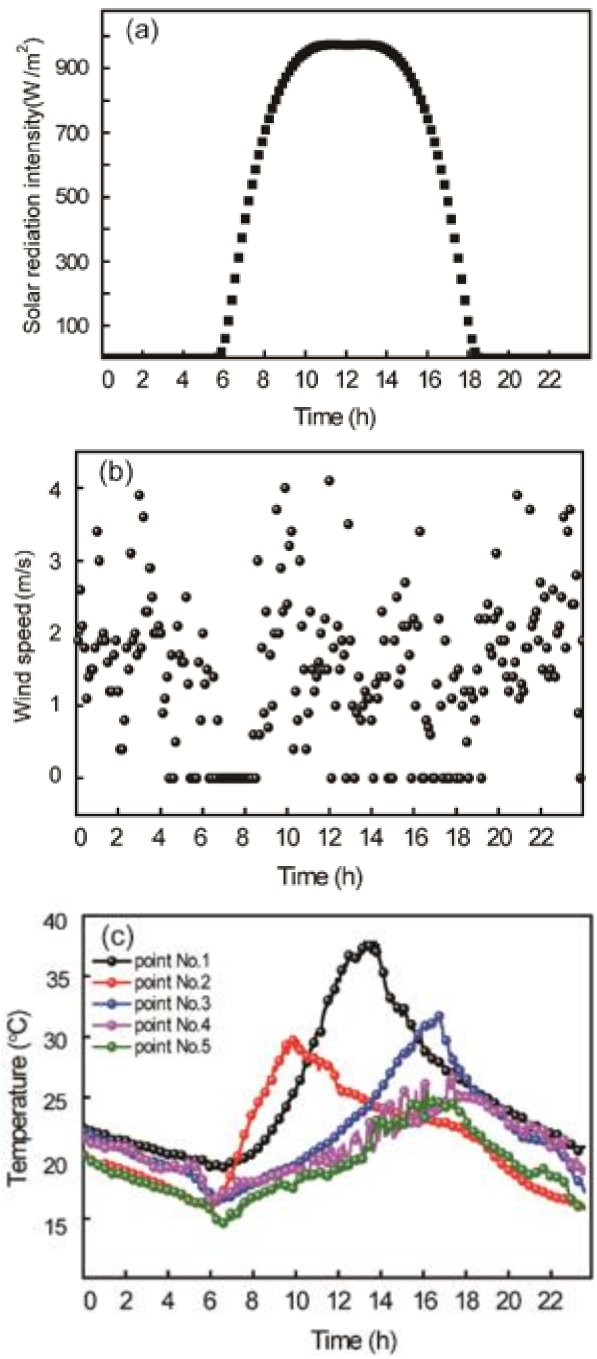

Figure 4. Diurnal variation of (a) the intensity of solar radiation, (b) the wind speed around the rock face at point No.1, (c) the rock face temperatures and local atmospheric temperatures at each measuring point.

From Figure 4(a), the intensity of solar radiation increased gradually with the sunrise, and reached a peak value of 960 W / m2 at 12 o'clock. And then it decreased to 0 W / m2 gradually with the sunset. Usually, the wind speed was changed randomly, which depends on the detailed weather. Taking point No.1 for example, the wind speed was measured to vary from 0 m/s to 4.5 m/s (see Figure 4(b)). Although the wind speed is not a dominate factor for the variation of the temperature of the rock face in general, it is vital for the instantaneous change of the temperature, which is important in the establishment of empirical model discussed below. It can be seen from Figure 4(c) that the temperatures of each point were changed between 15 ℃ and 38 ℃, and the variation range of the local atmospheric temperature was the smallest. Although the solar radiation has been dropped after 12:00 am for point No.3 and point No.4, the solar radiation was too weak to make the saturation of energy absorption of these two points, thus the temperatures would further increased until 16:00 just before the sunset, whose time reaching the peak temperatures were basically the same as the local atmospheric temperatures.

5. Conclusion

(1) Based on the principle of heat transfer and field experiments and considering the effects of thermal radiation, thermal conduction and thermal convection, solar radiation, temperature, and wind speed are three main factors affecting the temperature of palisades.

(2) The palisades temperature is directly related to the time of solar radiation. When the sun begins to irradiate, the temperature of the palisades begins to rise. After reaching the peak value, the palisades temperature decreases slowly and reach the minimum value before sunrise. Therefore, the earlier the palisades temperature reaches the peak value, the longer the exothermal time is, the more heat is released and the lower the temperature value reaches at last.

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