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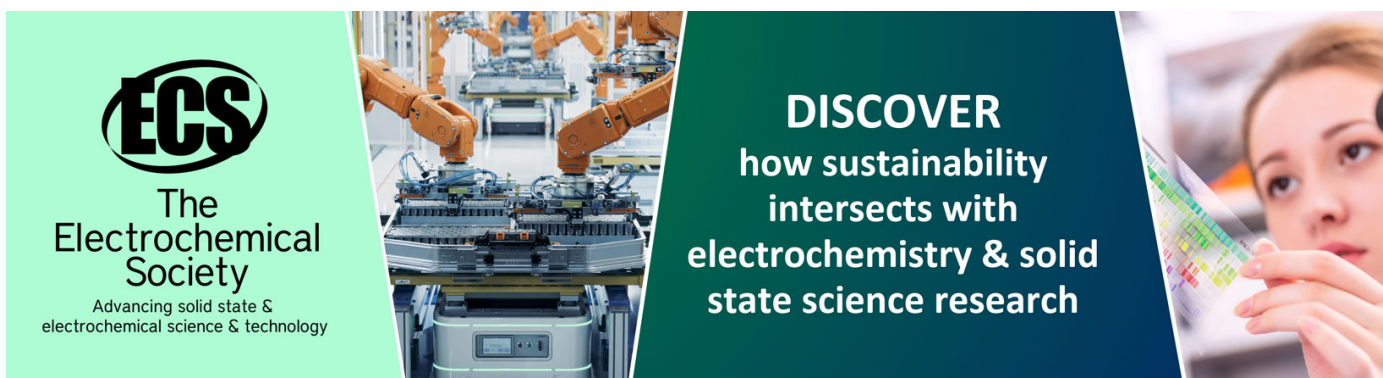
Transferring heat performance for controlling the spontaneous combustion in coalfield of heat pipe

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Transferring heat performance for controlling the spontaneous combustion in coalfield of heat pipe

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Abstract: A heat pipe coal pile experiment platform was established to test the performance of the heat pipe in the heat transfer of the coal pile. Experiments were carried out to measure and analyze the continuous cooling characteristics and cooling rate of the internal heat dissipation of coal piles of different heights under different temperature heat sources. The results show that when the heat source temperature is higher, there is a greater cooling rate inside the coal pile. The closer it is to the heat source, the more obvious the heat dissipation inside the coal pile will be affected by the heat pipe and heat source. This experiment verifies the feasibility of the heat pipe to automatically and continuously transfer the internal heat of the coal pile under the action of the difference between the outside temperature and the internal temperature of the coal pile, to achieve the purpose of preventing spontaneous combustion of the coal pile.

1. Introduction

The oxidation heat will generate continuously in the open-pit coal pile for a long time, and it will form a high-temperature heat storage area. The gradual oxidation in the coal pile will eventually lead to the decline of coal quality and spontaneous combustion of coal^[1,2]. It is mainly considered from two aspects: isolate oxygen and reduce the temperature in the coal pile. The commonly used treatment and protection measures include making dense holes on the coal pile, water cooling, filling inert gas and foam colloid inside the coal pile.^[3-7] However, these methods can only inhibit the spontaneous combustion of coal pile in a short time and can not ensure that the coal pile will not reignite twice. How to transfer the heat in the coal pile for a long time and effectively, prevent the accumulation of heat inside the coal pile, and prevent the temperature inside the coal pile from overheating, heat pipe^[8] can be used to derive the heat accumulated in the coal pile. The heat pipe can run under the condition of small temperature difference. It also has the advantages of large heat transfer and good isothermal performance. The Heat pipe has been widely used in a lot of practical projects. Insert the heat pipe into the grain storage silo can reduce the grain temperature to 0°C within 19 days, and the cooling rate can reach 0.28°C/ day^[9]. The heat pipe buried under the foundation of Qinghai-Tibet Railway can prevent the permafrost under the subgrade from melting and softening due to temperature rise^[10]. These experiments and practical engineering applications have proved that the heat pipe has excellent thermal conductivity and good operation ability under small temperature difference^[11]. Deng^[12,13] also have shown that heat pipe can realize continuous heat dissipation of "warm-cold skin" of underground coal seam in the experiment of coal pile-heat pipe. However, at present, the cooling law of heat pipe acting on coal pile at different heights with different heat source temperature and different liquid filling rate is still unclear. However, at present, the cooling law of heat pipe acting on coal pile at



different heights with different heat source temperature and different liquid filling rate is still unclear. In view of this, this paper established a heat pipe-coal storage reactor cooling experimental platform, analyzed the relationship between temperature drop and time of coal reactor through data fitting, and analyzed the influence law of heat pipes on continuous heat dissipation performance of coal at different heights under different heat source intensity.

2. Principle of heat pipe to inhibit spontaneous combustion of coal

FIG. 1 shows the functional principle of gravity heat pipe. After inserting the heat pipe into the coal pile, the evaporating end of the heat pipe starts to run driven by the oxidation heat inside the coal, and the working medium is heat-absorbing and gasified. Under the action of pressure difference, the gaseous working medium rises to the condensing end of the heat pipe. The working medium exchanges heat with the surrounding environment in the condensing section, cools and liquefaction, and returns to the evaporating end of the heat pipe under the action of gravity, and then absorbs heat and evaporates again to complete the cycle[14-16]. In this way, the oxidation heat inside the coal pile can be continuously extracted in the form of liquid phase transformation of the working medium of the heat pipe, thus rapidly diffusing the heat accumulation in the deep part of the coal pile and avoiding spontaneous combustion of coal.

3. Experimental apparatus and methods

3.1. Experimental device

FIG. 2 shows the experiment bench of coal storage reactor gravity heat pipe heat transfer. The whole experiment consists of temperature acquisition and control system, electric heating plate, coal storage tank and gravity heat pipe. In order to simulate the high temperature area inside the coal pile more truly, the circular heating plate with the power of 1.5kW was selected to heat up the coal pile, which avoided the high temperature zone with strip distribution of U-type heater during operation and caused certain error effect on the overall experimental results. The experimental coal used in this experiment is anthracite coal, the coal particle size is small, it can increase the heat exchange area with the gravity heat pipe. The coal is installed in a rectangular loading cabinet with refractory heat preservation interlayer (thickness = 0.04m). The length and width of the cabinet are 0.68m and the height of the cabinet is 1m.

In this experiment, the heat pipe is a gravity heat pipe made of carbon steel-water material, with an internal hairless fine structure and a working temperature range of 50-250°C. A total of 4 gravity heat pipes were used in the experiment. The heat pipe used in the experiment is a circular fin heat pipe. The heat pipe is filled with different volumes of working liquid, and the filling rate is 10%, 20%, 30% and 40% respectively. The specific parameters of heat pipes are shown in FIG. 3, in which the thickness of finned heat pipes is 2mm, and the number of circular finned heat pipes is 75.

3.2. Experimental Methods

Experiment of the heat pipe pile embedded depth of 480 mm, 80 mm distance below the heat pipe placed circular electric heater, heating of the circular plate is used to simulate the actual pile internal high temperature heat source, when the heat source temperature reached 75°C and 120°C when stop heating of coal pile experiment by changing the amount of heat pipe working medium liquid filling, comparison between groups of late before the quantitative analysis of the heat pipe cooling rate and cooling rate on the thermal performance of pile are studied.

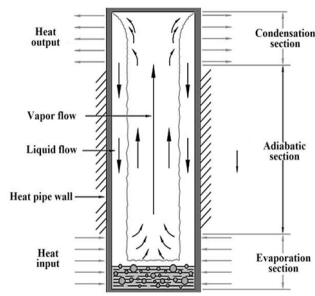


Figure 1. Working principle diagram of gravity heat pipe

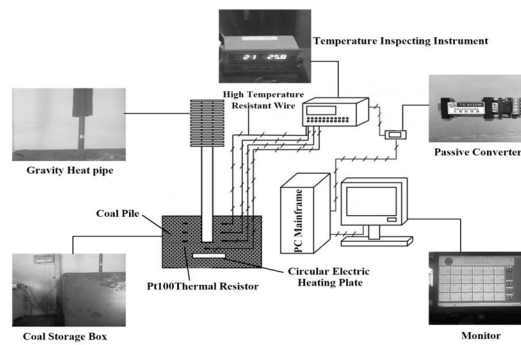


Figure 2. Simulation experiment platform for heat pipe prevention of coal spontaneous combustion

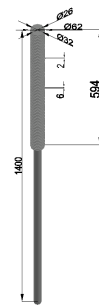


Figure 3. Schematic diagram of heat pipe parameters for experiment

3.3. Data processing method

Calculation formula of coal pile cooling rate:

$$\nu = \frac{\Delta T}{t} \quad (1)$$

Where, ν is the cooling rate of the coal pile in the high-temperature area, $^{\circ}\text{C}\cdot\text{h}^{-1}$; ΔT is the temperature change value of the coal pile temperature measuring point in the high-temperature area, $^{\circ}\text{C}$; t is the cooling time, h.

The formula of temperature variation amplitude in the high temperature area of coal pile is as follows:

$$\Delta T = T_b - T_e \quad (2)$$

Where: T_b is the temperature value at the beginning of cooling in the high-temperature area of the coal pile, $^{\circ}\text{C}$; T_e is the temperature value of the high-temperature area after time T , $^{\circ}\text{C}$.

The attenuation amplitude of the cooling rate in the high temperature area when it drops to 50°C is as follows:

$$\eta = \frac{\nu_1 - \nu_2}{\nu_1} \times 100\% \quad (3)$$

Where: η is the attenuation range of the cooling rate in the high temperature area of the coal pile; ν_1 is the cooling rate at the early stage when the initial temperature of the coal pile drops to 50°C , and the unit is $^{\circ}\text{C}\cdot\text{h}^{-1}$; ν_2 is the cooling rate at the later stage of the same period after 50°C , and the unit is $^{\circ}\text{C}\cdot\text{h}^{-1}$.

4. Experimental results and discussion

4.1. Cooling characteristics analysis of heat pipe coal reactor system

FIG. 4 shows the temperature measurement point T21, max cooling characteristic curve in the high temperature area of the coal pile at the positive lower end of the heat pipe. In the experiment, the heating was stopped and the heat pipe was inserted when the temperature at the measuring point reached 75°C . It can be seen from the figure that, on the whole, four kinds of heat pipes with different liquid filling rate can be started rapidly after being inserted into the coal pile, and the temperature in the high temperature area near the heat source of the coal pile decreases rapidly under the action of the

heat pipe. With the passage of time, the decreasing trend of coal pile temperature in the high temperature region gradually slows down.

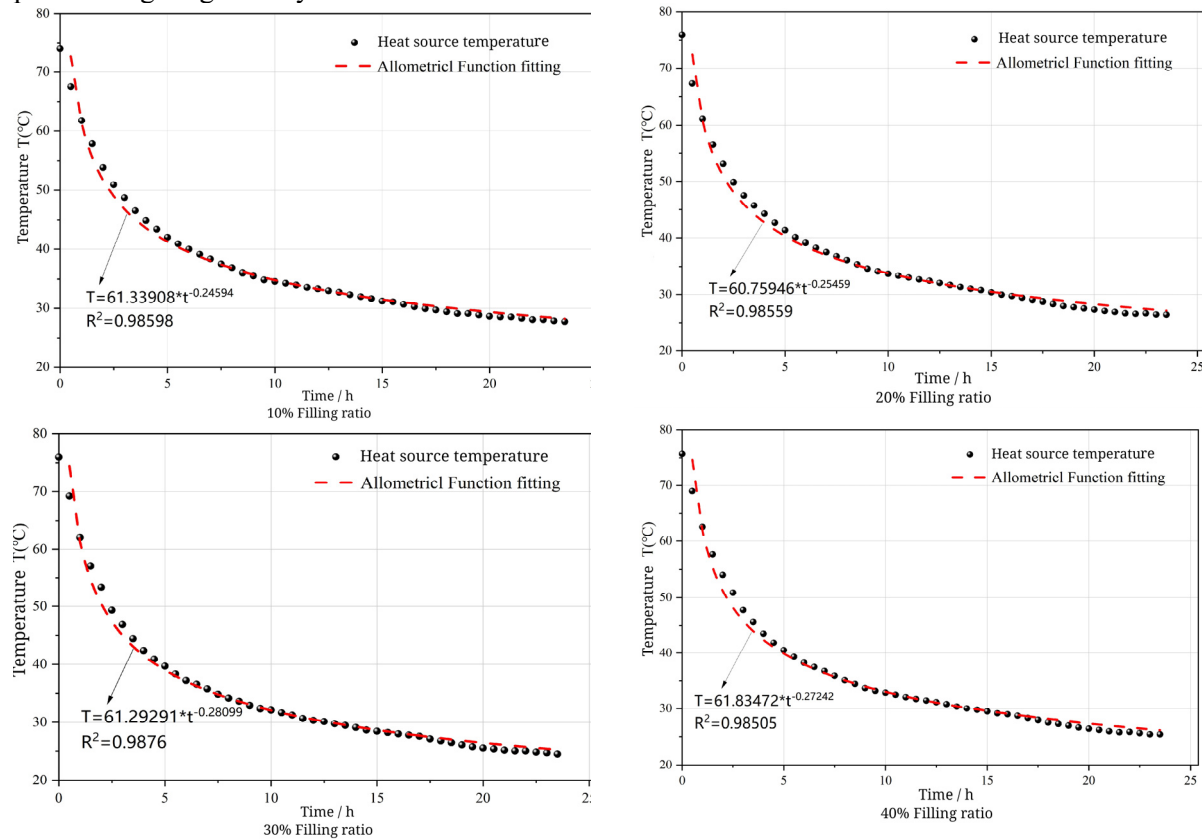


Figure 4. Temperature change with time in high temperature zone after inserting heat pipe into coal pile

Fitting analysis shows that the cooling curves of heat pipes with different liquid filling rates on the internal temperature and time of coal pile conform to Allometrical function, and the fitting formula of temperature and time in coal pile under the action of gravity heat pipe is obtained:

$$T = \mu \cdot t^{\nu} \quad (4)$$

Where: T is the temperature of the high temperature measuring point in the coal pile, °C; t is the cooling time of the heat pipe acting on the coal pile, h; μ and ν are the modified parameters related to the initial temperature in the coal pile and the liquid filling rate of the heat pipe. Under the influence of different liquid filling rates, the fitting degree of temperature drop curve at the high temperature measuring points of the coal pile is between 0.98505 and 0.9876, indicating that the overall fitting effect of temperature drop curve is good, which can be used for the approximate calculation of temperature change in the coal pile with time at the critical temperature.

4.2. Cooling characteristics of heat pipe to coal pile at different heat source temperatures

FIG. 5 shows the relationship between the temperature at the measured point inside the coal pile and time at different thermal energy temperatures. Under the action of heat pipe, the coal pile in the dangerous state of high temperature ignition can cool down quickly and get out of the danger period of coal spontaneous combustion. In order to study the cooling characteristics of the coal reactor under different heat source temperatures, the average cooling rates of the measured points in the coal reactor under the action of heat pipe with different liquid filling rates were analyzed respectively. Can be seen from the FIG 6, the cooling rate of heat pipe is related to the heat source temperature: In the first three hours, the changing rate of the coal pile can reach 18.44 °C·h⁻¹ when the heat source temperature is

130 °C , and the cooling rate is 9.24 °C·h⁻¹ when the heat source temperature is 75 °C, the temperature drop rate is almost 2 times. It shows that the higher heat source temperature is, the better heat transfer performance of the heat pipe to the coal pile. At the same filling rate, the higher the temperature difference between the heat source and the outside is, the better the heat transfer performance of the heat pipe is. As the temperature difference between the internal temperature and the ambient temperature decreases, the average velocity of the coal pile decreases gradually.

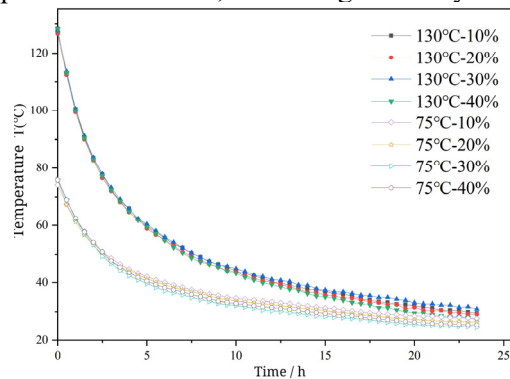


Figure 5. Temperature change of heat pipe on coal pile under different heat source temperature

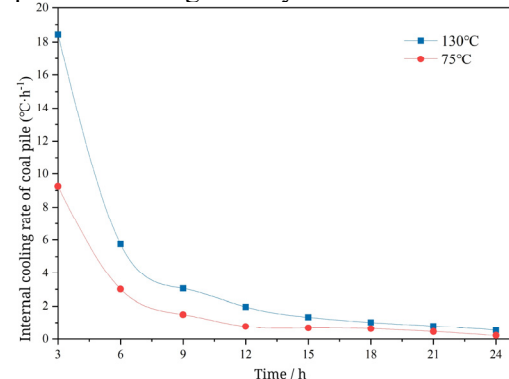


Figure 6. Variation of average cooling rate of heat pipe under different heat source temperature

4.3. Temperature distribution law of coal pile at different heights

Inside the coal tank, temperature measuring points with distances of 100mm and 200mm from the heat pipe are arranged on the upper, middle and lower layers. FIG. 7 shows the changing rule of the temperature inside the coal pile under the influence of the heat pipe at different horizontal heights of the coal tank. The lowest coal pile is closest to the heat source and is affected by heat source heating and heat pipe cooling. Because the coal seam receives the heat from the heat source has the delayed effect, the average temperature variation range of coal at different distances in the lower part of the initial stage is different to some extent. At the same level, the coal temperature change at 100mm is greater than that at 200mm. After that, due to the efficient heat dissipation of the heat pipe, the temperature of the coal decreases gradually and finally falls below the safe storage temperature. The middle coal seam is also less affected by heat source, and the temperature change of the two coal is almost the same, but it is delayed in time. The upper coal seam is close to the external environment and has little effect from the heat source. The temperature change of coal body is greatly affected by the temperature change of the external environment.

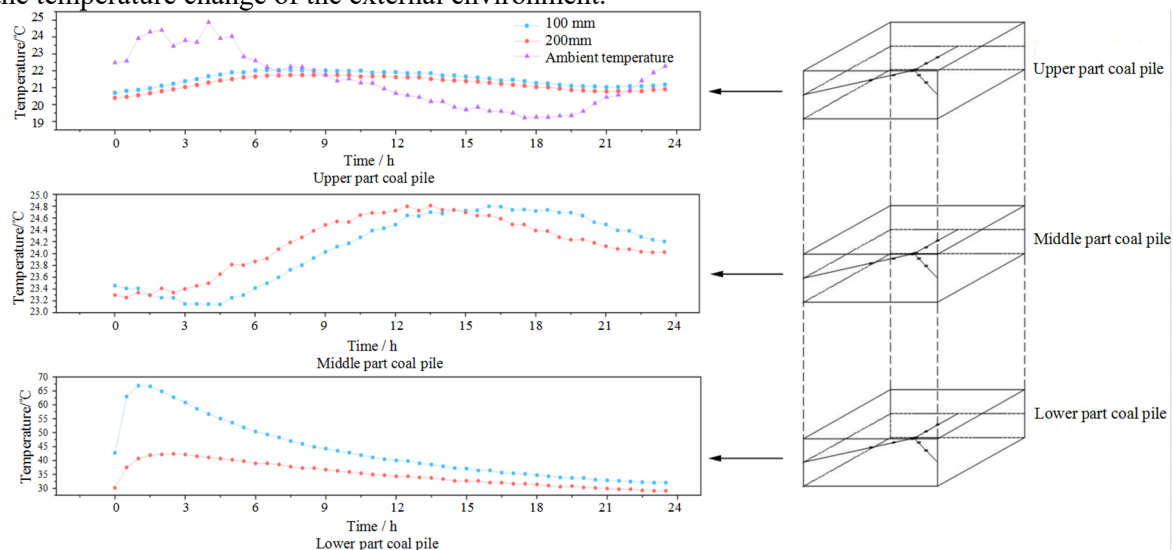


Figure 7. Variation of temperature distribution in different coal layers

In this case, the coal temperature at 100mm and 200mm changes with time basically the same, but because of the coal at 100mm is close to the heat pipe, it will be affected by the cooling effect of the heat pipe, and the average coal temperature is slightly lower than that at 200mm, which also indicates that the heat pipe can diffuse the heat accumulated in the coal pile.

5. Conclusion

(1) The cooling curve of the temperature measuring point with time after the heat pipe with different liquid filling rate is inserted into the coal pile satisfied with $T = \mu \cdot t^v$. The cooling curves of heat pipes with different filling rates are similar.

(2) The higher the heat source temperature is, the faster the temperature drop rate of the coal pile is under the condition of the same liquid filling rate of the heat pipe with different heat energy grades. The cooling rate of the coal pile under the high temperature heat source is twice that under the low temperature heat source.

(3) The lower coal seam is affected by both heat source and heat pipe, and at the same level, the closer to the heat source, the more obvious the change of coal temperature. The overall fluctuation range of the middle coal seam affected by the heat source is not large, but there is still a difference of 2-3°C. The temperature of the upper coal seam is subject to the change of ambient temperature.

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