Cooling Effect Analysis of Suppressing Coal Spontaneous Ignition with Heat Pipe

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Abstract. Suppression of spontaneous ignition of coal stockpiles was an important issue for safe utilization of coal. The large thermal energy from coal spontaneous ignition can be viewed as the latent energy source to further utilize for saving energy purpose. Heat pipe was the more promising way to diffuse effectively concentrated energy of the coal stockpile, so that retarding coal spontaneous combustion was therefore highly desirable. The cooling mechanism of the coal with heat pipe was pursued. Based on the research result, the thermal energy can be transported from the coal seam to the surface continuously with the use of heat pipe. Once installed the heat pipes will work automatically as long as the coal oxidation reaction was happened. The experiment was indicated that it can significantly spread the high temperature of the coal pile.

1. Introduction
With the acceleration of the coal exploitation, coal spontaneous combustion greatly threatens the safety of miners and properties[1]. When it was exposed to air, the coal was oxidized slowly by oxygen and generates lots of thermal energy[2]. During the process of coal extraction and transportation, the coal carbon molecule with the surrounding oxygen molecules slow oxidation exothermic reaction would also arise. This reaction can lead to spontaneous combustion with the release of toxic gases [3].

Most of studies were focused on modeling and prediction of self-heating or ignition of coal stockpiles, however, there were only a few studies devoted to prevention of spontaneous ignition of coal stockpiles[4]. Several well-known methods to suppress spontaneous ignition of coal stockpiles were periodic compaction of stockpiles[5], a low slope angle of the pile[6], pile protection by wind barriers[7] , water spray on the coal pile[8], and covering the pile with an inert layer[9].Each method had been verified to retard spontaneous ignition time in some way. However, these cooling measures had absorbed the latent heat of vaporization of water mainly in coal by heating vaporization, through hole "chimney effect" of heat to cool things down, and so this approach was affected by the influence of coal moisture[10]. In addition, coal moisture could take away vaporization latent heat in the form of water vapor. Moisture escape would increase contact area close to accelerate coal oxidation and produce large heat to strength coal fires hazard[11]. So the effect of these cooling coal fire measures was very limited.

2. Experimental Result And Discussion

2.1. The temperature distribution of coal pile with heat pipe
Fig.1 provided the comparison coal temperature distribution of the same radius range, and the same heating power with or without heat pipe,it was shown the variation curve of temperature with the

heating time.It was indicated that the temperature of the coal pile was about reduced by 12℃with heat pipe working after 14 hours . The range of temperature drop can reach 30.1% with the effect of heat pipe, which had indicated the advantage of extract thermal energy with heat pipe.

When the radius distance from heat pipe was 50cm, as shown Fig.2,the range of temperature drop was about 10℃, and decreasing temperature was by 23.5%, and however the radius distance from heat pipe 75cm, the range of temperature drop was only around 4℃, the temperature drop was of 16.7%,as Fig.3. After 14 hours of the heat source working, it was almost the same temperature for the presence of coal pile without heat pipe.

It was indicated larger reduced temperature range was arisen in the given depth coal level for the nearer from heat pipe, and it should be noted that due to high efficiency phase change heat transfer, it can rapidly make coal pile cooling with the heat pipe operation. When heat pipe was inserted into the coal pile, the temperature rise of the coal pile was very slow. Reducing temperature was faster for heat pipe extracting thermal energy than that of the natural convection cooling.

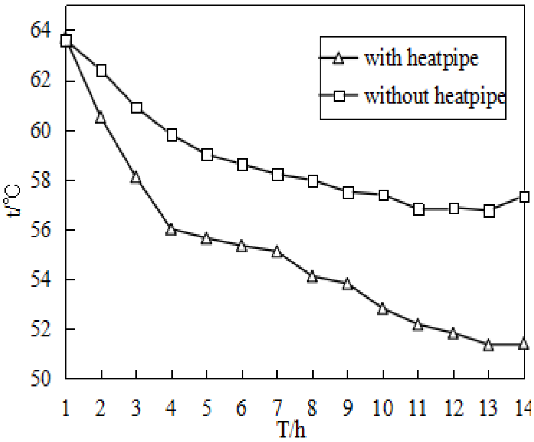

Fig 1. Temperature distribution from heat pipe radius 20cm.

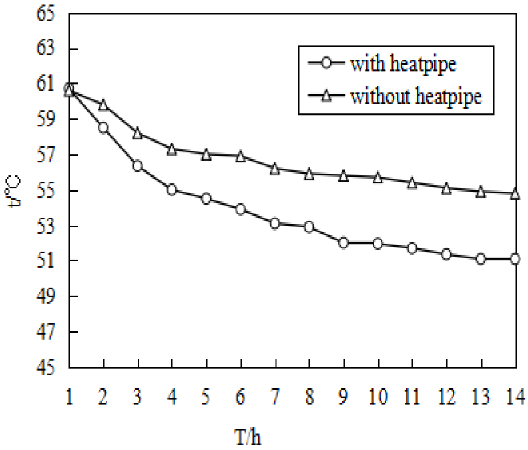

Fig 2. Temperature distribution from heat pipe radius 50cm.

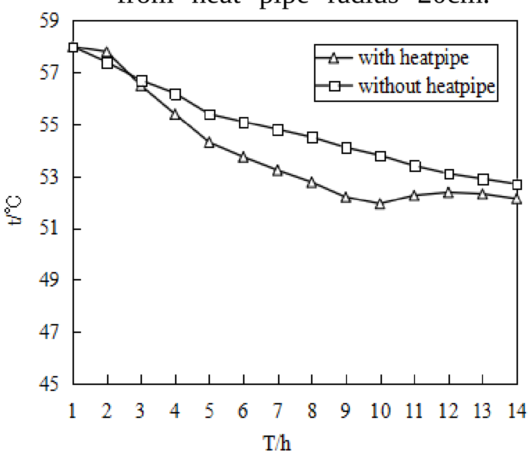

Fig 3. Temperature distribution from heat pipe radius 80cm.

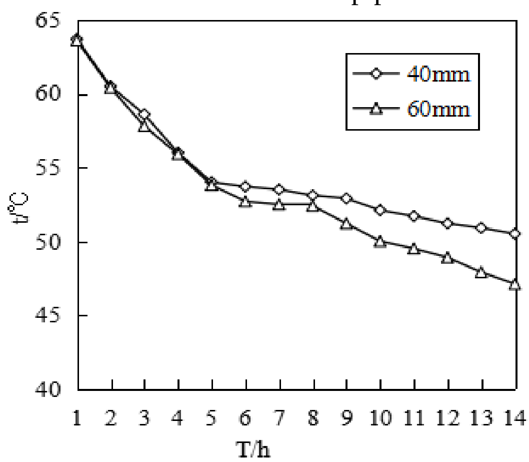

Fig 4. Temperature distribution with different depth change.

2.2. Depth change of heat pipe penetration

When the insertion depth of the heat pipe was changed from 60mm to 40mm, the temperature drop scale was reduced by 4.16% , as was shown in Fig.4.If the condensation length of the heat pipe was 30cm, the ration of condensation and evaporation section was adjusted from 1 to 2, however, the cooling effect of the heat pipe was decreased.

When it was reduced to the heat tube insertion depth of the coal pile, and thus decreasing the evaporation length, however, the length of the condensation section was increased as well. Moreover, it was decreased contact area of the thermal resource and heat pipe. Hence, the cooling effect of heat pipe was reduced on the same internal thermal source conditions.

There was a bigger cold capacity for coal depth under the 150cm, which can absorb the thermal energy of the deep coal level, and then it would make the deep level coal obviously natural cooling. However, the middle level coal was the cold source from the top and bottom, and natural temperature drop by air cooling was very slowly. After the heat pipe was inserted into the coal pile, which was served as extra central cold source. Accordingly, the range of cooling was bigger for the middle level of the natural cooling than that of the shallow coal level and deep coal level. Compared to the natural air cooling, the range of maximum temperature drop was about 13℃ on the regular deep coal pile lever. When heat pipe was closer to coal level, the more obvious cooling effect for coal level with heat pipe operation.

Due to the isothermal effect of heat pipe, hence it would carry thermal energy from the cold source of the surroundings to the coal pile, the heat flow of the high temperature coal pile was circulated to the cold source of the surroundings air, and then form the temperature gradient in the fixed range of the coal pile. The research result indicated that the cooling range was more obvious in the nearer distance from the heat pipe than that of the far distance.

2.3. The influence of heat pipe inclination angle

The heat pipe layout angle was changed by original 90 °to 60 °, the temperature of the coal pile was increased by 5.15%, Fig.5 provided temperature distribution of coal level for the depth 40cm with heat pipe, far from the heat pipe radius distance 20mm. It should be noted that due to bubble growth and movement rules as well as the common effect of flushing action for heat pipe wall, so energy transfer had some relation with the inclination angle of heat pipe.

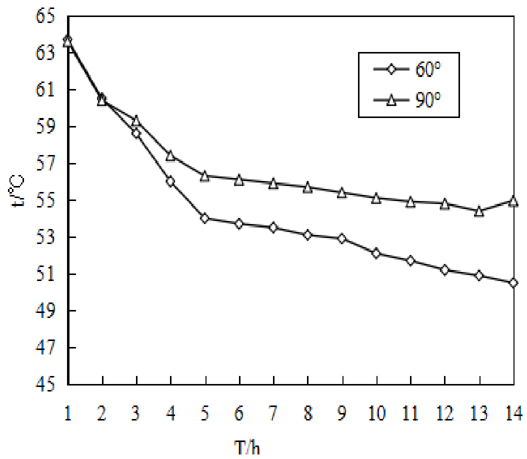

Fig 5. Temperature distribution with different angle.

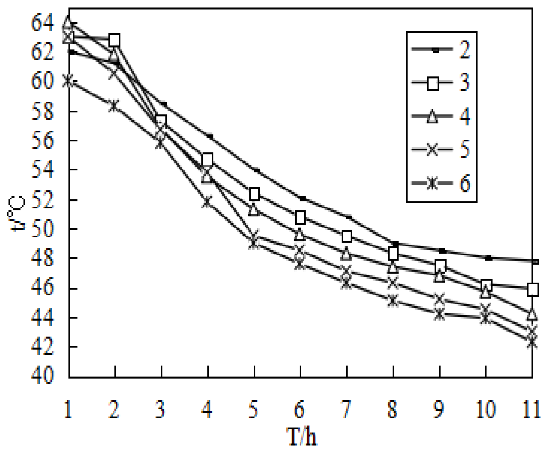

Fig 6. Temperature distribution with heat pipe number.

When the superheat of heat pipe was larger, the tube boiling was more intense for the liquid working medium. A large of the gas bubble was produced, and causing the gas disturbance in the liquid pool, some bubbles were gathered and becoming larger bubbles. Moreover, a lot of bubbles were gathered and rushed from the evaporator to condenser section by the pressure difference. When the bubbles were gathered to so big enough and reaching a certain size, which could carry some a certain amount of liquid rushing to the condensation section,which can make heat transfer power increasing under the common effect of the turbulent flow scour movement and droplets scattering, and so as to strengthening the coefficient of heat transfer.

2.4. The influence of heat pipe number

When the number of heat pipe inserted into the coal pile was different, the temperature change was shown in depth 4 cm and radius 2 cm range from heat pipe in Fig.6. The cooling effect of coal pile was more obviously with the increasing of heat pipe number. The temperature drop was more 3.5℃ when the number of heat pipe was increased from 2 to 6. Moreover, the temperature of coal pile was decreased by 1.5°C when the number of heat pipe was increased from 2 to 3.Accordingly, the number of inserted heat pipe was more, the cooling effect of coal pile more better.

2.5. Heat pipe number effect of the coal lever temperature distribution

In general, the rated power was more than that of the effective heat power for the given heat pipe. So the produced cold energy was obtained by the effective power of the heat pipe.

If spontaneous combustion was occurred, the minimum temperature limitation was 60°C. In order to release this thermal energy of the coal dump, assume it was natural convection heat transfer between heat pipe and outdoor air surrounding. The accumulated thermal energy of the coal dump was calculated by the Equation(1).Only it would release these thermal energy accumulated coal dump in time, the coal temperature would be controlled less than 60°C.

$$Q=\alpha A(t_w - t_f) \quad (1)$$

Where, Q was thermal energy, α was natural convection heat transfer coefficient, A was heat transfer area of the heat pipe, t_w was the outside surface temperature of heat pipe, t_f was environmental temperature.The heat transfer coefficient of natural convection was derived by the basis of approximate formula.

$$\alpha = 9.77 + 0.07(t_w - t_f) \quad (2)$$

When assume $\alpha = 10.33\mathrm{W}/(\mathrm{m}^2 \cdot \mathrm{K})$,and then get $Q = 16.66\mathrm{W}$. In order to make coal dump temperature control was under 60°C, about 3 roots heat pipes should be inserted in the coal dump.

Because of the definite heat pipe heat flow density was 28W/m^3, only the space of heat pipe was matched with the power of heat pipe, heat quantity of coal pile could be extracted from the underground so as to reuse secondly. If heat pipe had a plenty of power, the effect of coal cooling was more prominent for the deeper coal field and insure the safety exploitation.

3. Result

The application of heat pipe to support extinguishing coal fire, to prevent coal spontaneous as well for energy recovery purposes was thinkable.On the basis of experimental research result, it was concluded the different factors influencing the performance of coal stockpile cooling, and analyzed how these factors affect the heat transfer characteristics, some measures were proposed to strengthen thermal exchange performance of the heat pipe. With the effect of heat pipe operation, its evaporation section length, depth, and angle would also affect the temperature distribution of the coal level.The mechanism of heat pipe diffused the concentrated thermal energy for coal oxidation was pursued according to the experimental result.

The research idea for the extraction of coal fire combustion heat had provided a new way of thinking about the thermal energy reuse. Research result was shown that heat pipe could prevent and control the coal spontaneous combustion effectively, and availably diffuse heat accumulation inside the coal pile inducing temperature rise, which it had provided a new idea to suppress coal spontaneous ignition and the concentrated thermal energy extraction for coal pile.

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