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EXPERIMENTAL STUDY ON THERMO PHYSICAL PARAMETER OF LOOSE COAL BULK****

The coefficient of thermal conductivity and thermal capacity about loose coal are an important foundation parameters of study on the technology of coal spontaneous combustion fire position, and its testing method has been a hotspot of study. For example, In the lab, literature [1, 2] measure the loose thermal conductivity based on the Hot-wire method, and the experimental research carries out on the part of influencing factors about the coefficient of thermal conductivity. Literature [3] measure the thermal capacity about coal based on the water calorimeter method, and the research carries out on the influence of coalification degree, ash content and moisture on thermal capacity. Literature [4] measure the thermal capacity about coal based on the DSC method, and the experimental research carried out on the high temperature heat capacity about coal. The aforementioned method is a single thermal properties of the test method, for the same coal samples, in order to acquire the coefficient of thermal conductivity and thermal capacity, the experiment must be carried many times, but it results in inconvenience. Literature [5] measure the coefficient of thermal conductivity and thermal

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capacity about loose coal based on the hotline method, and develop a test system. The measurement system introduced in literature [5] is used in this article which gathered the different coal sample to carry on the volumetric heat nature test experiment about loose coal, and then carries out experimental research on the thermal conductivity and influencing factors about the thermal capacity.

1. The experimental method and principle

1.1. Samples preparation

In the samples preparation, four coal samples are selected such as bituminous coal that was produced in huainan panyi mine, yongcheng anthracite coal, li zuizi the bituminous coal, pingxiang bituminous coal, etc. the experimental research is carried out and the related correlation is analyzed between coal sample thermal conductivity, thermal capacity and temperature, particle size, moisture content, porosity [6].

The industrial analysis results of coal sample are show in Table 1.

TABLE 1
Industrial analysis of coal sample

Name of coal sample	Volatile matter, %	Ash content, %	Carbon content, %
Panyi bituminous coal	33.20	13.20	43.70
Pingxiang bituminous coal	21.13	23.16	54.56
Lizuizi bituminous coal	30.24	23.18	49.39
Yongcheng anthracite coal	9.660	17.92	70.31

In order to study the thermal conductivity of coal samples at different temperatures, before the experiment it needs to preheat the coal sample to the expectation temperature and ensure that the temperature in each point of specimen is uniform.

1.2. Measurement principle of loose coal thermo-physical parameters

Put a hot wire into coal sample with uniform initial temperature, if the size meet the infinite line source condition, and the heat only radial transfer perpendicular to hot wire, it will be construct a cylindrical heat transfer model [7]. When the hot wire electrified and steady heating, if the per unit length calorific value is known as q, W/m, and $y = \frac{r}{2\sqrt{a\tau}}$, the temperature response of coal sample is written as

$$\theta(r,\tau)=\frac{q}{2\pi\lambda}\int_y^{\infty}\frac{1}{y}e^{-y^2}\mathrm{d}y=\frac{q}{2\pi\lambda}\Omega(y) \tag{1}$$

where:

$\theta(r,\tau)$ — denotes the temperature rise of certain point in coal sample, °C,

r — the distance of certain point in coal sample from hot wire, m,

a — the thermal diffusivity, m^2/s,

λ — the thermal conductivity, $W/(\mathrm{m}\cdot K)$,

τ — the time, s,

$\Omega(y)$ — is a special function, can be written as

$$\Omega(y)=\int_y^{\infty}\frac{1}{u}\cdot e^{-u^2}\mathrm{d}u.$$

Direct insert the temperature data $\theta(r,\tau)$ that radial distance from center of hot wire r into equation (2), we can gain λ,

$$\lambda=\frac{UI}{4\pi L}\times\frac{-E_i\left(\frac{-r^2}{4a\tau}\right)}{\Delta\theta(r,\tau)} \tag{2}$$

Where, I denotes the electric, *A*, *U* the voltage, *V*, *L* the length of hot wire, m. $-E_i\left(\frac{-r^2}{4a\tau}\right)$ is exponential integration, when $\Delta\theta\ (r,\ 2\tau)/\Delta\theta\ (r,\ \tau)$ is fixed, $-E_i\left(\frac{-r^2}{4a\tau}\right)$ can gained through looking up table [8].

Insert λ into equation (1),

$$\Omega(y)=(\theta(r,\tau)\cdot 2\pi\lambda)/q \tag{3}$$

Where

$q=(UI)/L.$

Lets

$p=r^2/(4a\tau),$

$$\Omega(y)=-\frac{1}{2}Ei(-p)=-\gamma-\ln p-\sum_{n=1}^{+\infty}\frac{(-1)^n p^n}{nn!} \tag{4}$$

Then,

$$\Omega(y) = (\theta \cdot 2\pi\lambda)/q = \frac{1}{2}\left(-\gamma - \ln p - \sum_{n=1}^{5} \frac{(-1)^n p^n}{nn!}\right) \tag{5}$$

Where, γ is Euler constant.

After thermal diffusivity *a* is gained, the thermal capacity c_p can be calculated by,

$$c_p = \lambda/(\rho a) \tag{6}$$

2. Analysis of experimental results

2.1. Analysis of influencing factors of the thermal conductivity λ

1) The impact of temperature on the thermal conductivity

It can be seen from the measurement principle, coal samples in direct contact with the heating rods, which affect the temperature rise process and then affect the testing results of the thermal conductivity. During the heating process of heating rods, while the temperature of coal samples in contact with the heating rods is changing, the thermal conductivity also changes. Although it is very difficult to express the change process, but it can be assumed that at a certain temperature rise in scope(it specified by GB/T 10297-98 that if the temperature of hotline in the whole experimental process increase no more than 15°C, the impact of temperature changing on coal samples thermal conductivity can be ignored, then the coal samples heat conduction performance is constant (the thermal conductivity is invariable).

It can be seen from the experiment that the greater the heating power of heating rods, the faster the temperature of coal samples in contact with heating rods rises, and the higher the temperature rise Tys begin to enter the effective data segment, if the total temperature value adding from the beginning of entering the effective data segment to the end of experiment is no more than 15°C, the coefficient of thermal conductivity in this stage is a fixed value. So if gain the thermal conductivity of coal samples in different heating power condition, we can approximately obtain the variation between the coal samples thermal conductivity and temperature. In order to facilitate comparison, all of the coal samples illing density are controlled at 940 kg/m^3.

The experiment results of Panyi and Lizuizi coal samples are shown in Figure 1a and Figure 1b. It can be seen from the figures, that the thermal conductivity of Panyi coal sample and Lizuizi coal sample show an approximately linear proportional relationship with temperature.

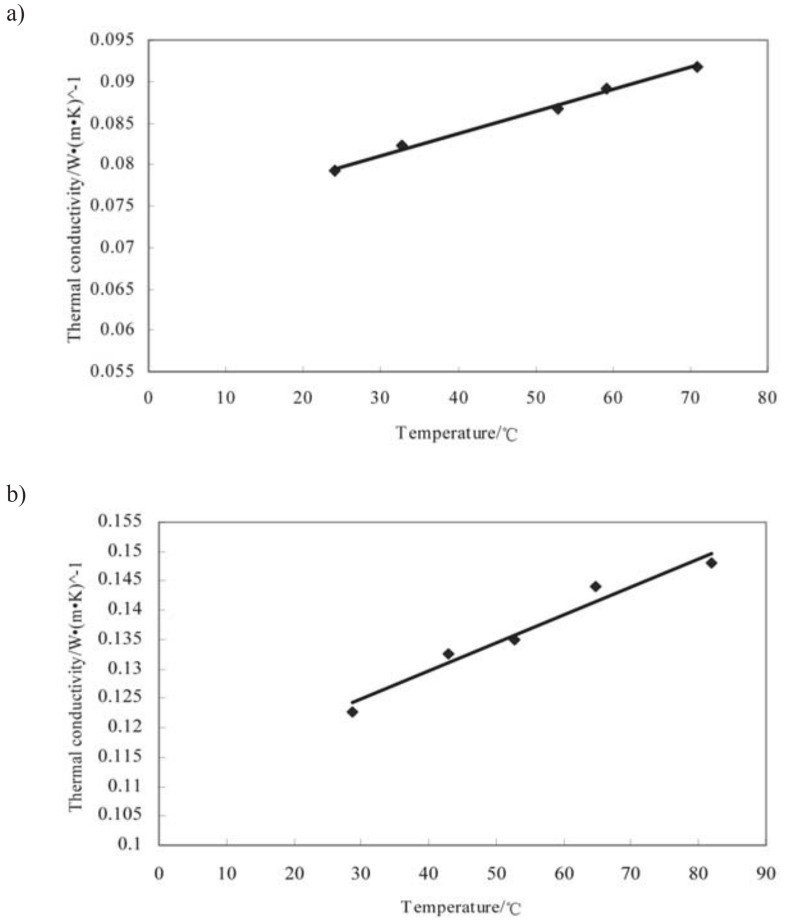


Fig. 1. Relationship between thermal conductivity and temperature of Panyi coal sample

2) The impact of accumulation porosity on the thermal conductivity

For a specified coal sample, its granularity moisture and coal are fixed value, and its thermal conductivity is mainly affected by particle packing porosity.

The changing trend between each of coal samples thermal conductivity and the porosity of the different particle accumulation is show in Figure 2, and the abscissa denotes the pore porosity of accumulation for particles. All of the coal samples are completely dried before the experiment began, so it is need not consider the impact of moisture. It can be seen from Figure 2 that thermal conductivity decreases with the increase of voidage, and which has a linear relationship, this is because with the increase of voidage, the quantity of gap gas that participate in heat transmitting is increase, then the thermal conductivity of loose coal bulk decreases, which is actually consistent with the fact.

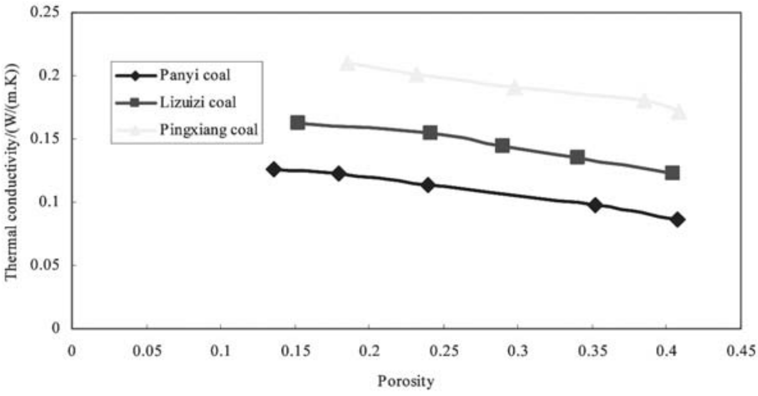


Fig. 2. Relationship between thermal conductivity and packing density

3) The impact of moisture content on the thermal conductivity

Because the quantity of sample is large, we adjust the moisture of coal sample though wet air and drying. When the moisture content of coal samples meet the experimental level, the required amount of coal samples is taken into sample cone, then test the thermal conductivity of coal samples. The measurement results of Panyi and Lizuizi coal samples are shown in Figure 3a and 3b.

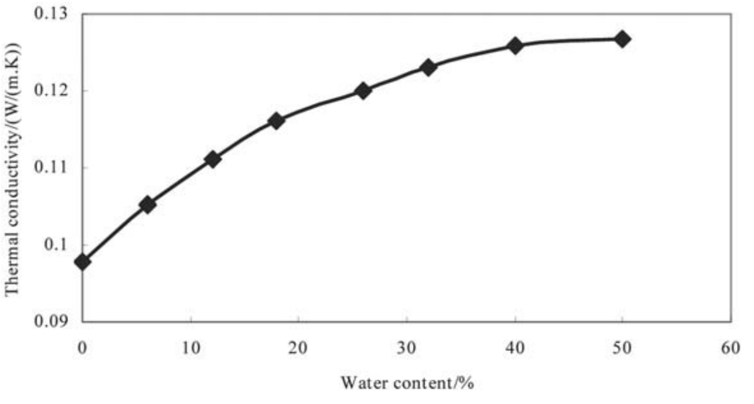
It can be seen from Figure 3 that the thermal conductivity of Panyi and Lizuizi coal samples ascends with the increase of moisture content, and it shows that the thermal conductivity ascends quickly in the beginning and tends to steady later, it may be that the thermal conductivity of water is bigger than that of air, because of the existence of water, the heat transfer process in the particles of loose coal is strengthened, but when the moisture content reaches a certain level, enhanced effect of moisture increasing on the heat transfer process weakened gradually, so the rate of increase about the coefficient of thermal conductivity in loose samples becomes slow.

4) The impact of coalification degree on the thermal conductivity

In order to ensure that the test results of different coal samples are comparable, all samples are fully dried and the water contained in the samples should be removed before the test, the size of heating power in heating rods should be considered in the testing requirements of the parallel wire method, at the same time, it should try to make the total temperature of each coal sample close to each other, then the influence of temperature on the λ could be ignored, the impact of degree of coalification on the λ will be directly studied with testing results .

The adjusted heating power of coal sample is shown in Table 2.

a)



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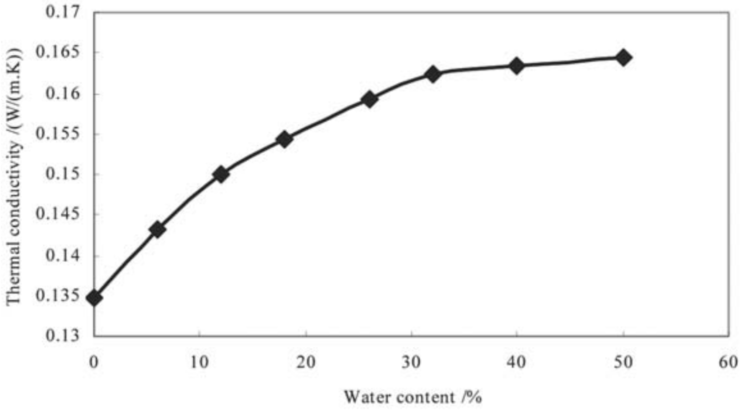

Fig. 3. Relationship between thermal conductivity and water content

TABLE 2
Heating power of coal sample

Coal sample	**Lizuizi coal bituminous coal**	**Panyi coal bituminous coal**	**Pingxiang coal bituminous coal**	**Yongcheng anthracite coal**
Heating power/(W/m)	23.53	12.99	23.53	41.83

The thermal conductivity variation laws of four kinds of coal samples are shown in Figure 4.

It can be seen from Figure 4 that there is a certain correlation between the coefficient of thermal conductivity and coal ranks, and it shows a rising trend, this is because the deeper and more denser the degree of coalification of the solid coal particles becomes, the greater the thermal conductivity.

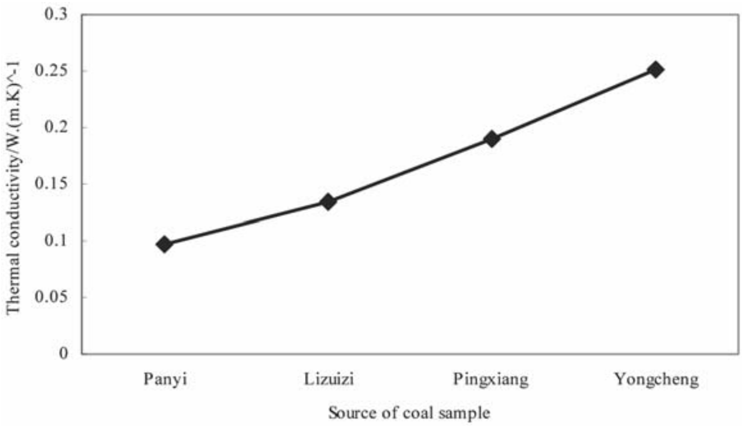

Fig. 4. Relationship between thermal conductivity and coal ranks

2.2. The analysis of the influencing factors of thermal capacity C_p

The impact of porosity of coal sample fixed carbon content and volatile grade on thermal capacity C_p are experimental studied, and the heating power of each of coal sample is shown in Table 2.

1) The impact of volatile grade on the thermal capacity

The thermal capacity of lizuizi bituminous coal pinxiang bituminous coal panyi bituminous coal and yongcheng anthracite are shown in Figure 5, It can be seen from Figure 5a that the thermal capacity of coal sample ascends with the increase of volatile grade, on the contrary, the coal ranks about the coal of low volatile grade is high, such as bituminous coal whose structure unit contains less side-chain, thus, the thermal capacity is little and it makes the thermal capacity of coal become small.

2) The impact of fixed carbon content on the thermal capacity

It can be seen from Figure 5b that the thermal capacity of sample descends with the increase of carbon content. It is because that the coal sample in low coal ranks is high in inorganic mineral content, and the thermal capacity of inorganic minerals is larger than pure coal, which causes the thermal capacity of coal increase.

The inorganic minerals of coal sample descends with the increasing of coal ranks, then the thermal capacity of coal decreases, the fixed carbon content of anthracite is the highest in these four kinds of coal, so its thermal capacity is lowest, when the coal ultimately evolves into the graphite, the thermal capacity will be further reduced.

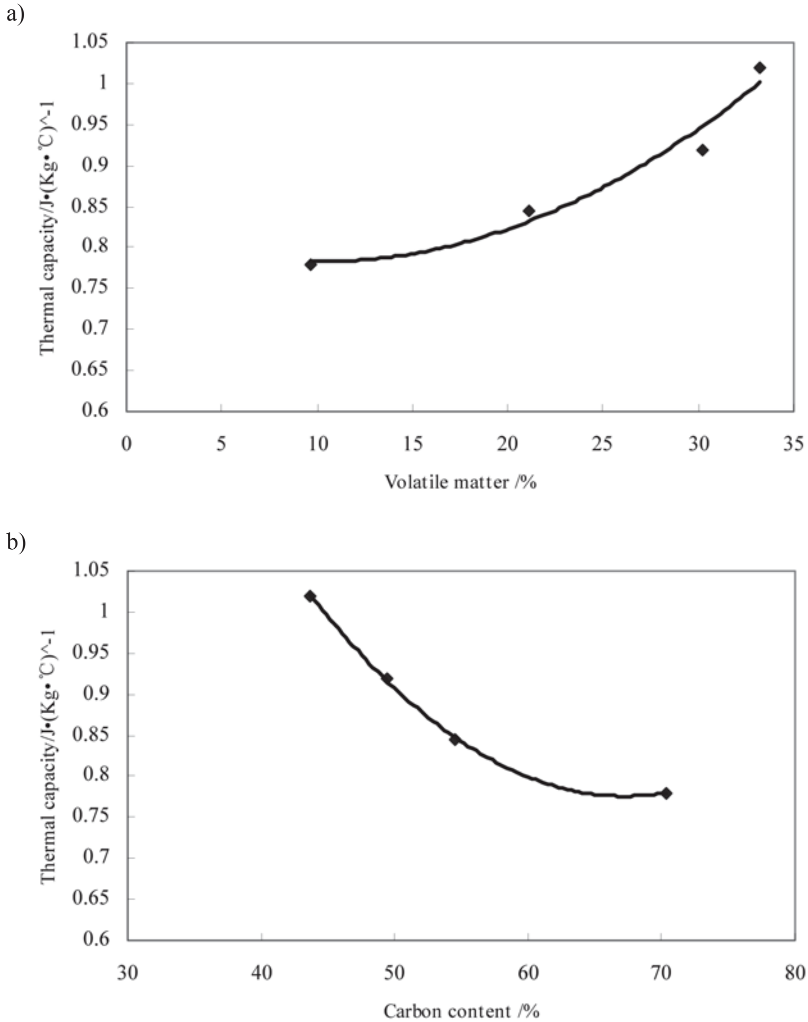

Fig. 5. Relationship between thermal conductivity and volatile matter and carbon content

3) The impact of coal accumulation porosity on the thermal capacity

Figure 6 shows the thermal capacity of the coal sample about lizuizi bituminous coal in different porosity conditions.

It can be seen from Figure 6 that the correlation between porosity and thermal capacity is not obvious, it may because that the thermal capacity of dry air is pretty close to the coal, it is generally stated that the thermal capacity of coal is 0.84–1.38 kJ/(kg·K) [1] at room temperature.

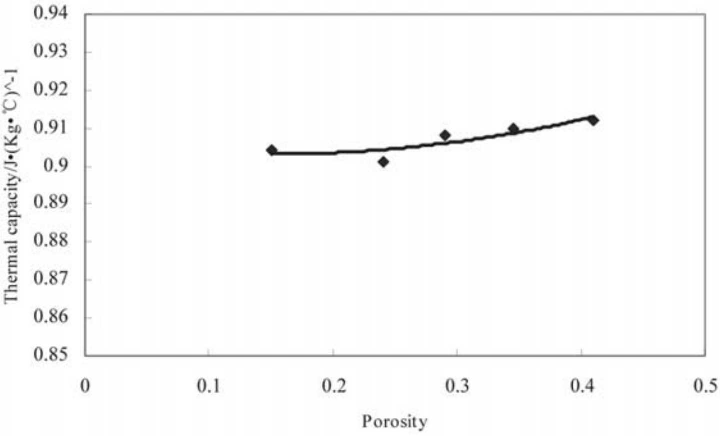

Fig. 6. Effect of porosity in coal sample on the thermal capacity

3. Conclusion

1) Four kinds of coal samples are collected to do the experimental research on parameters affecting factors of thermo-physical properties about loose coal based on hot-wire method and to analyze the correlation between coefficient of heat conductivity, thermal capacity and affecting factors.
2) The coefficient of heat conductivity about loose sample ascends with the increase of temperature, moisture in coal and coal ranks, and the coefficient of heat conductivity descends with the increase of accumulation porosity.
3) The thermal capacity of loose coal sample ascends with the increase of volatile, but the thermal capacity of loose coal sample descends with the increase of fixed carbon content, this may have a close relationship between the thermal capacity of dry air and the thermal capacity of coal.

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