Analysis on the Secondary Carbonization Experiment and the Rule of Temperature Field Evolvement of Coal Sample

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Abstract

The coal sample preparation is an important part for the study of coal’s character, and therefore, the man-made secondary carbonization method of coal sample preparation was explored in the text. Firstly, the scheme of secondary carbonization was designed, and then, according to it, the heat transmission and the temperature field evolvement rule were analyzed in the process of carbonization. Finally, the secondary carbonization experiment of coal sample preparation was conducted, and the coal sample was obtained successfully. The results show that the temperature rise velocity in the center of coal sample is from fast to slow in the process of secondary carbonization, and the reasonable calefaction time is about 15000 seconds.

Keywords: secondary carbonization, temperature field, coal sample preparation

1. Introduction

The coal is the main energy in China. In 2010, the coal production was about 3.2 billion tons\textsuperscript{[1]}. While the high yield of coal, many scholars carried out scientific studies about the nature of the coal from different angles in order to ensure mine safety. Among them, part of the study is the coal sample with tidy shape, specifically including briquettes coal sample and raw coal sample\textsuperscript{[2-3]}. The briquettes coal sample is made with powder coal suppressed in mold in the laboratory. While the raw coal sample is made with
original coal taken back from the scene, the original coal is been further processed to formation the standard coal sample for laboratory\textsuperscript{[6]}. The two coal samples have been affected by mining activities before field sampling. Therefore, the pore and fracture distribution of the briquettes coal sample is different from the original coal sample. This is bound to have some influence on the experimental results, especially the gas adsorption and desorption experiments which is closely related to the pore and fracture distribution. So we should study the preparation of the secondary coal carbonization.

2. Design of the secondary coal carbonization

The secondary coal carbonization includes three steps of coal crushing screening, coal pillar production and heat and pressure test. Among them, the heat and pressure is the key.

1) Coal filter
Whether the coal can bond or not, the bonding quality depends on the quantity and quality of colloid from the coal pyrolysis. The low coal rank coal (lignite coal, long flame coal) have no adhesion or poor adhesion. The high coal rank coal (lean coal, anthracite coal) generates almost no liquid, so there is no adhesion or very poor adhesion. Only medium coal rank coal can generate more colloid and thus have good adhesion, because its thermal decomposition products have more liquid, and the products have high thermal stability.

2) Coal crush
Fresh coal in the field is collected and sealed back to the lab, and be crushed into 40~80mesh by using the crushing system. The mass of coal is about 16kg.

3) Coal pillar production
The crushed coal and coal tar is mixed evenly, and the Mass ratio is about 10:1. The mixture is put into coal bins and to be compressed into molding. Finally, we take out the coal formed some shape and Natural drying at room temperature.

4) Heat and pressure test
We wrapped a layer of newspaper on the outer surface of the coal sample and put it into the coal core tube. After that we attach the coal core tube and other experimental devices. As shown in figure 1.

![Fig.1 Principle map of coal sample post-carbonization experiment](image-url)
The speed of heating coal and maximum temperature can be controlled by regulating the output voltage of the temperature control box, and we can put the pressure on coal by cranking the rocker to promote the piston. The edge and center temperature of the coal can be transferred to the temperature control box through the thermocouple and can be displayed.

If the heating temperature is too high, all of the volatile is pyrolysised and the coal tar also was separated out, pressurized coal cannot be formed. If the temperature is too low, the coal cannot melt and cannot bond. Also, the load control, pressure size and loading speed still need to experiment.

3. The thermal conduction differential equation of carbonization process

The coal sample used to secondary carbonization is cylinder. The side of the coal sample is wrapped by Heaters to heat, and the both ends of the coal sample was were insulated by insulation flange. Therefore, the heat transfer in the coal during secondary carbonization can be approximated as infinitely long cylinder of heat conduction.

According to classical thermodynamics, the thermal conduction differential equation of secondary carbonization process can be shown as follows.

\[
\rho c \frac{\partial t}{\partial \tau} = \frac{1}{r} \frac{\partial}{\partial r} \left( \lambda r \frac{\partial t}{\partial r} \right) + q
\]

Where, \(\rho\) represents the density of coal, kg/m³; \(c\) represents the heat capacity of coal, J/(kg · K); \(t\) represents the temperature of coal, K; \(\tau\) represents time, s; \(r\) represents the distance from the center of coal, m; \(\lambda\) represents thermal conductivity, W/(m · K); \(q\) represents heat release of coal per unit time per unit volume, J/(m³·s).

There are some differences between the heat transfer in the coal during secondary carbonization and the general heat transfer problems. These differences are mainly reflected in the carbonization process. Coal heating will inevitably lead to thermal decomposition accelerated, while the thermal decomposition needs energy, higher of the coal temperature rises, the greater energy is need provided by the outside world and the more completely of thermal decomposition. So, \(q\) is negative, and the absolute value of \(q\) increases with temperature increasing. Here, we assume a linear relationship between the absolute value and temperature. It can be expressed as the following formula.

\[
q = b(t - t_1)
\]

Where, \(b\) represents coefficient, J/(m³·s·k); \(t_1\) represents the initial pyrolysis temperature, k.

Put the formula (2) into formula (1), there

\[
\rho cr \frac{\partial t}{\partial \tau} - \frac{\partial}{\partial r} \left( \lambda r \frac{\partial t}{\partial r} \right) - brt = -b r t_1
\]

Formula (4) is a standard parabolic equation,

\[
d \frac{\partial t}{\partial \tau} - \frac{\partial}{\partial r} \left( c \frac{\partial t}{\partial r} \right) + at = f
\]

Compare formula (3) and formula (4), there, \(d = \rho cr, c = \lambda r, a = -br, f = -b r t_1\). The initial conditions of the Equation is: \(\tau = 0, \ t = t_0\), \(t_0\) represents the initial temperature of coal, k. boundary conditions: \(r = r_1, t = t_2\), \(r_1\) represents the radius of coal, m. \(t_2\) represents the temperature of the heater. These equations have no analytic solution, only can be solved by numerical methods.
4. Evolution of temperature field of carbonization process

During the carbonization process, the heating device situated outside the coal sample, this will inevitably lead to the temperature to be different between outside of coal and center of coal. If the control inaccurate, there will be some kind of phenomenon that the center of the coal has not yet melted, but the outside of coal loses bonding capacity due to temperature is too high and heating time is too long. The coking temperature of coal is 350-1000°C, and it is 623-1273K converted into Kelvin temperature. So, only the temperature of the coal is in this range, and heating time is least, can we get the highest probability of experimental success.

According to formula (3), initial conditions, boundary conditions and the experimental parameters, we can get the results of temperature distribution and changes by numerical calculation using computer program.

The density of coal is about 1400 kg/m³, and the heat capacity of coal is about 1200 J/(kg · k). The radius of coal is 0.1m, and the thermal conductivity of coal is about 0.2W/(m · K). In formula(3), coefficient b is about 1000J/(m³.s.k). The initial pyrolysis temperature is about 400k, the initial temperature is 300k and the heating temperature is 1100k.

Through the numerical calculation, the temperature distribution nephogram of coal under different heating time can be gotten.

In figure.2, the deep or shallow of the collar represents the high or low of the temperature. Under each of the temperature distribution nephogram, the red arrow represents the direction of heat flow, the annular ring is the temperature distribution contours.
From the overall, the temperature outside of coal is higher, and the temperature in the center of coal is lower. The temperature in the center of coal will be higher and higher with the time increasing (the distance is gradually increasing between the center and bottom of the temperature distribution nephogram). Take the center of the coal for example, the trend of temperature changing with heating time is shown in figure 3. As is shown in figure 3, the growth rate of temperature in the center of coal is first
increased and then decreased. Thus, at a later stage, it is inefficient to improve the temperature in the center of coal by heating. As is shown in the trend of temperature distribution curve, the reasonable heating time should be 15000 seconds or so.

5. Experiment of secondary coal carbonization

According to the experimental program of second coal carbonization, the first step is to filter coal, then to crush the coal to make coal pillar. Finally, it is to heat and load in the coal to make the carbonization experiment. The heating current is 10A, and the voltage is 50V. We apply load to the coal using the torque wrench, and the maximum torque of the torque wrench is 300N·m. There are smoke, flames and a small amount of black coal tar generated in heating process, and it issues a "creak" sound when we apply load to the coal.

![Image](image_url)

Fig.4 The post-carbonization experiment of coal sample

The heating time is set to 16000 seconds, but the actual heating time was 4 hours 32 minutes (16,320 seconds). The coal core temperature is 500 °C shown in thermocouple, and at this time, the temperature of tube center of coal is 855°C. These temperature are within the scope of coal coking temperature(350-1000°C).

After natural cooling, the coal sample is pushed out, and its shape is shown in figure 5. The carbonization coal sample is basically complete, but there are some broken at both ends of the edge. This may be due to stress concentration when we apply load.
6. Discussion

Although this study has made some progress in the aspect of secondary coal carbonization, there are some work remains to be further improved in the following aspects if we want the secondary carbonization coal and raw coal to be highly similar. 1) Although the temperature of coal sample is within the scope of coal coking temperature, but the temperature outside of the coal is higher than inside. The higher the temperature is, the more serious the pyrolysis chars, and the better pore generates. So we need to increase the thermal conductivity of coal and to reduce the uneven temperature distribution in the coal, which makes coal more uniform pore distribution. 2) Although the technical measures is to basic ensure the success of carbonization experimental that applying load and isolating heat at both ends of the coal, there are some measures to avoid stress concentration, prevent heat loss effective and release pyrolysis gas.

7. Conclusions

1) Temperature control is the key to decide whether the secondary coal carbonization is success or not. Only the heating time is the least to make the coal in the scope of coal coking temperature, can we ensure a high success rate of the experiment.

2) In the carbonization experiment, the heat flows gradually from the outside to the center, and the temperature of the coal increases gradually. Among them, temperature growth Velocity in the center of coal increases firstly, then slows down.

3) In order to prevent the outside of coal from over-charring, and ensure that the center of the coal can be carbonization, the reasonable heating time is about 15000 seconds.

4) According to the heating time determined by experiment and theoretical analysis, a successful secondary coal carbonization experiment is carried out and the briquette after artificial carbonization is obtained.

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