THERMAL PROPERTIES OF CHINESE OIL SHALE

--Measurement of thermal conductivity of oil shale--

Lu Shaoxin Wang Tingfen Guan-Mi* Huang-Yong*
(陆绍信) (王廷芬) (关 密) (黄 勇)
Beijing United Research Institute of Applied Chemistry and Chemical Engineering, SINOPEC, Beijing, China
Beijing Graduate School of East China Petroleum Institute
*Nanjing Institute of Technology, Nanjing, China

ABSTRACT

The thermal conductivity is one of the important thermal character of oil shale. Many previous authors have used a transient line-probe method to measure the thermal conductivity of oil shale that is handicapped by several difficulties. This paper reports on the development of a steady-state guarded hot plate method for the measurement of thermal conductivity of oil shale. A NK-III-50S type thermal conductivity meter was buit up by us. Measurements were carried out in the temparater range 50-300°C on fused quartz and oil shale. In order to eliminate the effect of the thermal contact resistance of the apparatus with the oil shale sample surfaces on the measurement, the overall thermal resistance of three different thickness Fushun oil shales were measured. Predictive equations showing the variation of the overall thermal resistance with thickness are presented. The results of the present investigation show that it is very good straight line. According to the slope of the straight line obtained in the present study, the thermal conductivity of Fushun oil shale was determined. Their thermal condutivities were 0.9849-1.0005 W/mk. The relative equation showing the variation of thermal condutivity with temparature for Fushun oil shale is presented.

INTRODUCTION

The majority of techniques currently envisaged for retorting processing is based on the application of heat to oil shale. A knowledge of the thermal conductive behaviour of oil shale is therefore relevant to the design and optimization of the retorting process. The rate at which shale beds are heated to the pyrolysis temperature range is of considerable economic significance. Consequently, the thermal conductivity is one of the important thermal character of oil shale.

Many previous authors have used a transient line-proble method to measure the thermal conductivity of oil shale that is handicapped by several difficulties.(1) The theoretical unperfectness, the technical uncertainties, and the problems of thermal contact resistance are particularly severe with this technique, as perfect contact between the shale and the heating source is not attainable. Therefore, the overall accuracy is not good. R. Nottenburg, et.al.(2) have developed a thermal comparator technique to measure the thermal conductivity of Green River oil shale. But it has to employ the reference samples whose thermal conductivities were known. It is difficult for us to get such standard material. In veiw of the above, it was deemed advantageous to use alternative methods for the measurement of the thermal conductivity of Chinese oil shale. Consequently, this paper reports on the development of a steady-state guarded hot plate method for the measurement of thermal conductivity of oil shale. A NK-III-50S type thermal conductivity test apparatus which was built up by us was employed in this experiment. Results are reported for thermal-conductivity values varied with temperature.

EXPERIMENT

According to the principle of the steady-state guarded hot plate method, the test sample is sandwiched between the upper and lower heaters. After the temperatures have reached thermal steady-state, the thermal transmissbility of the test sample is computed from the equation.(3)

$$\Gamma = \frac{Q}{A_m(T_1-T_2)} = \frac{1}{R} \quad W/m^2K \quad \text{------ (1)}$$

Thus, the equation (1) times δ (thickness of test sample) yields the thermal conductivity form:

$$\lambda = \frac{Q\,\delta}{A_m\,(T_1-T_2)} \qquad W/mK \quad \text{------ (2)}$$

In order to calibrate the charateristic of the NK-III-50S type GHP, the fused quartz was used as the test sample (measurements were carried out in the temperature range 50-300°C). Figure 1. shows typical calibration results obtained on the test apparatus.

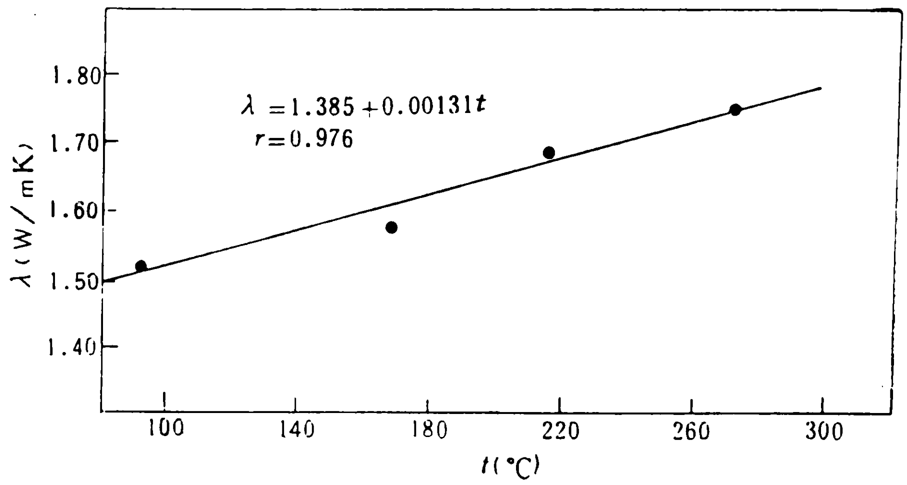

Figure 1. Thermal conductivity of fused quartz obtained in the experiment.

The first-order equation relating thermal conductivity to temperature for fused quartz is found to be as follows:

$$\lambda = 1.385 + 0.00131\, t_m \qquad W/mK \quad \text{------ (3)}$$

$$(80 \leqslant t_m \leqslant 280°C)$$

According to the literature values for fused quartz[4], a statistical analysis of these data yields the following equation:

$$\lambda = 1.33 + 0.00154\, t_m \qquad W/mK \quad \text{------(3a)}$$

$$(50 \leqslant t_m \leqslant 100°C)$$

The values of fused quartz computed from equation (3) are nearly as same as the literature values. It means that the NK-III-50S type test apparatus is suitable for us to measure the thermal conductivity of oil shale.

Oil shale samples for the present study were obtained from Fushun. Right-circular cylindrical samples, 50 mm diameter and 10, 15, 20 mm thickness, were cored from shale blocks perpendicular to the shale bedding planes. All samples were carefully dried to remove free moisture. In order to eliminate the effect of the thermal contact resistance of the apparatus with the oil shale sample surfaces on the measurement, the overall thermal resistance of three different thickness Fushun oil shales were measured. Then, the thermal conductivity of Fushun oil shale will be determined.

RUSULTS AND DISCUSSION

Figure 2. shows the variation of the overall thermal resistance of Fushun oil shales with different thickness and temperature in the range 10-20 mm and 80-220°C, respectively. Standard statistical and computer techniques were used to determine the equations relating the overall thermal resistance to temperature. The obtained equations are as follows:

$$R = a+a_1t+a_2t^2+a_3t^3+a_4t^4 \quad m^2K/W \quad \text{------}(4)$$

$$(80<t<220°C)$$

Where a, a_1, a_2, a_3, a_4 are empirical contants.

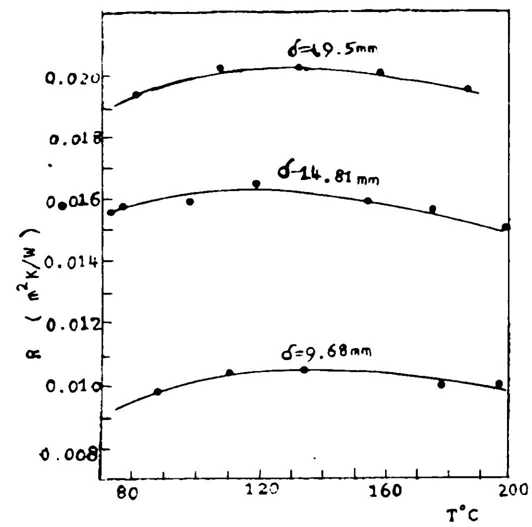

Figure 2.

The relationship between the overall thermal resistance and temperature

Table 1. Values of coefficients in Eq. 4

sample thickness mm	a	a_1	a_2	a_3	a_4	relation coefficient r
19.5	$1.059*10^{-2}$	$1.767*10^{-4}$	$-8.678*10^{-7}$	0	$5.128*10^{-12}$	0.99
14.81	$1.148*10^{-2}$	$8.856*10^{-5}$	$-4.840*10^{-7}$	$6.491*10^{-10}$	0	0.92
9.68	$-1.946*10^{-3}$	$2.493*10^{-4}$	$-1.606*10^{-6}$	$3.275*10^{-9}$	0	0.99

These predicative equations can be used to caculate the overall thermal resistance values (R) of Fushun oil shale in the temperature range 80-220°C with the sample thickness 9.68 mm, 14.8mm and 19.5mm, respectively. From the point of view of theory, if the contact resistances negligible by small, the thermal resistance (R) vs. sample thickness (δ) relation curve must be a straight line passed the origin and the thermal conductivity of the test sample may be caculated from the slope of the straight line. Figure 3. and Figure 4. show that the variation of the thermal resistance with sample thickness for Fushun oil shale at temperature 80, 200°C, respectively. It can be seen from Figure 3. and Figure 4. that it is a good straight line.

The relation equations between (R) and (δ) are summarized in Table 2.

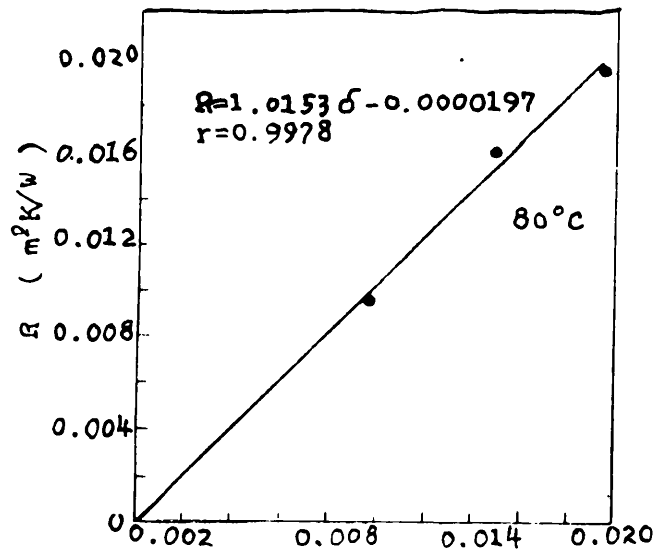

Figure 3. The relationship between (R) and (δ) for Fushun oil shale at temperature 80°C

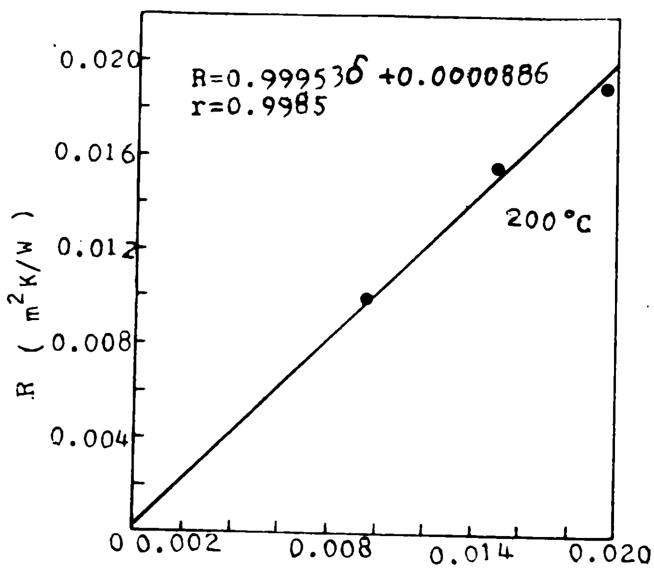

Figure 4. The relationship between (R) and (δ) for Fushun oil shale at temperature 200°C

Table 2. The relation equations between (R) and (δ) for Fushun oil shale

temperature °C	R-δ relation equations	relation coefficient r
80	R=-0.0000197 + 1.0153 δ	0.998
100	R= 0.0001147 + 1.04547 δ	0.999
120	R= 0.0001681 + 1.05684 δ	0.999
140	R= 0.0000529 + 1.07555 δ	0.999
160	R= 0.0001369 + 1.0375 δ	0.999
180	R= 0.0001036 + 1.01752 δ	0.999
200	R= 0.0000886 + 0.99953 δ	0.998

The thermal conductivity of Fushun oil shale which were calculated from the equations summarized in Table 2 are listed in Table 3.

Table 3. The thermal conductivity of Fushun oil shale

temperature °C	80	100	120	140	160	180	200
thermal conductivity W/mK	0.9849	0.9565	0.9462	0.9298	0.9639	0.9828	1.0005

The thermal conductivity variation with temperature for Fushun oil shale can be described by a third-order equation:

$$\lambda=2.0817-2.3167*10^{-2}t + 1.488*10^{-4}t^2 - 3.026*10^{-7}t^3 \quad \text{W/mK} \text{ -------- } (5)$$

$(50\leq t\leq 220°C)$

ACKNOWLEDGMENT:

The authors are grateful to Professor Zhu Yajie for enthusiastic help in the experiments reported here.

LITERATURE CITEC:

1. Parts, M. and O'Brien, S.M., J.Petroleum Tech. 94, (1945)
2. Nattenburg, R. et. al., Fuel, 57, 789, (1978)
3. ANSI/ASTM C_{177-76}" Standard test method for steady-state thermal

transmission properties by means of guarded hot plate"

4. L.L.Vaceelef., C.A.Tanaeva. "Thermophysical Properties of Porous Media".

(In Russian)