北京航空航天大学
实验报告

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实验名称: Thermal conductivity of poor conductive materials measured by steady-state method.

Part 1: Abstract

In this experiment, we use the steady-state method to measure the thermal conducting of the poor conductive material. First, we measured the sample and copper plate parameters, and recorded the steady-state as Θ_1, Θ_2. Then during the temperature rising and cooling progress, we recorded the data of these two parts. In this repord, the original experimental process, experimental data and data processing are given, and the analysis of uncertainty are obtained. In addition, I gave my own thoughts on some problems in the experiment and putformed some ideas for experimental improvement, including shorting the duration of the experiment, improvement ~~of data~~ the method of data collection and so on.

Part 2: Introduction

①. The thermal conductivity of a material is a measure of its ability to conduct heat. It is commonly denoted by k, λ or κ. Heat transfer occurs at a lower rate in materials of low thermal conductivity than in materials of high thermal conductivity. For instance, metals typically have high thermal conductivity and are very efficient at conducting heat. Correspondingly, materials of high thermal conductivity ~~and ar~~ are widely used in heat sink application, in this experiment, I used metal as the heat dissipation material. Materials of low thermal conductivity are used as thermal insulation. As for the strict defination, I got some information form WikiPedia: " Thermal conduction is defined as the transport of energy due to random molecular motion across a temperature gradient. It is distinguished from energy transport by convection and molecular work in that it does not involve macroscopic flows or work-performing internal stresses." In a word, thermal conductance is defined as the quantity of heat that passes in unit time through a plate of particular area and thickness when its opposite faces differ in temperature by one kelvin. The relationship between thermal conductivity and conductance is analogous to the relation between electrical conductivity and electrical conductance.

Thermal conductivity units are [W/(m·k)] in the SI system. In addition, factors that affect thermal conductivity are temperature, the chemical phase of the material, thermal anistropy, the electrical conductivity of the material, influence of magnetic fields, isotope purity of the crystal and so on.

There are a number of possible ways to measure thermal conductivity, such as: Steady-state methods, Time-domain methods, Frequency-domain methods and so on. ~~this~~ During this experiment, we used Steady-state method to measure thermal conductivity. In general, steady-state techniques perform a measuredment when the temperature of the material measured does not change with time. This makes the signal analysis straightforward (steady-state implies constant signals). The disadvantage is that a well-engineered experimental step is usually needed.

Major sources of error in steady-state measurements include radiation and convective heat losses in the setup, as well as errors in the thickness of the sample propagating to the thermal conductivity.

(2). experiment principle

~~Round~~ Round copper plate P, sample B to be tested and thick base copper plate A were success-fully placed on the support D. Heat A with infrared lamp L on the top to keep the upper and lower surface of the sample at stable temperatures θ_1 and θ_2 respectively. According to Fourier's heat conduction theorem $\frac{\delta Q}{\delta t} = \frac{k\pi d_B^2}{4}\frac{\theta_1-\theta_2}{h_B}$, when the heat transfer reaches a stable state, the heat flow through the surface of disc B is equal to the heat dissipation rate of brass disc P to the surrounding environment. At this point, sample B was removed. after heating plate P, cylinder A was removed to allow it to cool natually, and the temperature changing with time t was observed, thus the heat dissipation of the brass disc can be modified.

Part 3: Formulation

$$k = m_P c \frac{\delta\theta}{\delta t} \frac{d_P + 4h_P}{d_P + 2h_P} \frac{h_B}{(\theta_1 - \theta_2)} \frac{2}{\pi d_B^2}$$

The "k" is thermal conductivity and we use this formulation to calculate it of the sample.

Part 4: Discussion

(1). the experimental progress

1>. Remove the fixing screw and place the rubber sample between the heating plate and the cooling plate. Adjust the three fine tuning screws under the cooling plate to make the sample in good contact with the heating plate and the cooling plate.

2>. Plug in the FD-TC-B type thermal conductivity measuring apparatus, and insert the sensor into the heating plate and the cooling plate.

3>. Set the temperature of the heater to 75 °C, then press the ensuring button and turn on the fan switch, the instrument will start heating.

4>. When the temperature of heating plate rises to the set temperature value, record the cooling plate's temperature every one minute, when the temperature of the heating plate and heat dissipation plate is basically unchanged, it can be considered that the stable state has been changed.

5>. Press the reset button to stop the heating, take away the sample, and then set the temperature of the heating plate at 75 °C to accelerate the temperature rising of the cooling plate, and make the temperature of the cooling plate 15 °C higher than the steady-state temprature.

6>. Remove the heating plate and allow the cooling disc to cool in the presence of a fan. Record values every 10 seconds.

(2). data collection

Time / object	1	2	3	4	5	Average
M_p(g)	1141.14	1141.15	1141.16	1141.16	1141.16	1141.15
d_p(mm)	130.00	129.98	129.97	129.90	130.00	129.97
h_p(mm)	9.98	9.97	9.98	9.96	9.98	9.97
d_B(mm)	129.82	129.82	129.84	129.88	129.90	129.73
h_B(mm)	8.28	8.20	8.24	8.24	8.24	8.24

time/min	1	2	3	4	5	6	7	8	9
θ_1/°C	75.0	74.9	75.0	74.9	75.0	75.1	75.0	74.9	75.0
θ_2/°C	46.4	46.6	46.8	46.9	47.0	47.1	47.3	47.3	47.5
time/min	10	11	12	13	14	15	16	17	18
θ_1/°C	75.0	75.0	75.0	75.1	75.1	75.1	75.3	75.2	75.0
θ_2/°C	47.5	47.5	47.6	47.6	47.7	47.8	47.9	48.0	48.0
time/min	19	20	21	22	23	24	25	26	27
θ_1/°C	74.8	74.9	74.9	74.9	74.9	74.9	74.9	74.9	74.9
θ_2/°C	48.0	48.0	48.1	48.1	48.1	48.1	48.1	48.2	48.2
time/min	28	29	30	31	32	33	34	35	36
θ_1/°C	74.9	74.9	74.9	74.9	74.9	74.9	74.9	74.9	74.9
θ_2/°C	48.2	48.3	48.3	48.3	48.3	48.3	48.3	48.3	48.3

$\theta_1 = 74.9°C$ $\theta_2 = 48.3°C$

time/s	15	30	45	60	75	90	105	120	135
θ_2/°C	63.3	62.8	62.2	61.2	60.3	59.5	58.7	57.9	57.1
time/s	150	165	180	195	210	225	240	255	270
θ_2/°C	56.3	55.5	54.8	54.1	53.3	52.7	52.1	51.5	50.8
time/s	285	300	315	330	345	360	375	390	405
θ_2/°C	50.2	49.6	49.0	48.4	47.9	47.3	46.8	46.3	45.8

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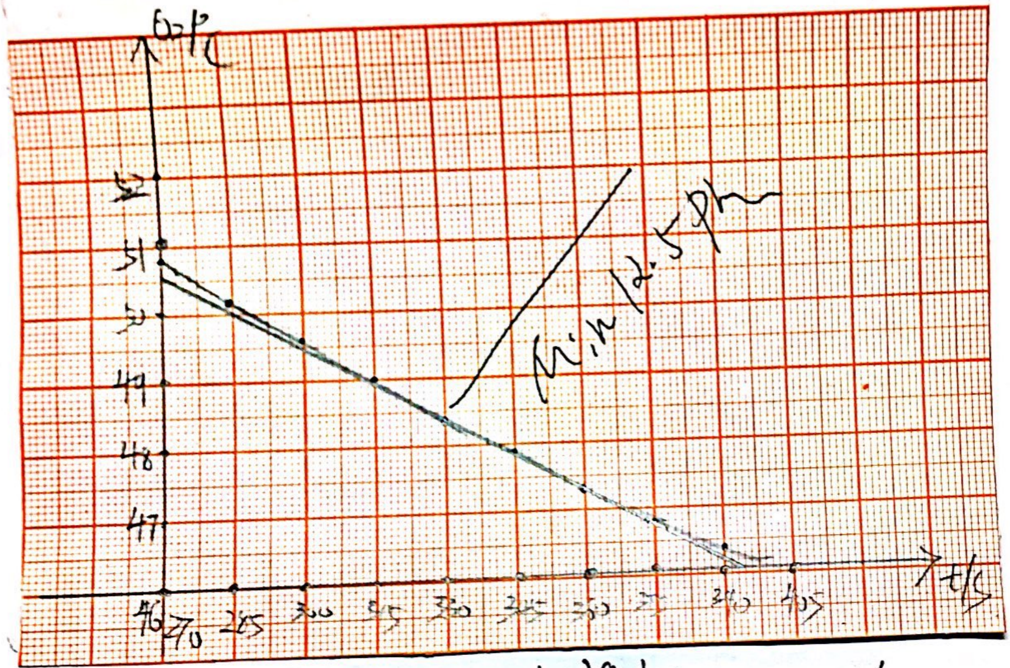
(3). Data processing



$C = 0.389 \times 10^3 \ J/(kg \cdot {}^\circ C)$ $\left|\dfrac{\partial \theta_2}{\partial t}\right| = 0.038095 \ {}^\circ C/s$

$$K = m_P C \frac{\delta\theta}{\delta t} \frac{d_P + 4h_P}{d_P + 2h_P} \frac{h_B}{\theta_1 - \theta_2} \frac{2}{\pi d_B^2} = 0.22369 \ W/(m \cdot K).$$

(4). Analysis of uncertainty

$U_a(m_P) = 0$ $U_b(m_P) = \dfrac{0.01}{\sqrt{3}} g = 5.7735 \times 10^{-6} kg$

$U_a(d_P) = \sqrt{\dfrac{\sum (d_{Pi} - \bar{d_P})^2}{5 \times 4}} = 1.8439 \times 10^{-5} m$ $U_b(d_P) = U_b(h_P) = U_b(d_B) = U_b(h_B) = 1.1547 \times 10^{-5} m.$

$U_a(h_P) = \sqrt{\dfrac{\sum (h_{Pi} - \bar{h_{Pi}})^2}{5 \times 4}} = 4.4721 \times 10^{-6} m.$

$U_a(d_B) = \sqrt{\dfrac{\sum (d_{Bi} - \bar{d_B})^2}{5 \times 4}} = 6.3127 \times 10^{-5} m.$

$U_a(h_B) = \sqrt{\dfrac{\sum (h_{Bi} - \bar{h_B})^2}{5 \times 4}} = 1.2649 \times 10^{-5} m.$

$u(d_P)=\sqrt{u_a^2(d_P)+u_b^2(d_P)}=2.1756\times10^{-5}\,m$

$u(h_P)=\sqrt{u_a^2(h_P)+u_b^2(h_P)}=1.2383\times10^{-5}\,m$

$u(d_B)=\sqrt{u_a^2(d_B)+u_b^2(d_B)}=6.4174\times10^{-5}\,m$

$u(h_B)=\sqrt{u_a^2(h_B)+u_b^2(h_B)}=1.7127\times10^{-5}\,m$

$u(m_P)=5.7735\times10^{-6}\,kg$

$$\frac{u(k)}{k}=\sqrt{\left(\frac{u(m_P)}{m_P}\right)^2+\left(\left(\frac{1}{d_P+4h_P}-\frac{1}{d_P+2h_P}\right)u(d_P)\right)^2+\left(\left(\frac{4}{d_P+4h_P}-\frac{2}{d_P+2h_P}\right)u(h_P)\right)^2+\left(\frac{u(h_B)}{h_B}\right)^2+\left(\frac{2u(d_B)}{d_B}\right)^2}$$

$$=2.306\times10^{-3}$$

$\therefore u(k)=5.157\times10^{-4}\,W/(m\cdot K)=\cancel{5\times10^{-4}\,W/(m\cdot K)}=0.5\times10^{-3}\,W/(m\cdot K)=0.001\,W/(m\cdot K)$.

$\therefore k=(0.224\pm0.001)\,W/(m\cdot K)$

Part 5 Conclusion.

(1) The thermal conductivity of the poor conductor is $(0.224\pm0.001)\,W/(m\cdot K)$.

(2). Thinkings:

①. The fan's function in the experiment

The fan is used to forced convection heat transfer, reducing the heat release radio between the side and bottom of the sample, increasing the temperature gradient inside the sample, so as to reduce the experimental error. If turn off the fan while cooling down the cooling plate, the temperature gradient inside the sample will be lower and the experimental error will be larger.

②. Questions in book.

1). The error mainly comes from $\theta_1-\theta_2$. First, during the measurement, the side of the sample also dissipates heat, which makes the heat transferred from the upper and lower sides of the sample unequal. Second, the air gap between the top and bottom surface of the sample and the metal cannot be ignored.

2). Because of the low thermal conductivity of the air, there is a negative error. A, B, P can be compressed by adjust the bolts and the upper and lower surfaces can be cleared cand coated with silicon oil.

(2). The thermal conductivity of metals is high. According to $\theta_1-\theta_2=\frac{\delta Q}{\delta t}\frac{h}{SK}$. in order to ensure $\theta_1-\theta_2$ is large enough, we should increase the value of $\frac{h}{S}$, So the sample is made into a rod. Choose a metal bar with good perpendicularity, small area and long length so that it is in contact with the copper-plate as well as possible, and cover the surface with an insulating material.

(3). Future improvement schemes:

①. Due to the long heating time (especially when the temperature is close to steady-state), there might be an error when collect the data, we can use some kinds of sensor to read the temperature and record by software, such as thermistor and so on.

②. The experiment data may changed by some other reasons, such as voltage instability, heating coil aging and so on. To avoid these problems, we can use some software to draw a continuous temperature curve. When we analys the experiment data, we can eliminate some datas with significant fluctuations.

③. As the side of the sample deliver heat, we can select more samples of different thickness to solve the problem.