Measurement of the Thermal Conductivity of Liquid

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I. Objective

Learn to measure the thermal conductivity of liquids using steady-state and transient methods.

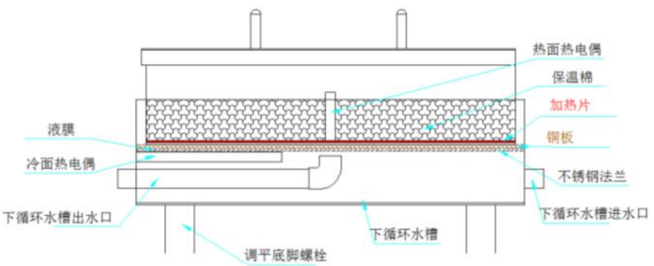
Understand the structure and principle of the experimental device, and master the liquid thermal conductivity test method.

Understand the advantages and disadvantages of the two methods.

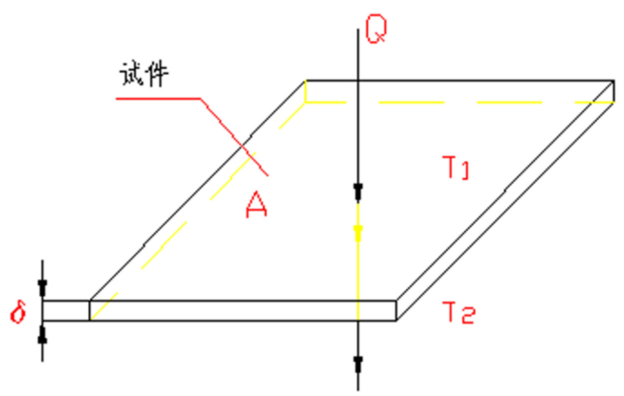
II. Principle

1.Steady-state method

To minimize heat loss and improve test accuracy, the device includes a thermal insulation layer (thermal insulation material) so that most of the heat is only conducted downward.



Structure of the measuring part



Schematic diagram of heat conduction of flat plate specimens

According to the basic principle of the Fourier single conduction process:

$$Q = \lambda \frac{T_1 - T_2}{\delta} A$$

Q is the heat flux per unit time through the area A of the flat plate specimen

A is the cross-sectional area perpendicular to the direction of thermal conduction

T_1 is the temperature of the hot surface

T_2 is the temperature of the cold surface

δ is the thickness of the gasket placed in the liquid tank

λ is the thermal conductivity of the testing material

So the thermal conductivity can be obtained by:

$$\lambda = \frac{Q\delta}{(T_1 - T_2)A}$$

2.Transient method

Using the transient-hot-wire approach, the thermal conductivity of a substance is calculated by the rate at which its temperature rises when heated by a thin hot wire. The influence of natural convection may be avoided because of the quick measurement period, and the hot wire serves as both a heater and a thermometer.

The thermal conductivity of the medium can be obtained from the temperature rise relationship with time:

$$\Delta T(r_0, t) = \frac{q}{4\pi\lambda} lnt + \frac{q}{4\pi\lambda} \ln\left(\frac{4\alpha}{r_0^2 C}\right)$$

T is the initial temperature

r_0 is the radius of the hot wire

t is the heating time

$\Delta T(r_0, t)$ is the temperature rise over time t

q is the heating power

λ is the thermal conductivity of the liquid

α is the thermal diffusivity of the liquid

The thermal conductivity of the liquid can be determined if the slope of the curve of Δ T to lnt is measured.

III. Data Processing and Results

1.Steady-state method

1.1 In this experiment, the liquid is square with a side length of 0.28m. Calculated the thermal conductivity and compared with the standard values and calculate the relative deviation.

Standard value: thermal conductivity of liquid water at room temperature and pressure is about 0.59 W/(m*K)

For heating power around 100W

Time/Min	20	25	30	35	40	45	50	55	60
Q(W)	106.4	107.5	105.3	105.3	104.1	105.3	106.4	105.3	104.1
T1(℃)	29.3	29.4	29.4	29.3	29.4	29.4	29.4	29.5	29.5
T2(℃)	21	21.1	21.1	21.2	21.2	21.2	21.3	21.4	21.4
ΔT(℃)	8.3	8.3	8.3	8.1	8.2	8.2	8.1	8.1	8.1
Averaged ΔT(℃) (for the last 4 stable record)	8.125								
λ(W/(m*K))	0.7602								

Relative deviation= $\frac{0.7602-0.59}{0.59} * 100\% = 28.85\%$

For heating power around 200W

Time/Min	20	25	30	35	40	45	50	55	60
Q(W)	216.1	213.9	213.9	217.3	218.4	217.3	212.8	213.9	216.1
T1(℃)	38.3	38.3	38.4	38.6	38.7	38.8	38.9	39	39
T2(℃)	22.2	22.3	22.3	22.4	22.5	22.6	22.6	22.7	22.7
ΔT(℃)	16.1	16	16.1	16.2	16.2	16.2	16.3	16.3	16.3
Averaged ΔT(℃) (for the last 4 stable record)	16.275								
λ(W/(m*K))	0.7752								

Relative deviation= $\frac{0.7752-0.59}{0.59} * 100\% = 31.39\%$

Please see attached data log sheet for calculation details.

1.2 Analyze the result and make a conclusion.

1) The thermal conductivity of liquid water at room temperature and pressure is calculated to be 0.7602W/(m*K) and 0.7752W/(m*K) by the steady-state method for two experiments with heating power about 100W and 200W, and the two test results are very close to each other.

2) Comparing the experimental results with the standard value, it can be found that the calculated results of the two experiments at different powers are both greater than the standard value, and the calculated result is higher when the heating power increases

from 100W to 200W.

2.Transient method

2.1 List the measurement data in a table, and calculate the average value of the measured thermal conductivity along with the relative deviation for each measurement.

Number	Temperature (K)	Thermal Conductivity (W/(m*K))	Relative Deviation
1	291.63	0.6013	-0.46%
2	291.67	0.6013	-0.46%
3	291.82	0.5981	-0.99%
4	301.09	0.6072	0.51%
5	301.14	0.6065	0.40%
6	301.03	0.6100	0.98%

Average measured thermal conductivity

$$=\frac{(0.6013+0.6013+0.5981+0.6072+0.6065+0.6100)}{6}=0.6041\frac{W}{m*K}$$

2.2 Compared the results with the standard values and calculate the relative deviation.

Number	Temperature (K)	Thermal Conductivity (W/(m*K))	Relative Deviation
1	291.63	0.6013	1.92%
2	291.67	0.6013	1.92%
3	291.82	0.5981	1.37%
4	301.09	0.6072	2.92%
5	301.14	0.6065	2.80%
6	301.03	0.6100	3.39%

The results are all larger than the standard value 0.59W/(m*K).

2.3 Analyze the result and make a conclusion.

The six thermal conductivities obtained from experimental measurements at 20°C and 30°C using the transient method are very close to each other, while the relative deviation from the standard value is small, and the experimental results are more accurate compared to the results using steady-state method.

IV. Questions

1.Discuss the sources of experimental error in the steady-state method and transient method for measuring thermal conductivity.

Sources of experimental errors using steady-state method

1) In the actual experiment, convective heat transfer occurs in the liquid, resulting the temperature difference ΔT between the upper and lower plates smaller when compared to the ideal situation that calculates the result by using the equation mentioned above, so a large thermal conductivity will be obtained.
2) The heat loss phenomenon in the experiment cannot be completely avoided, but the contribution of this factor to the experimental error is small compared with 1).

Sources of experimental errors using transient-state method

1) The thermocline is measured in liquid, acting as both a heater and a thermometer. The accuracy of the measurement may be affected due to the flow of liquid in the experiment.
2) The theoretical model of hot wire measurement assumes infinitely small diameter and infinite length, but the diameter and length of the hot wire are limited under actual conditions, so there will be some deviations between the value derived from the formula and the actual value.

2.Discuss the advantages, disadvantages, and scope of measurement of thermal conductivity by steady-state method and transient method.

For steady-state method

Advantages:

1) Simple instrument, easy to operate, low cost.
2) The calculation principle is simple, so thermal conductivity can be obtained directly.

Disadvantages:

1) In this experiment, the accuracy of the measurement is low because the thermal convection phenomenon cannot be avoided.
2) Longer measurement period.
3) This experiment requires demanding external conditions, such as a thermal insulation layer to minimize heat loss.

Scope: It is mainly suitable for the measurement of low thermal conductivity materials at moderate temperatures.

For transient method

Advantages:

1) The influence of natural convection can be avoided.
2) Shorter measurement period.
3) One of the most accurate methods.

Disadvantages:

1) The instrument is expensive and complicated to operate

Scope:

It can be used to determine the thermal conductivity of solids, powders, and fluids for isotropic and anisotropic materials, having a wide range of applications, especially suitable for high thermal conductivity materials and testing at high temperatures.

3.Discuss the device defects and improvement suggestions.

For steady-state device:

Defects:

1) Slow temperature rise and long measurement times during the heating period.
2) The presence of heat loss.

Improvement suggestions:

1) Add insulation to minimize heat loss.

For transient-state device

There seems no defects for this device, but it is encouraged to renew the experiment computer if possible.

The data log sheet is attached in the next page.

Measurement of the thermal conductivity of liquid

Data Log Sheet

1. Basic Information

Name： 邹佳驹　　　　Date： 2022 . 12. 15

2. Data Record

Table 1

Time/min	20	25	30	35	40	45	50	55	60
Q (W)	106.4	107.5	105.3	105.3	104.1	105.3	106.4	105.3	104.1
T_1(°C)	29.3	29.4	29.4	29.3	29.4	29.4	29.4	29.5	29.5
T_2(°C)	21.0	21.1	21.1	21.2	21.2	21.2	21.3	21.4	21.4
ΔT(°C)	8.3	8.3	8.3	8.1	8.2	8.2	8.1	8.1	8.1
Averaged ΔT(°C) (for the last 4 stable record)	$\frac{1}{4} \times (8.2+8.1+8.1+8.1) = 8.125$								
λ(W/(m * K))	$\frac{(105.3+106.4+105.3+104.1)}{4} \times (4.60\times10^{-3}) / 8.125 \times 0.28^2 = 0.7602$								

Table 2

Time/min	20	25	30	35	40	45	50	55	60
Q (W)	216.1	213.9	213.9	217.3	218.4	217.3	212.8	213.9	216.1
T_1(°C)	38.3	38.3	38.4	38.6	38.7	38.8	38.9	39.0	39.0
T_2(°C)	22.2	22.3	22.3	22.4	22.5	22.6	22.6	22.7	22.7
ΔT(°C)	16.1	16	16.1	16.2	16.2	16.2	16.3	16.3	16.3
Averaged ΔT(°C) (for the last 4 stable record)	$\frac{1}{4} \times (16.2+16.3+16.3+16.3) = 16.275$								
λ(W/(m * K))	$\frac{(217.3+212.8+213.9+216.1)}{4} \times (4.60\times10^{-3}) / 16.275 \times 0.28^2 = 0.7752$								

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$$\left.\begin{aligned} \delta_1 &= 4.60 \text{ mm} \\ \delta_2 &= 4.62 \text{ mm} \\ \delta_3 &= 4.59 \text{ mm} \end{aligned}\right\} \Rightarrow \delta = 4.60 \text{ mm}$$