3. Theory

1) PT100 platinum resistance

The resistance value of a conductor changes with temperature change. PT100 platinum resistance uses this property to measure temperature. At 0 °C, the resistance of PT100 is 100 Ω, and its resistance increases with temperature rising. However, the relationship between them is not a simple linear relationship, but more close to a parabola. Usually, we can get an accurate temperature value by looking up the resistance-temperature table.

2) Principle of measuring specific heat capacity of metal by cooling method

The heat required to increase temperature by 1 K (1 °C) for a substance of unit mass is called the specific heat capacity of the substance. Its value changes with temperature. According to Newton's law of cooling, it is one of the commonly used methods in calorimetry to determine the specific heat capacity of metals by the cooling method. If the specific heat capacity of the standard sample at different temperatures is known, the specific heat capacity of various metals at different temperatures can be measured by making a cooling curve.

In this experiment, copper is used as the standard sample to determine the specific heat capacity of iron and aluminum samples at 100 °C. After heating a metal sample of mass M_1, placing it in a medium with a lower temperature (for example, air at room temperature), the sample will gradually cool down. The heat loss per unit time ($\Delta Q / \Delta t$) is proportional to the rate of temperature decrease, so the following relationship is obtained:

$$\frac{\Delta Q}{\Delta t} = C_1 M_1 \frac{\Delta \theta_1}{\Delta t},$$

(1)

where C_1 is the specific heat capacity of the metal sample at temperature θ_1, $\frac{\Delta \theta_1}{\Delta t}$ is the rate of temperature drop of the metal sample at θ_1. According to the cooling law:

$$\frac{\Delta Q}{\Delta t} = a_1 s_1 (\theta_1 - \theta_0)^m,$$

(2)

where a_1 is the heat exchange coefficient, s_1 is the area of the outer surface of the sample, m is a constant, θ_1 is the temperature of the metal sample, and θ_0 is the temperature of the surrounding medium. From equations (1) and (2), we get:

$$C_1 M_1 \frac{\Delta \theta_1}{\Delta t} = a_1 s_1 (\theta_1 - \theta_0)^m$$

(3)

Similarly, for another metal sample with mass M_2 and specific heat capacity C_2, the same expression can be used:

$$C_2 M_2 \frac{\Delta \theta_2}{\Delta t} = a_2 s_2 (\theta_2 - \theta_0)^m$$

(4)

From the above formulas (3) and (4), we can get:

$$\frac{C_2 M_2 \dfrac{\Delta\theta_2}{\Delta t}}{C_1 M_1 \dfrac{\Delta\theta_1}{\Delta t}} = \frac{a_2 s_2 (\theta_2 - \theta_0)^m}{a_1 s_1 (\theta_1 - \theta_0)^m}. \tag{5}$$

and so:

$$C_2 = C_1 \frac{M_1 \dfrac{\Delta\theta_1}{\Delta t} a_2 s_2 (\theta_2 - \theta_0)^m}{M_2 \dfrac{\Delta\theta_2}{\Delta t} a_1 s_1 (\theta_1 - \theta_0)^m}. \tag{6}$$

If the shape and size of the two samples are the same, i.e. $s_1 = s_2$; the surface condition of the two samples is also the same (such as coating, color, etc.), and the nature of the surrounding medium (air) is unchanged, then there is $a_1 = a_2$. Therefore, when the temperature of the surrounding medium is constant (i.e. the temperature in the sample chamber is constant) and the samples are at the same temperature $\theta_1 = \theta_2 = \theta$, the above formula can be simplified as:

$$C_2 = C_1 \frac{M_1 (\dfrac{\Delta\theta}{\Delta t})_1}{M_2 (\dfrac{\Delta\theta}{\Delta t})_2}. \tag{7}$$

If the temperature drop range $\Delta\theta$ of the two samples is the same, equation (7) can be further simplified to:

$$C_2 = C_1 \frac{M_1 (\Delta t)_2}{M_2 (\Delta t)_1} \tag{8}$$

If the specific heat capacity C_1 and mass M_1 of the standard metal sample is known; the mass of the sample to be tested is M_2 and the ratio of the cooling rates of the two samples at temperature θ is measured, the specific heat capacity C_2 of the metal material to be measured can be obtained from equation (8).

The accepted values of specific heat capacity of several common metal materials are:

Copper: $C_{Cu} = 0.39 J/(g \cdot \text{℃})$, Iron: $C_{Fe} = 0.46 J/(g \cdot \text{℃})$ and aluminum: $C_{Al} = 0.88 J/(g \cdot \text{℃})$

3) **Error analysis and improvement on traditional experimental methods**

    a) Influence of sample surface condition and environmental temperature change

In the experimental principle, several assumptions about experimental conditions were made to ensure the establishment of the calculation formula. The assumption that the standard sample and the sample to be tested have the same shape and size can be realized by precision processing methods, but there are two assumptions that are difficult to establish strictly under traditional experimental conditions.

The first is the assumption that the surface conditions of the samples are the same. For metal materials, different metals have different colors. In order to allow them to have the same surface condition, sometimes the same surface treatment can be used. But not all metals are suitable for the same surface treatment method, such as copper, iron and other materials can be

chrome plated and polished, while the aluminum surface chrome plated is easy to fall off. Different surface treatment methods will make the color and roughness of the metal sample surface different, resulting in differences in the rate of radiation heat transfer, affecting the experimental results.

There is also the assumption that the temperature of the medium surrounding the sample is constant, that is, the ambient temperature in the sample chamber has not changed. During the experiment, the sample will continuously radiate heat to the chamber in the cooling process. For the traditional experimental method of natural cooling, this heat will accumulate in the sample chamber and causes the temperature in the sample chamber to increase. Therefore, when the experiment is performed under the condition of natural cooling, the ambient temperature of the sample will gradually increase, and it cannot strictly meet the experimental condition $\theta_1 = \theta_2$.

In order to solve the above two problems, a fan is added to the apparatus to change the cooling environment of the sample from natural cooling to forced convection cooling. At this time, forced convection becomes the main heat transfer mean for the sample to transfer heat to the environment, thereby greatly reducing the impact of the difference in radiant heat transfer rate; at the same time, it can also continuously take away the heat in the sample chamber. During the experiment, if the room temperature and the rotation speed of the fan are unchanged and there are no other interference factors, the chamber temperature θ and air flow field of the sample will be also stable. This way, the problem of temperature change in the sample chamber is solved.

b) Error of thermocouple temperature measurement

The measurement of temperature using a thermocouple requires a constant cold-end temperature environment of 0 °C, usually provided by an ice-water mixture. If there are not enough ice cubes in the ice-water mixture, the temperature inside the thermos will not be uniform because the ice floats on the water surface, and the ice cubes will gradually melt during the experiment. This will cause error for temperature measurement using a thermocouple.

This apparatus uses a high-precision PT100 platinum resistor to replace the thermocouple. There is no need for an ice-water mixture, thereby reducing the source of errors.

c) Error introduced by timing

During the experiment, a timer is used to manually record the time Δt for the temperature drop $\Delta\theta$ of the sample. The timer has a response time or refreshing frequency for the change of the measured object. In addition, the user has a reaction time to read the timer. Both the factors will cause error in time measurement.

If the recorded time difference Δt is too short, the error will be large. Therefore, in order to reduce the error introduced by timing, in addition to the data processing method that uses multiple measurements to average, it must be appropriately increased Δt. First of all, the mass of the sample can be increased, so that the heat capacity of the entire sample is increased, thereby increasing the time Δt required for the sample to drop to the same temperature. At the same time, the range of temperature drop can also be increased, such as from the traditional

98 ℃ -102 ℃ to 95 ℃ -105 ℃, which can not only ensure the approximate linearity of $\dfrac{\Delta\theta}{\Delta t}$ in the temperature measurement range, but also increase Δt to reduce the error caused by timing.