Thermal Normal Emissivity Measurement at Medium Temperature

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I.Objectives

Understand the basic principles and parameters of thermal radiation.

Learn to solve problems using the principle of thermal equilibrium.

Using the comparative method, determine the emissivity of the object.

II.Equipment and Principles

The device as a whole is a hollow cylinder. The cap on one side is the heat source, and the cap on the other side is the body to be measured. The two caps are connected by a hollow conduction chamber. The temperature of the heat source and chamber can be controlled separately by changing the heating power. They are made black as blackbodies. Thermocouples are used to monitor the temperature of the heat source, chamber, and body to be measured. An operation interface can be used for the control and data reading.

The equipment and the operation interface

Thermal radiation is the electromagnetic radiation emitted by all objects at temperatures above absolute zero. According to Planck's law, the thermal emission of a standard blackbody depends largely on its temperature. The emissivity of an object is expressed as the ratio of the energy radiated by the object at the same temperature to the energy of the ideal blackbody. The emissivity of an ideal blackbody is 1. The emissivity depends on the properties of the object, its temperature, its surface state, and the wavelength and direction of the radiation. The emissivity of different materials is different, and the blackness of the same object varies with temperature.

In a radiative heat exchange system composed of n objects,
the net radiative heat transfer on the surface i is:

$$Q_{net.i} = Q_{abs.i} - Q_{e.i} = \alpha_i \sum_{k=1}^{n} \int_{F_k} E_{eff,k} \Psi_i(dk) dF_k - \varepsilon_i E_{b.i} F_i \qquad (1)$$

$Q_{net.i}$ is the net radiative heat exchange for surface i

$Q_{abs.i}$ is the heat absorbed by the surface

$Q_{e.i}$ is the heat radiated by the surface

α_i is the absorptivity of surface i

$E_{eff,k}$ is the effective radiative forcing of surface k

$\Psi_i(dk)$ is the view factor from face k to face i

F_i is the area of surface i

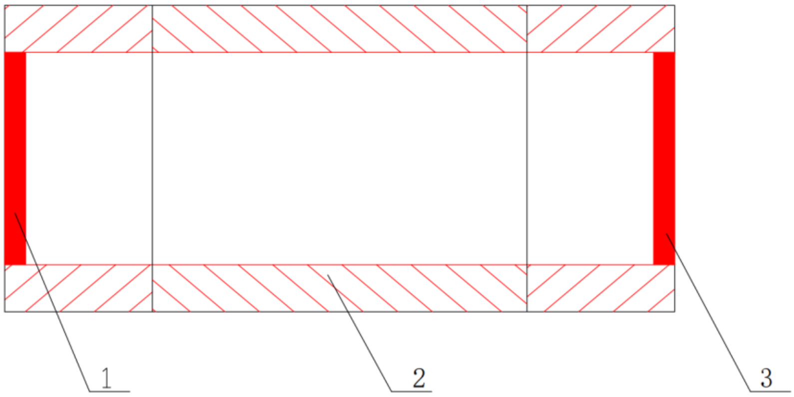
ε_i is the emissivity of the surface

$E_{b.i}$ is the radiative forcing of surface i

The following assumption can be made according to the equipment setup:

1) The heat source and the chamber are blackbody.

2) The temperature on the surface of the heat source, chamber, and object to be measured (receptor) is uniform.



Schematic diagram of the measuring system

1. heat source 2. conduction chamber 3. object to be measured

With these assumption and equation 1,

we may get:

$$Q_{net,3} = \alpha_3\left(E_{b,1}F_1\Psi_{1,3} + E_{b,1}F_1\Psi_{2,3}\right) - \varepsilon_3 E_{b.3}F_3 \tag{2}$$

As F_1=F_3, $\Psi_{3,2} = \Psi_{1,2}$, $F_2\Psi_{2,3}$= $F_3\Psi_{3,2}$

$\alpha_3 = \varepsilon_3$ (Kirchhoff's Law of thermal radiation)

we may get:

$$\begin{aligned} q_3 = \frac{Q_{net,3}}{F_3} &= \varepsilon_3\left(E_{b,1}\Psi_{1,3} + E_{b,2}\Psi_{1,2}\right) - \varepsilon_3 E_{b.3} \\ &= \varepsilon_3\left(E_{b,1}\Psi_{1,3} + E_{b,2}\Psi_{1,2} - E_{b.3}\right) \end{aligned} \tag{3}$$

As the heat source, chamber and receptor form a closed system in geometry:

$$\Psi_{1,3} + \Psi_{1,2} = 1$$

Assume the temperature of the heat source and chamber are the same:

$$E_{b,1} = E_{b,2} = \sigma {T_1}^4$$

$$E_{b,3} = \sigma {T_3}^4$$

We may get:

$$q_3 = \varepsilon_3\left(E_{b,1} - E_{b.3}\right) = \varepsilon_3\sigma(\sigma T_1^4 - \sigma T_3^4) \tag{4}$$

Since the receptor is in thermal equilibrium with the environment through natural convection, we may get:

$$q_3 = \alpha_d(T_3 - T_0) \tag{5}$$

Where α_d is the convection heat transfer coefficient, T_3 is the temperature of the receptor and T_0 is the environment temperature.

Combing equations (4) and (5),

We may get:

$$\varepsilon_3 = \frac{\alpha(T_3 - T_0)}{\sigma(T_1^4 - T_3^4)} \tag{6}$$

If we have two different objects to be measured (receptors) a, b with different emissivity:

$$\varepsilon_a = \frac{\alpha_a(T_{3a} - T_f)}{\sigma(T_{1a}^4 - T_{3a}^4)} \tag{7}$$

$$\varepsilon_b = \frac{\alpha_b(T_{3b} - T_f)}{\sigma(T_{1b}^4 - T_{3b}^4)} \tag{8}$$

If we assume the environment does not change during the experiment, approximately, $\alpha_a = \alpha_b$, then:

$$\frac{\varepsilon_a}{\varepsilon_b} = \frac{T_{3a} - T_0}{T_{3b} - T_0} \cdot \frac{T_{1b}^4 - T_{3b}^4}{T_{1a}^4 - T_{3a}^4} \tag{9}$$

When b is a blackbody, $\varepsilon_b \approx 1$, so the emissivity of object a is:

$$\varepsilon_a = \frac{T_{3a} - T_0}{T_{3b} - T_0} \cdot \frac{T_{1b}^4 - T_{3b}^4}{T_{1a}^4 - T_{3a}^4} \tag{10}$$

In this experiment, we use a comparative method to determine the emissivity of the object.

III. Data recording and processing

1. Record the experimental parameters on the datasheet, calculate the emissivity, and write out the detailed calculation process.

No.	Heat source(°C)	Chamber(°C)		Receptor (Smooth coppersurface) (°C)	Room Temperature(°C)
		1	2		
1	85.8	83.1	87.3	44.1	24.1
2	86.1	83.2	87.3	44.2	24.1
3	85.8	83.3	87.4	44.3	24.1
Averaged (°C)	85.9	83.2	87.3	44.2	24.1
No.	Heat source(°C)	Chamber(°C)		Receptor (Blackened coppersurface) (°C)	Room Temperature(°C)
		1	2		
1	85.6	84.9	89.2	49.3	24.8
2	85.8	84.8	89.1	49.2	24.9
3	85.5	84.7	89.1	49.3	25.0
Averaged (°C)	85.6	84.8	89.1	49.3	24.9
Emissivity	$\varepsilon_a=\frac{T_{3a}-T_0}{T_{3b}-T_0}\cdot\frac{T_{1b}{}^4-T_{3b}{}^4}{T_{1a}{}^4-T_{3a}{}^4}=\frac{44.2-24.1}{49.3-24.9}\cdot\frac{(85.6+273.15)^4-(49.3+273.15)^4}{(85.9+273.15)^4-(44.2+273.15)^4}=0.7318$				

2. Discuss the result and make a conclusion.

   Based on the following assumptions:

   1)The heat source and the chamber are blackbody.

   2)The temperature on the surface of the heat source, chamber, and receptor is uniform.

   3)The environment does not change during the experiment.

4)receptor b is a blackbody.

With the approximately same and stable temperatures of the heat source and chamber, using a comparative method, we obtain the emissivity of the object (copper) at 44.2℃ as 0.7318.

IV.Questions

1 . Search related materials for the emissivity of copper, compare and analyze with the experimental results, and discuss the source of experimental error.

The emissivity of copper is as follows:

Copper	Temp℉ （℃）	Emissivity
Cuprous Oxide	100 (38)	0.87
Cuprous Oxide	500 (260)	0.83
Cuprous Oxide	1000 (538)	0.77
Black, Oxidised	100 (38)	0.78
Etched	100 (38)	0.09
Matte	100 (38)	0.22
Roughly Polished	100 (38)	0.07
Polished	100 (38)	0.03
Highly Polished	100 (38)	0.02
Rolled	100 (38)	0.64
Rough	100 (38)	0.74
Molten	1000 (538)	0.15
Molten	1970 (1077)	0.16
Molten	2230 (1221)	0.13
Nickel Plated	100-500 (38-260)	0.37

Emissivity-Chart-139697ART.pdf (kleintools.com)

The sources of experimental error are as follows:

1) The heat source, the chamber, and receptor b are assumed to be blackbodies.
2) The environment could not be the same during the experiment, which means the T_0 is changeable.
3) During the experiment, the temperature of the heat source and chamber always fluctuated. When the fluctuation range is small, reading the value and

then taking the average value for calculation will lead to errors.

4) The degree of blackening of the receptor surface (the thickness of smoke) may be different when the receptor surface is blackened by candle smoke.
5) The position of the receptor after the reinstallation is different from that before, and there may be gaps in the junction compared with that before.

2 . Discuss whether the use of different heating power can affect the experimental results.

Emissivity is only related to the object emitting it, not to external conditions. It depends on the properties of the object, the temperature of the object, the surface state, the wavelength of the radiation, and the direction.

Using different heat source power will produce different heat source temperatures, after the recorded data is stable, the temperature of receptors will be different, so the use of different heating power will affect the experimental results.

The experimental data

1. Record the experimental parameters on the datasheet, calculate the emissivity, and write out the detailed calculation process.

No.	Heat source (°C)	Chamber(°C)		Receptor (Smooth copper surface) (°C)	Room Temperature (°C)
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Emissivity					

2. Discuss the result and make a conclusion.

VI. Questions

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