

Steady-state Calorimetry Measurement Method for Total Hemispherical Emissivity of Thermal Insulating Coating

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Abstract. The steady-state calorimetry technique was used to measure the total hemispherical emissivity of thermal insulating coating, after testing the the total hemispherical emissivity of thermal insulating coatings, the result showed that with the gradual increase of the test temperature, the hemispherical emissivity of heat insulation coating decreases as a whole, and with the increase of temperature, the radiation ability of heat insulation coating is reduced.

1. Introduction

The total hemispherical emissivity is an important thermo physical parameter for radiation thermal analyses in engineering applications and scientific research. The total hemispherical emissivity can be measured using radiometric or calorimetry techniques. Calorimetry techniques are commonly used due to their accuracy and simplicity for transient and steady-state measurements [1-3]. For the steady-state calorimetry measurement method, the radiation heat flux from the sample to the environment is measured when the sample reaches the desired steady-state temperature. The total hemispherical emissivity is calculated from a simple energy balance for the steady-state conditions. Various studies have used the steady-state calorimetry technique to measure the total hemispherical emissivity at various temperatures. Govinda et al. [4] used a steady-state calorimetry technique to estimate the emittance of Aeroglaze Z307 thermal control coating in the temperature range 80 K to 150 K and PUC thermal coating in the temperature range 70 K to 200 K. The results present that the emittance of Aero glaze Z307 coating varied from 0.751 to 0.840 and the emittance of PUC coating varied from 0.619 to 0.762. Wang et al. used the steady-state calorimetric bolometer, the total hemispherical emittance of optical solar reflector and a new variable emittance material were measured between 190 K and 350 K. Tang et al. constructed the steady-state calorimetric bolometer to measure the total hemispherical emittance of materials in the temperature range from 173 to 373 K.

This study analyzes the steady-state calorimetry technique for measuring the total hemispherical emissivity of thermal insulating coating. The emissivity was measured in a small central region in a vacuum chamber.



2. Test

2.1. Experiment apparatus

The schematic of the experiment apparatus used in this work is shown in Fig.1. The steady-state calorimeter hemisphere emissivity apparatus consists of a vacuum chamber 1, a constant temperature cooling device 2, a sample heating component 3, a vacuum device 4, a data measurement and processing device 5, and a test host. The vacuum chamber 1 includes a vacuum cover 11, a flange 12 and a heat sink 13. One side of the heat sink 13 and the flange 12 constitute a vacuum test space, and a cooling medium passage 14 is left between the outward facing surface and the inner wall of the vacuum cover 14. The constant temperature cooling device 2 communicates with the cooling medium passage 14 of the vacuum chamber 1 through a pipeline, which generates a cooling medium and exchanges heat with the heat sink to keep the temperature of the heat sink constant. The sample heating component 3 is set in the vacuum chamber 1, and the sample to be tested is placed on the sample heating component 3, and heated by the sample heating component 3. The vacuum device 4 is connected with the vacuum test space of the vacuum chamber 1, and is used for vacuuming the vacuum chamber 1. The data measurement and processing device 5 is used to measure the data of the tester running. When the sample temperature reaches the preset temperature and the vacuum chamber keep a state of thermal stability, the total hemispherical emissivity ϵ_H of the sample is calculated.

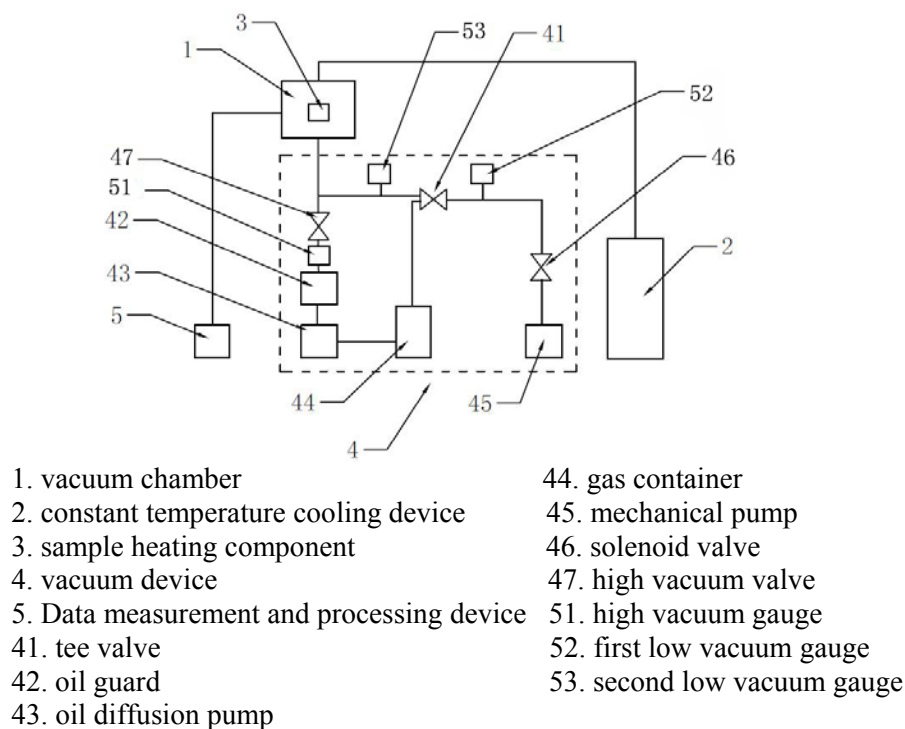


Figure 1. Schematic of the experimental apparatus

A lifting pin 15 fixed on the outer wall of the vacuum cover 11 is connected with a power unit, the power unit is electrically connected with the ascending button and falling button. By controlling the rise or fall of operator button on the lifting pin 15, to control the vacuum chamber 11 moves up and down. The heat sink 13 toward the side of the coated matte black paint, and the coolant channel 14 is provided with a coolant inlet 16 and a coolant outlet 17. The cooling medium which is from the constant temperature cooling device 2 through the coolant inlet 16 into the coolant channel 14 that heat exchange with the heat sink 13 to maintain the temperature of the heat sink 13, and through the coolant outlet 17 back the constant temperature cooling device 2.

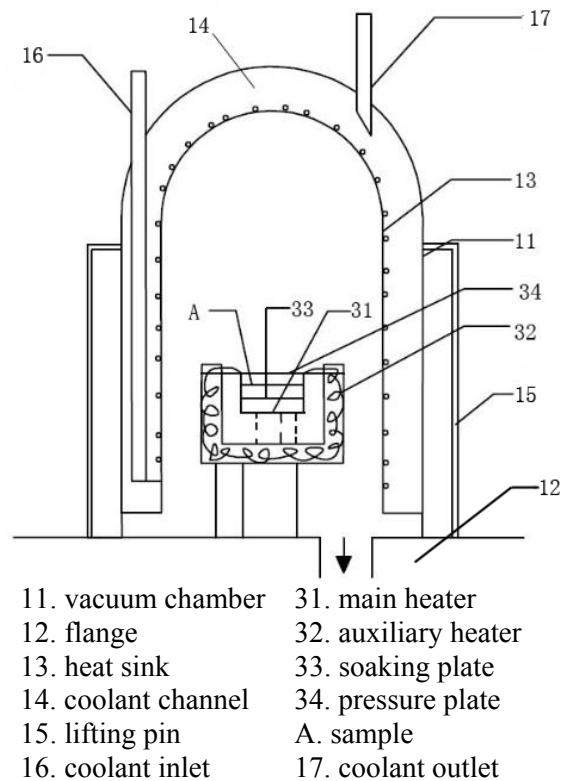


Figure 2. Schematic of the experimental vacuum chamber



Figure 3. View of the experimental apparatus

2.2. Test procedure

The test sample assembly is suspended inside the steady-state calorimeter hemisphere emissivity apparatus (as shown in Fig.1) and all connections are made before closing the vacuum chamber. Throughout this experiment the vacuum pumps maintain the pressure 1.0×10^{-3} Pa. When the test needs to use the heat insulation coating (CY-6000 type nano heat insulation coating, a Guangdong paint company) covering the aluminum substrate for $40\text{mm} \times 40\text{mm} \times 1\text{mm}$ on the preparation of test samples. The specific steps are as follows: firstly, put the sampler, beaker, glass rod, aluminum plate size $40\text{mm} \times 40\text{mm} \times 1\text{mm}$ using deionized water to clean and dry reserve. Secondly, the mixing heat insulation coating uniform scraping appropriate thickness of the layer in the surface of the aluminum

plate, ensure that the film surface is smooth, no bubbles, cracks, bump no obvious defects appear. Thirdly, scrap good samples in curing box at 7 days, and observe whether the dry film surface appears defects. Finally, the trapped sample was put into the instrument for testing. In the process of sample preparation, we should ensure that the temperature is 23 ± 2 °C, and the relative humidity is $50 \pm 5\%$ conditions, at the same time we should ensure good maintenance of the preparation sample surface.

It is difficult to precisely control the thickness of the coating in the process of sample preparation. In order to study the effect of the thickness of hemispherical emissivity, the optimal thickness range, the heat insulation coating made of coating thickness range of three samples 0.040 mm, 0.100 mm, 0.200 mm, in respectively. The dry film thickness is measured as shown in Table 1.

Table 1. Thickness of Sample

No.	Thickness of aluminium alloy plate(mm)	Thickness of Sample(mm)	Dry film thickness(mm)
A1	1.283	1.324	0.041
A2	1.521	1.557	0.036
A3	1.370	1.418	0.048
B1	1.442	1.559	0.117
B2	1.241	1.334	0.093
B3	1.364	1.470	0.106
C1	1.365	1.560	0.195
C2	1.488	1.700	0.212
C3	1.426	1.655	0.229
D	1.357	0	0

3. Result and Discussion

A detailed theoretical approach for the analysis of the experimental data to estimate the total hemispherical emissivity is presented in this section. In the steady-state calorimetric method, the test sample assembly is suspended in a vacuum chamber, and the emittance is determined based on an energy balance with the shroud. Assuming that the test sample assembly and shroud are diffuse (emitters and reflectors), the following expression is obtained:

$$\varepsilon_H = \frac{\frac{V_1}{R}V}{\sigma A(T^4 - T_0^4)}$$

Where ε_H is the total hemispherical emissivity, σ is the Stephen-Boltzmann constant (5.67×10^{-8} W/(m²•K⁴), V_1 is the terminal voltage of standard resistor(V), V is the terminal voltage of main heater(V), R is the resistance value of standard resistance(Ω), A is the Specimen radiation surface area(m²), T is the Sample temperature(K), T_0 is the average temperature of inner surface of heat sink(K).

Hemisphere emissivity ε_H reflects the radiation material at a certain temperature which take the average value in different three temperature tests. The measured values of hemispherical emissivity are different at two different temperatures, indicating that the change of temperature has a certain influence on the hemispherical emissivity of heat insulation coatings. This is mainly caused by two reasons: at first, the change of the temperature break the structure components and thermal stability of thermal insulation coatings, resulting in changes in hemisphere emissivity; at last, the hemispherical emissivity of heat insulation coating change with the temperature change. With the gradual increase of the test temperature, the hemispherical emissivity of heat insulation coating decreases as a whole, and with the increase of temperature, the radiation ability of heat insulation coating is reduced.

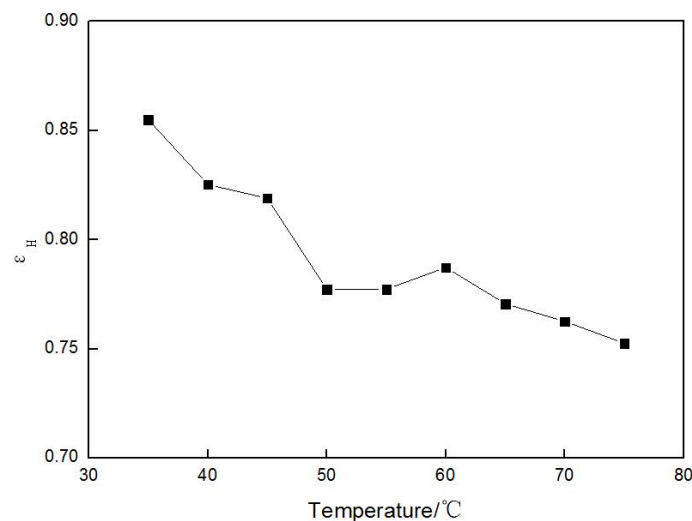


Figure 4. Hemisphere emissivity ϵ_H in different temperature

4. Conclusion

The steady-state calorimetric technique was used to measure the total hemispherical emissivity of thermal insulating coating, after testing the total hemispherical emissivity of thermal insulating coatings, the result showed that with the gradual increase of the test temperature, the hemispherical emissivity of heat insulation coating decreases as a whole, and with the increase of temperature, the radiation ability of heat insulation coating is reduced.

Acknowledgments

This work is supported by Guangdong Provincial Science and Technology Plan Program of China (2015A030401059) and (2017A040402005).

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