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Measurement of emissivity of a non-black test plate surface: An experimental study

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ABSTRACT

An ideal black surface is one which absorbs all the incident radiation on it with no part of it being reflected or transmitted. The following study elucidates the procedure to find out the emissivity of a non-black test plate surface. Through detailed theoretical analysis and experimental results it was observed that the emissivity of a body is a function of the surface temperature of the body, the ambient temperature, and the surface area of the body.

Keywords: Black body, radiation, emissivity

THEORY

An ideal black surface is one which absorbs all the incident radiation with reflectivity and transmissivity equal to zero. The radiation per unit time per unit are from the surface of the body is called as emissive power. The emissivity of a surface is the ratio of the emissive power of the surface to the emissive power of a black surface at the same temperature.

When radiant energy falls on a body, part may be absorbed, part reflected, and the reminder transmitted through the body. In mathematical from :

$$\alpha + \rho + \tau = 1$$

Where α = absorptivity or the fraction of the total energy absorbed.

ρ = reflectivity of the fraction of the total energy reflected.

τ = transmissivity or the fraction of the total energy transmitted through the body.

For the majority of opaque solid materials encountered in engineering except for extremely thin layers, practically none of the radiant energy is transmitted through the body. if the discussion is limited to opaque bodies the above mathematical from becomes :

$$\alpha + \rho = 1$$

An arrangement which will absorb all the radiant energy at all wavelengths and reflect none is called perfect black body. Actually no material with $\alpha = 1$ and $\rho = 0$ exists. Even the blackest surface occurring in nature still have reflectivity of about 1% ($\rho = 0.01$). The physicist G. Kirchhoff, however, conceived the following possibility of making a practically perfect black body. If a hollow body is provided with only one small opening, and is held at uniform temperature, then any beam of radiation entering by the hole is partly absorbed, and partly reflected inside. The reflected radiation will not find outlet, but will fall again on the inside wall. There it will be only partly reflected and so on. By such a sequence of reflections the entering radiation will be weakened so much that almost no part of it will leave the hole. Thus the area of the hole is like a perfectly absorbing surface, and an arrangement of this kind will act just as a perfect black body. It may be considered a measure by which the absorptivity of any substances may be determined.

Any hot body maintained by a constant heat source, loses heat to surroundings by conduction, convection and radiation. If two bodies made of same geometry are heated under identical conditions, the heat loss by conduction and convection can be assumed same for both the bodies, when the difference in temperatures between these two bodies is not high. In such a case, when one body is black & the other body is gray from the values of different surface temperatures of the two bodies maintained by a constant power source emissivity can be calculated. The heat loss by radiation depends on:

a) Characteristic of the material
b) Geometry of the surface and
c) Temperature of the surface

If a body is losing heat to the surrounding atmosphere, then the area of atmosphere A2 >> area of body A1. Thus if any body is loosing heat by radiation to the surrounding atmosphere equation (1) takes the form.

$$Q = \sigma A1 \varepsilon (T41 - T42)$$

where, σ = Stefan Boltzmann constant = 5.6697 x 10-8 W/m² K4
A1 = Surface area in m²
ε = Emissivity
T1 = surface temperature of the body in K and
T2 = surrounding atmospheric temperature in K

Let us consider a black body & a gray body with identical geometry being heated under identical conditions, assuming conduction & convection heat loss to remain the same. Let Qb and Qg be the heat supplied to black & gray bodies respectively.

If heat input to both the bodies are same,
Qb = Qg
Assuming, heat loss by conduction and convection from both bodies to remain same.

Heat loss by radiation by the black body = heat loss by radiation by the gray body

$$\sigma \times Ab \times \varepsilon b \times (T4b - T4a) = \sigma \times Ag \times \varepsilon g \times (T4g - T4a)$$

As geometry of two bodies are identical,
A = Ag = Ab and εb = 1 for black body.

Therefore,
$$\varepsilon g = \frac{(T^4_b - T^4_a)}{(T^4_g - T^4_a)}$$

Where,
Suffix 'b' stands for black body,
Suffix 'g' stands for gray body,
Suffix 'a' stands for ambient.

EXPERIMENTAL SETUP

The experimental set up consists of two circular brass plates of identical dimensions. One of the plates is made black by applying a thick layer of lamp black while the other plate whose emissivity is to be measured is a gray body. Heating coils are provided at the bottom of the plates. The plates are mounted on asbestos cement sheet and kept in an enclosure to provide undisturbed natural convection condition. Three thermocouples are mounted on each plate to measure the average temperature. One thermocouple is in the chamber to measure the ambient temperature or chamber air temperature. The heat input can be varied with the help of variac for both the plates, that can be measured using digital volt and ammeter.

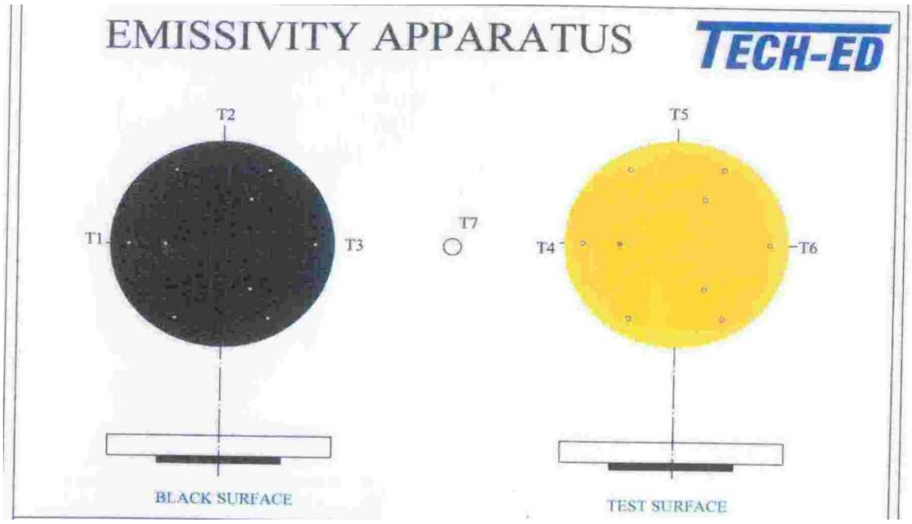

Figure 1. Schematic of the experimental setup.

SPECIFICATIONS

Specimen material	: Brass
Specimen Size	: ϕ 150 mm, 6 mm thickness (gray & black body)
Voltmeter	: Digital type, 0-300v
Ammeter	: Digital type, 0-3 amps
Dimerstat	: 0-240 V, 2 amps
Temperature Indicator	: Digital type, 0-300°C, K type
Thermocouple Used	: 7 nos.
Heater	: Sand witched type Nichrome heater,400 W

PROCEDURE

- Switch on the electric mains.
- Operate the Dimerstat very slowly and give same power input to both the heaters say 50 V by using/operating cam switches provided.
- When steady state is reached note down the temperatures T1 to T7 by rotating the temperature selection switch.
- Also note down the volt & ammeter reading
- Repeat the experiment for different heat inputs.

OBSERVATION TABLE

1. Diameter of the test surface plate = 0.15 m.
2. Stefan Boltzmann Constant = 5.67×10^{-8} W/m^{2}K^4
3. Emissivity of Black surface plate $\varepsilon b = 1$

Table 1: Same Heat Input Value

S. No.	Heater input			Temperature of black surface °C			Temperature of gray surface °C			Chamber Temperature °C
	V	I	V x I Watts	T_1	T_2	T_3	T_4	T_5	T_6	T_7
1.				62	62	61	41	41	41	31
2.				65	65	65	56	56	55	32
3.	61	0.26	15.86	67	67	67	65	65	65	34
4.				68	68	68	69	69	69	35
5.				69	69	69	71	71	71	36
6.				70	70	70	74	74	74	36
7.				71	71	71	76	76	76	37

Table 2: Different Heat Input Value

S. No.	Heater input			Temperature of black surface °C			Temperature of gray surface °C			Chamber Temperature °C
	V	I	V x I Watts	T_1	T_2	T_3	T_4	T_5	T_6	T_7
1.	50	0.21	10.5	60	60	60	63	63	63	34
2.	53	0.22	11.66	60	59	59	64	64	64	34
3.	54	0.24	12.96	49	50	49	51	52	52	28
4.	61	0.26	15.86	71	71	71	76	76	76	37
5.	65	0.29	18.85	66	66	66	72	72	72	35

CALCULATIONS

1. Temperature of the black body

$$T_b = \frac{(T_1 + T_2 + T_3)}{3} + 273.15 \quad K$$

2. Temperature of the gray body

$$T_g = \frac{(T_4 + T_5 + T_6)}{3} + 273.15 \quad K$$

3. Ambient temperature

   Ta = (T7 + 273.15) K

4. Heat input to the coils = V x I watt
5. Emissivity of gray body,

$$\varepsilon g = \frac{(T^4_b - T^4_a)}{(T^4_g - T^4_a)}$$

RESULTS

S. No.	Heat Input of Test surface(W)	Avg. test plate temperature (K)	Emissivity of test plate
1.	15.86	342.15	0.9659
		344.15	0.9339
		347.15	0.8779
		349.15	0.8514

S. No.	Heat Input of Test surface(W)	Avg. test plate temperature (K)	Emissivity of test plate
1.	10.50	336.150	0.8837
2.	11.66	337.150	0.8257
3.	12.96	324.817	0.8911
4.	15.86	349.150	0.8514
5.	18.85	345.150	0.8142

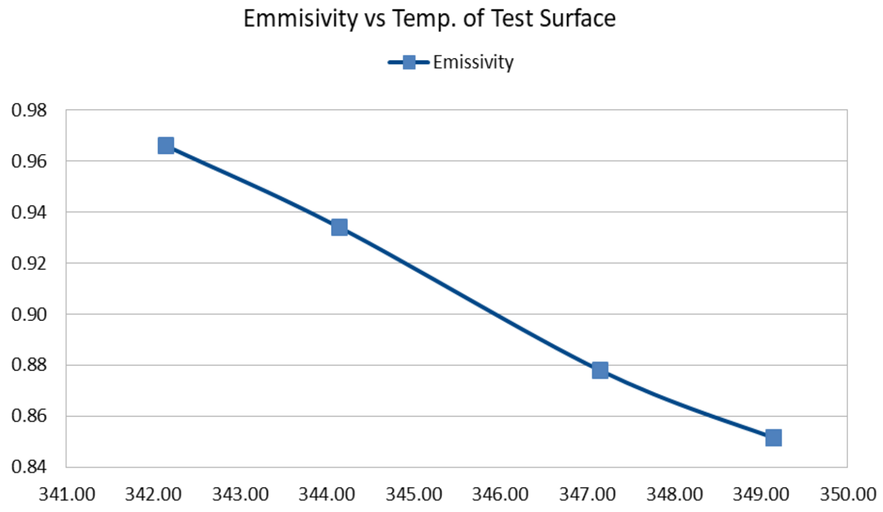

Figure 2. Emissivity as a function of temperature for same heat input values.

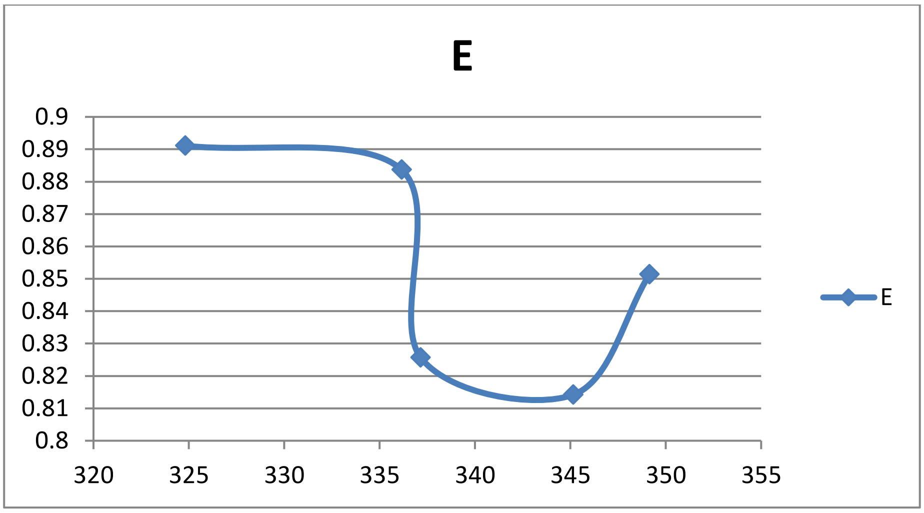

Figure 3. Emissivity as a function of temperature for different heat input values.

CONCLUSION

Thus we have successfully measured the emissivity of the gray body at different temperatures using the fundamental principle of radiation using the Stefan Boltzmann Law whose value comes out to be **0.8514**.

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