THE BLACKBODY BUILDING AND ITS EXPERIMENTAL EMISSIVITY MEASUREMENT IN THE INFRARED REGION

M. R. Shaeri and K. Jafarpur

Mechanical Engineering Department
School of Engineering, Shiraz University 71345, Shiraz, Iran

Corresponding author, E-mail: mrshaeri@yahoo.com

INTRODUCTION

A blackbody is an ideal body that absorbs all of the radiation that falls onto it; no radiation passes through and no radiation is reflected, as well[1]. At a given temperature, a blackbody emits the maximum possible amount of energy. This is true for radiation at all wavelengths and angles of incidences. In an on-going research, it was needed to build a blackbody. This poster is the report of the part of experiments done to validate the performance of the built blackbody. To do so and before presenting the experimental data, the theoretical background needed for the comparison will be briefly reviewed.

THEORETICAL BACKGROUND

The material and the notations used here are those given by[5], in their thermal radiation heat transfer book[5]. A quantity designated by $A'_{\lambda b}(\lambda,\theta,\phi,T)$ shows that $A'_{\lambda b}$ depends on four variables of wavelength λ, solid angles θ,ϕ and temperature T. The prime denotes a directional quantity and the subscript λ indicates that $A'_{\lambda b}$ is a spectral quantity, as well. More over the "b" in subscript stands for blackbody. An important law about blackbody is *Planck's distribution law*. This law states that for a blackbody, the spectral distributions of hemispherical emissive power and radiant intensity in vacuum are a function of wavelength and the blackbody's absolute temperature. This function is given by[5]:

$$e_{\lambda b}(\lambda,T)=\pi i'_{\lambda b}(\lambda,T)=\frac{2\pi C_1}{\lambda^5\left(e^{C_2/\lambda T}-1\right)} \qquad (1)$$

Where $C_1=hc_0^2$ and $C_2=h\frac{c_0}{k}$. h and c_0 are Planck's constant and light speed in the vacuum, respectively. In addition, k is the *Boltzmann constant*. For a body at low temperature, only a very small amount of energy is in the visible region (0.4 - 0.7 μm) and it is very difficult to be detected. Blackbodies almost below 700K produce very little radiation at visible wavelength and appear black. Blackbodies above this temperature however, start to produce radiation at visible wavelengths starting at red, going through orange, yellow and white before ending up at blue as the temperature increases. Thus as mentioned before blackbody not necessarily will look black in color. Integration from $i'_{\lambda b}(\lambda)$ over all wavelengths gives the total intensity, $i'_b=\int_0^\infty i'_{\lambda b}(\lambda)d\lambda$ We can solve this integral by substitution of *Planck's* distribution from equation (1). This is evaluated as[5]: $i'_b = \frac{\sigma}{\pi}T^4$

where $\sigma = \frac{2C_1\pi^5}{15C_2^4} = 5.67051\times10^{-8}\, W/\left(m^2.K^4\right)$

EMISSIVITY

Emissivity as a surface property shows that how a real body radiates energy in comparison with a blackbody at the same temperature. The emissivity depends on factors such as wavelength, body temperature, angle of emission and type of surface. The most general emissivity is directional spectral emissivity: $\varepsilon'_\lambda(\lambda,\theta,\phi,T) = \frac{i'_\lambda(\lambda,\theta,\phi,T)}{i'_{\lambda b}(\lambda,T)} = \frac{e'_\lambda(\lambda,\theta,\phi,T)}{e'_{\lambda b}(\lambda,\theta,T)}$

Unlike the intensity from a blackbody, the emitted intensity from a real body does depend on direction, and the (θ,ϕ) designation is included in the notation[5]. It is clear that for a blackbody $\varepsilon = 1$. We can specify types of emissivity such as hemispherical spectral, directional total and hemispherical total emissivity.

EXPERIMENT

The main structure of the blackbody made in the lab is of the type suggested in[4]. It consisted of a cupper elbow 3 inch in diameter and one small opening at one end to form a cavity. Radiation incident upon the hole from the outside enters the cavity and strikes the internal walls; a part is absorbed and the remainder being reflected. The reflected portion strikes other parts of the walls and is again partially absorbed. It is clear that if the cavity opening is very small, very little of original incident beam will escape through the opening. Therefore the opening area approaches the behavior of a black surface because essentially all the radiation passing through it is absorbed[5]. The inside surface temperature could be vary and reach to $400^\circ C$ .Figure 3 shows the built blackbody. The heating element and the insulation around the body were designed to produce an uniformly heated inside surface. The fact that the heated surface can reach $400^\circ C$ explains the body radiation limitation only in the infrared (IR) region. $(1-100\mu m)$. An IR photomultiplier was used to measure the energy at each wavelength at four different temperatures of 250, 300, 350 and $400^\circ C$. The results obtained are for the normal direction.

RESULTS

Figure 4 show the normal directional spectral emissivity at four different temperatures. Due to the last explanations none of the curves include the visible region. It is seen that the maximum error is 2.12%, 2.35%, 2.94% and 3.57% for 250 , 300 350 and 400°C respectively. With having the emissivities, the intensity can be obtained easily from equation (1) at each wavelength. The results are below. Figures 5a to 5d show the intensity with comparison between *Planck's* distribution law, equation (1), at the same temperature. It is clear that the obtained energy is the normal directional spectral intensity. The area under each curve gives the total intensity in the normal direction in the IR region. By integration of *Planck's* distribution and experimental curve in each diagram we can obtain normal directional total intensity in the IR region. The fraction of these energies at each temperature gives the normal directional total emissivity in the IR region at each temperature. The results are in Table 1. The obtained experimental results in each part show good agreement with theory. Therefore all of the energy reaches to the photomultiplier detector and emissivity is equal to one. At the second part of the determination of emissivity, a good agreement can be seen between the experimental results and *Planck's* distribution law. During four stages of measurements, the maximum error is 3.57% for the normal directional spectral emissivity and 6.6% for the normal directional total emissivity in the IR region. Moreover, the obtained results show that the built blackbody functions properly and its behavior matches very well with the theory.

Fig 1	Fig 2	Fig 3	Table 1
The built blackbody	Measured normal directional spectral emissivity	Comparison between experimental and ideal blackbody	Comparison of normal directional total intensity between experimental and ideal blackbody

Fig 1

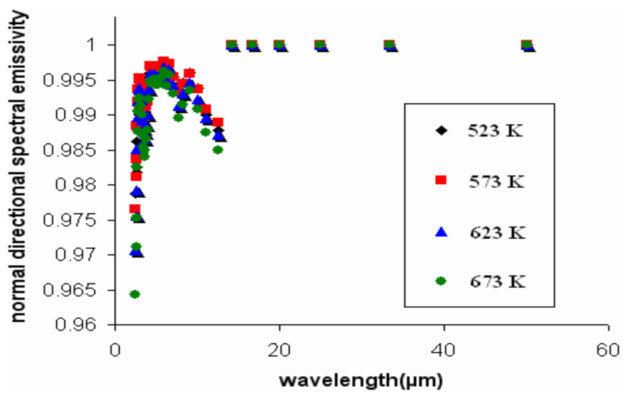

Fig 2

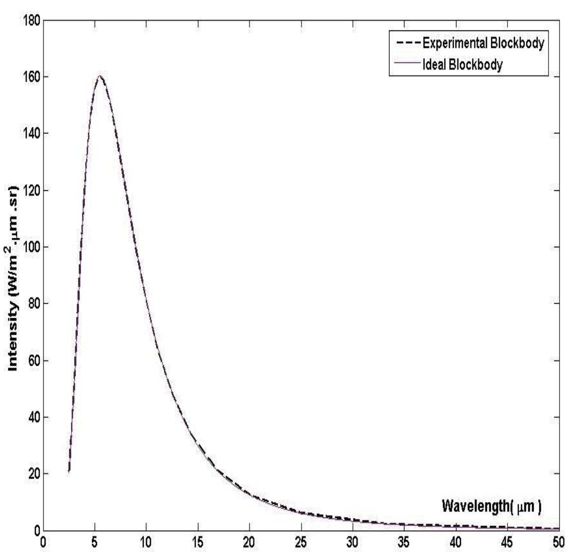

Fig 3a

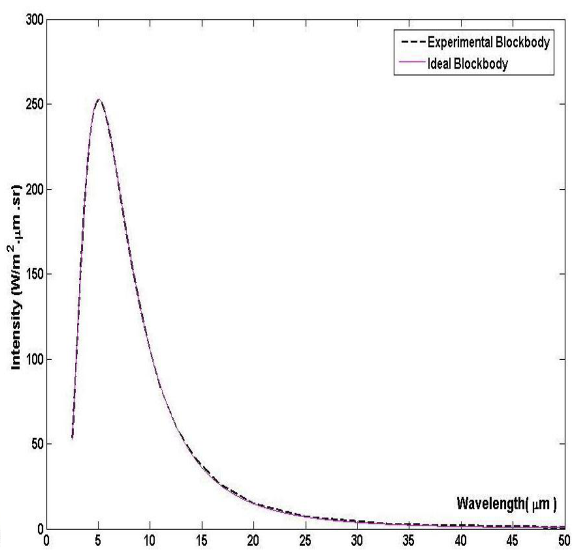

Fig 3b

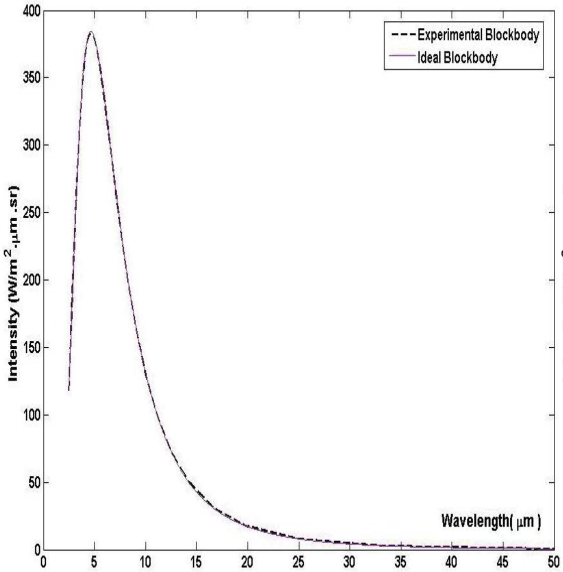

Fig 3c

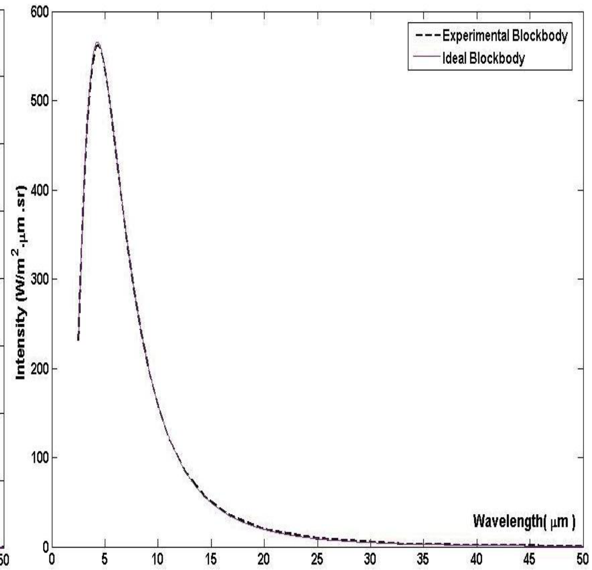

Fig 3d

Table 1

Temperature $^\circ C\ (K)$	Ideal blackbody - intensity $\left(\frac{W}{m^2.sr}\right)$	Experimental blackbody intensity $\left(\frac{W}{m^2.sr}\right)$	Error $(\%)$	Normal directional total emisivity in $(2.5-50\mu m)$
250 (523)	1334.99	1246.88	6.60	0.9340
300 (573)	1917.34	1864.73	2.74	0.9726
350 (623)	2662.58	2658.14	0.17	0.9983
400 (673)	3590.76	3588.18	0.072	0.9993

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