Experimental Validation of Kirchhoff's Law of Radiation

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Abstract – *The importance of Kirchhoff's law for radiation analysis is equivalent to the importance of Newton's law for mechanics. But still the law is not usually validated and even challenged about its validity. In present work, we have proposed an experimental setup and a procedure to validate the law. For this we are using first law of thermodynamics and Stefan Boltzmann law as basis law to develop the experimental procedure.*

***Key Words*: Kirchhoff's law, emissivity, absorptivity, radiation heat transfer, Blackbody**

1. INTRODUCTION

In heat transfer, Kirchhoff's law of thermal radiation refers to wavelength-specific radiative emission and absorption by a material body in thermodynamic equilibrium. A body at temperature T radiates electromagnetic energy. A perfect black body in thermodynamic equilibrium absorbs all Radiation that strikes it, and radiates energy according to a unique law of radiative emissive power for temperature *T*, universal for all perfect black bodies. Kirchhoff's law states that: For a body of any arbitrary material emitting and absorbing thermal electromagnetic radiation at every wavelength in thermodynamic equilibrium, the ratio of its emissive power to its dimensionless coefficient of absorption is equal to a universal function only of radiative wavelength and temperature. That universal function describes the perfect black-body emissive power. In simple words Kirchhoff's law states that the ratio of emissive power of grey body to emissive power of black body is equal to the ratio of energy absorbed by that grey body to energy incident on the same body for a given temperature. As the ratio of energy absorbed to energy incident is termed absorptivity (α). The ratio of emissive power of grey body to the emissive power of black body at a given temperature is termed as emissivity (ε). The theoretical treatment and formal proof of Kirchhoff's law is given by many physicists and is available in corresponding literature.

2. THE EXPERIMENT

2.1 Construction of Experiment

Kirchhoff proposed a thought experiment to validate his law. We have used that thought experiment as our basis to make setup. The assembled setup has an air tight wooden chamber which encloses the assembly of inner sphere inside the outer sphere. There are two geometrically identical spheres one is coated with black paint which acts as experimental blackbody and other one is fray body. Due to spherical shape, all emission of inner sphere is incident on the outer sphere and so face factor of inner body w.r.t. outer body becomes one. Also as the inner surface of outer body is coated to act as black surface the emission of inner sphere will not get reflected back to itself so face factor of inner body w.r.t. itself becomes zero. For heating these bodies we have used two heaters viz. fin type air heater for heating outer sphere and a clamp heater for inner sphere. For the radiation mode of heat transfer to dominate between the bodies during experimentation there should not be any medium to occur conduction and convection. So to reduce conduction, we suspended the inner sphere in outer with a Bakelite strip. Also we made vacuum in the annular space to retard the heat flow by convection.

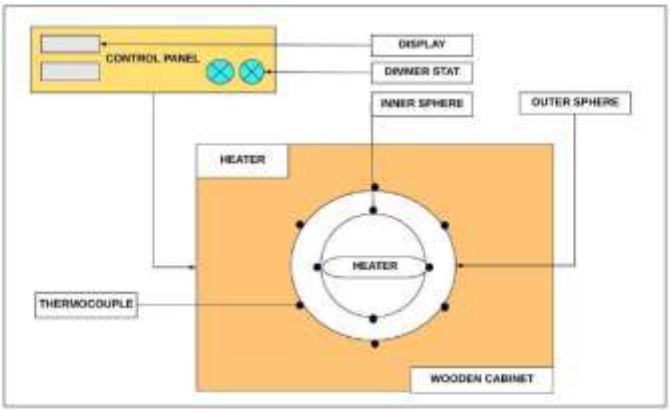

Fig -1: Sketch of setup

Table -1: Specification of apparatus

Specifications	
Name	Descriptions
Inner sphere	Mass 700 gram
Outer sphere	Mass 3 kg
Clamp heater	Power watt 250
Fin type of air heater	Power watt 1000

2.2 Measuring instruments and Control switches

We need temperature and time readings as the base of our calculations. So we have added measuring instruments like ammeter, voltmeter, thermocouples and temperature indicator. The most important thing in experimentation is to maintain temperature for this there is dimmer stat to each of the heater.

Table -2: Specification of measuring instruments.

Specifications	
Name	Descriptions
Thermocouple	K type
Temperature indicator	12 channel
Dimmer stat	Rating 2000W for both heater

2.3 Experimental Procedure

Calculation Procedure

First the inner sphere is heated and maintained to a steady state temperature (T_o).

$$\mathbf{Mo \times C \times (\Delta T \text{ in time } t) = \varepsilon \times \sigma \times T_0^{\,4} \times Ac \times (t)}$$

$\Delta T = T_{final} - T_{initial}$
$T_{initial}$ – Temperature at start of time 't'.
T_{final} – Temperature after time 't'.
t – allotted time. In our experiment 10 min
Mo – mass of outer sphere
C – Heat required to raise the temperature of Copper per unit mass by 1°C
ε – Emissivity of gray body

Ac – curved surface area of grey surface
'ε' can be found here.

Now to find absorptivity, place geometrically identical black body at the place of gray body, place whole setup in furnace. Maintain the furnace at T_o steady state temperature. Now the black inner sphere will absorb all the energy incident on it. So

$$\mathbf{M_{ib} \times C \times (\Delta T)_b = (energy\ incident\ on\ the\ inner\ sphere)}$$

M_{ib} - mass of inner black sphere
$(\Delta T)_b$ –change in temperature of black inner sphere in a time duration of 't'.

Time (t), this time is decided on the basis that in 10 minutes the body shows a reasonable temperature rise. If lower time is selected, temperature rise is very low.

(Now place the gray back to its position)
Make the coherent conditions in furnace as they were when black body

Energy absorbed = $\{M_{ig} * C * (\Delta T)_{\mathbf{g}}\}_{\text{inner gray sphere}}$

M_{ig} – mass of inner gray sphere
$(\Delta T)_g$ – raise in temp. of inner gray sphere in same time duration 't' as it was for black body

$$\alpha - \frac{\text{Energy absorbed}}{\text{energy incident on the inner sphere}}$$

3. RESULT

As per the procedure we conducted the experiment for both gray and blackbody at two different steady state temperatures and the result for gray body are as follows

Result Table		
Temperature(T_0)°C	Emissivity	Absorptivity
50	0.55	0.45
70	0.57	0.47

3. CONCLUSIONS

As stated in introduction according to Kirchhoff's law the emissivity and absorptivity at a steady state temperature should be equal. According to the proposed setup and experimental procedure these two values are crudely equal. So we can use this setup and procedure to validate Kirchhoff's law at institute level. The variation in the values of emissivity and absorptivity is due to following reasons:

1. It is not possible to make absolute vacuum throughout the experiment.
2. The experimental blackbody we used is not perfect blackbody.

3. It is very difficult to maintain steady state throughout the experiment.

REFERENCES

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