Indian Institute of Technology Gandhinagar

Radiation Heat Transfer

ME 351: Mechanical Engineering Lab-I

Experiment Report

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1. ***Objective:***

1. Describe radiation energy density variation with space and direction from the source

2. Understand the dependence of radiation heat transfer on temperature and emissivity of the surface.

2. ***Experiment:***

Using the lamp

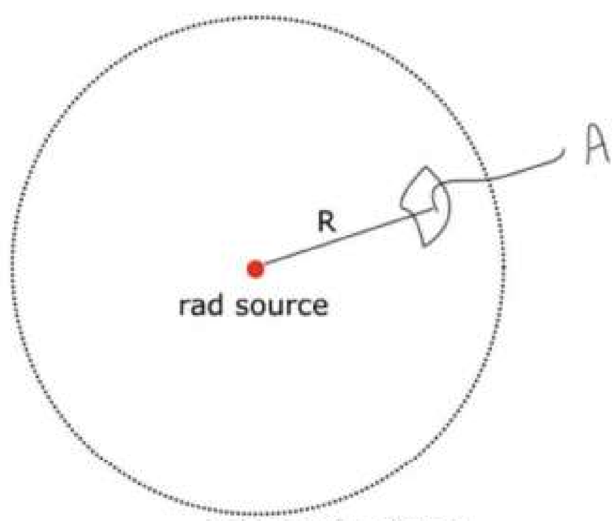
I. Measure the light intensity variation with distance from the lamp source. How does the light intensity reaching the sensor depends on distance from the lamp?

Using the high temperature radiation source

II. How does the radiated energy depend on the temperature of the radiation source?
III. How does the 'emissivity' of the surface affect its effectiveness as a radiation shield between the heat source and the radiation meter?

3. ***Essential background/Theory:***

1. How does the radiation energy density reaching a point vary as a function of distance from the source?



The fraction of radiation energy emitted by a radiation source that reaches of surface area A located at distance R from the source can be written as the ratio of the area A to the total surface area of the sphere (by symmetry) = $\frac{A}{4\pi R^2}$ = Ω (solid angle subtended by the area A at the radiation source in steradians).

Thus, we see that the radiant energy incident on a fixed area varies as the inverse square of the distance from the source.

2. Radiation heat transfer from a 'gray' surface: A gray surface is an approximation used for real (non-black) surfaces wherein the radiation energy density leaving the surface at any wavelength is lower than that associated with a black surface by the same factor. This factor is called the emissivity ε.

The radiation heat transfer from a gray surface to the ambient can be written as:

$$Q = \varepsilon A_{obj} \sigma (T_{obj}^4 - T_{amb}^4)$$

Where,

Q : energy radiated by a black body, (W/m^2)

σ : the Stefan Boltzman constant, $\sigma = 5.67 \times 10^{-8}$ W/(m^2- K^4)

T_{obj} : surface temperature of the heated plate, (K)

T_{amb} : surrounding temperature including the radiometer, (K)

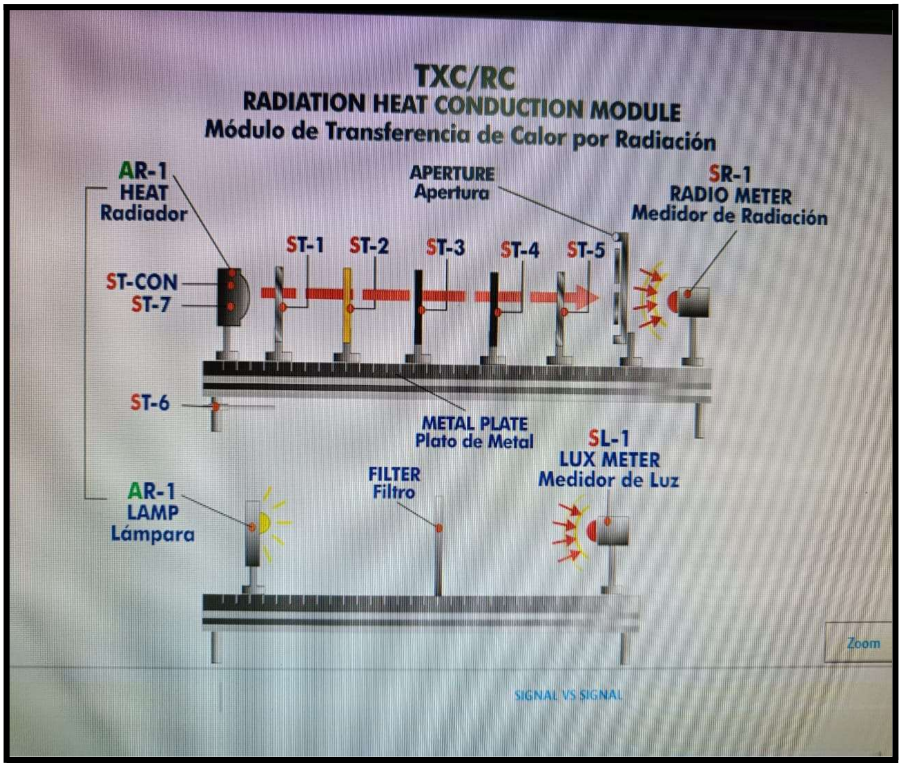
ε : the emissivity of the radiating surface.

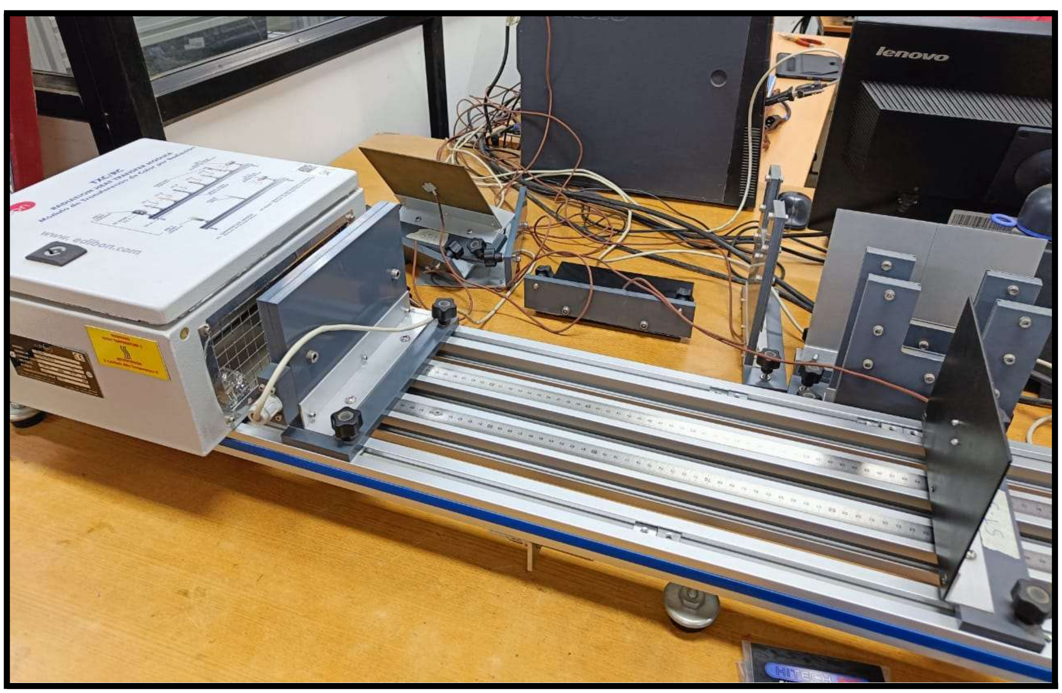
If a plate ST 3 is set on a proper support between the radiating surface (ST 7) and the radiometer and considering that the plate is not circular but square, the view factor will change. In this case, the emissivity of the plate set between the heat source and the radiometer is equal to

$$\varepsilon = \frac{R}{\sigma F (T_{obj}^4 - T_{amb}^4)}$$

4. ***Experimental Setup:***

Schematic:





Procedure:

- Start the heater on and record the heat intensity as SR1.
- Place the black plate (ST7) at a distance of 25 cm from the radiometer. The temperature is recorded in the ST7 column.
- Wait until the temperature reaches a steady state and note down the values.
- For experiment 1, plot the graph between the radiation intensity observed at the radiometer vsplate temperature.
- For experiment 2, repeat the same experiment with the distance x = 20 cm and x = 15 cm. Plot the radiation intensity vs Distance of sensor from heat source.
- For experiment 3, place a new plate (ST3) in between source plate and radiometer. The temperature is recorded as ST3. This new plate acts as a radiation shield.
- Record the change in radiation intensity reaching the radiometer over time until steady.
- Plot the steady state readings on the graph.

5. ***Results and Calculations:***

1. Variation of intensity of radiation with Temperature of the source

The distance between radiometer and the plate is x = 25 mm

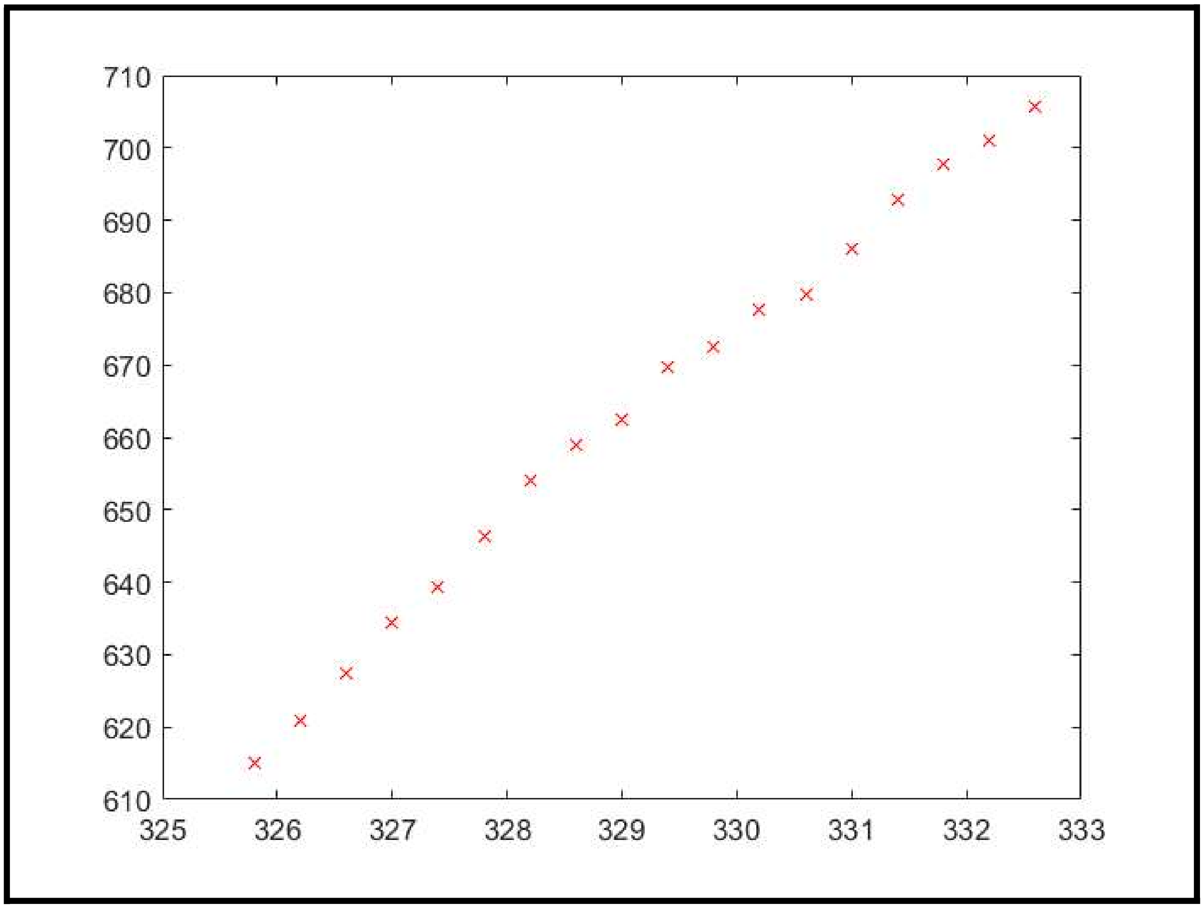
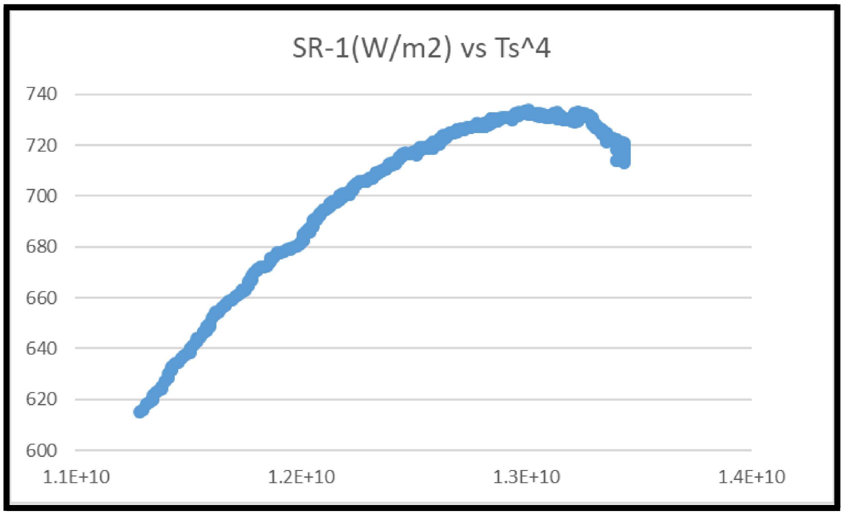
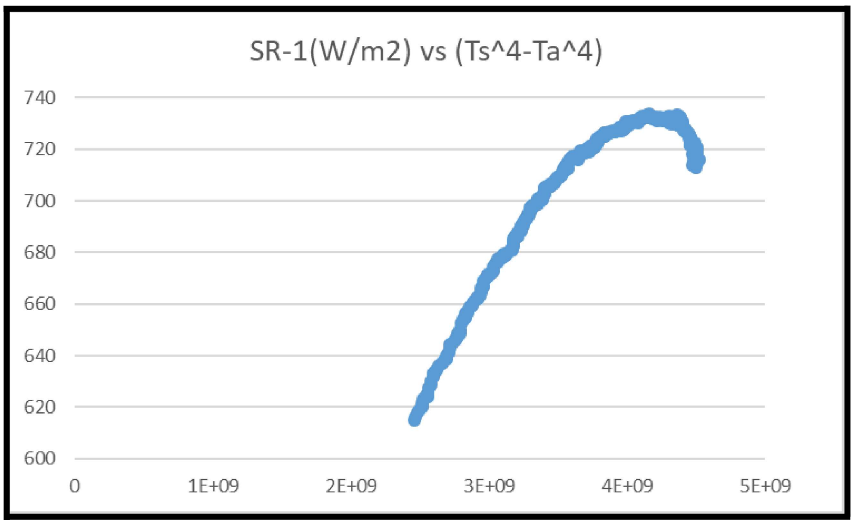


Figure : Emitted source radiation at different source temperatures





$T_s = T_{obj}$ = Temperature of object
$T_a = T_{amb}$ = Ambient temperature

The radiation intensity is linearly dependent on the Temperature as shown in above curves. That is, intensity increases with increase in temperature as indicated by Stefan Boltzmann Law.

$$Q = \varepsilon A_{obj} \sigma (T_{obj}^4 - T_{amb}^4)$$

Where Q is the energy radiated.

But this relationship is not linear over the entire range of temperature. Intensity is decreasing for higher temperatures. This may be because the emissivity of a body is lower at high temperatures.

2. Variation of Radiation with distance from heat source:

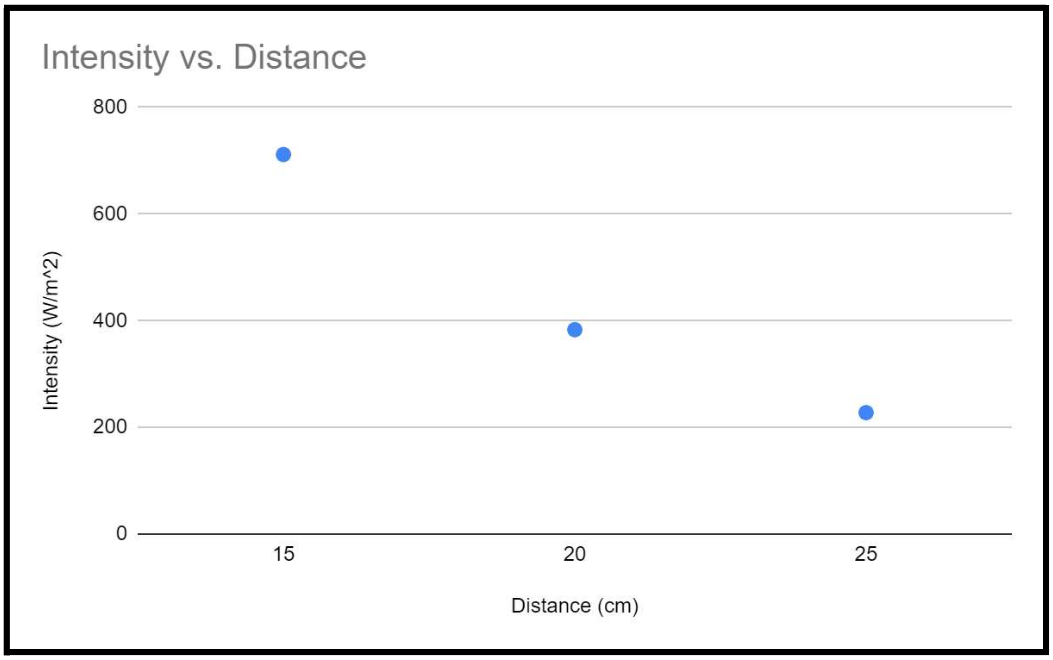


Fig : Graph showing radiation intensity vs Distance of sensor from heat source

We observed the radiation from the heat source for three different positions of the sensor.

Distance (cm)	Intensity (W/m^2)
15	711.5893617
20	383.088189
25	227.6368056

Inferences:

The radiation intensity decreases as the distance between the sensor and the heat source increases. The intensity decreases because as the distance increases, radiation diverges and some of the energy can be absorbed by the medium through which it is passing. It follows inverse square law i.e., intensity equals inverse of square of the distance from source.

Curve fitting for the intensity vs distance curve:

(i) Linear curve fitting

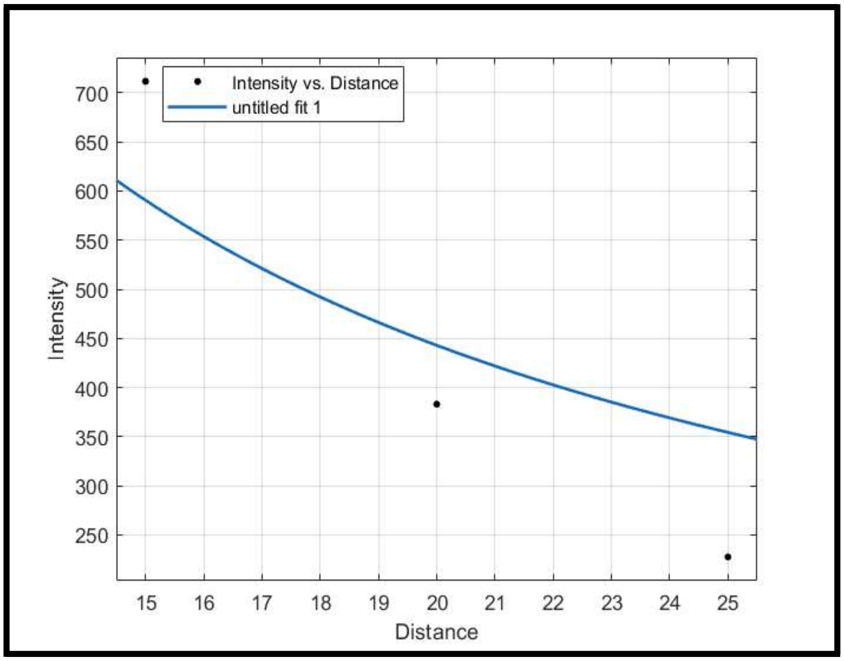


Figure : Best fit for intensity vs distance

General model:
  f(x) = a/x
Coefficients (with 95% confidence bounds):
  a = 8859 (2765, 1.495e+04)

Goodness of fit:
  SSE: 3.428e+04
  R-square: 0.7192

- This curve clearly shows that intensity is not varying as a function of 1/R.

(ii) Polynomial Curve fitting

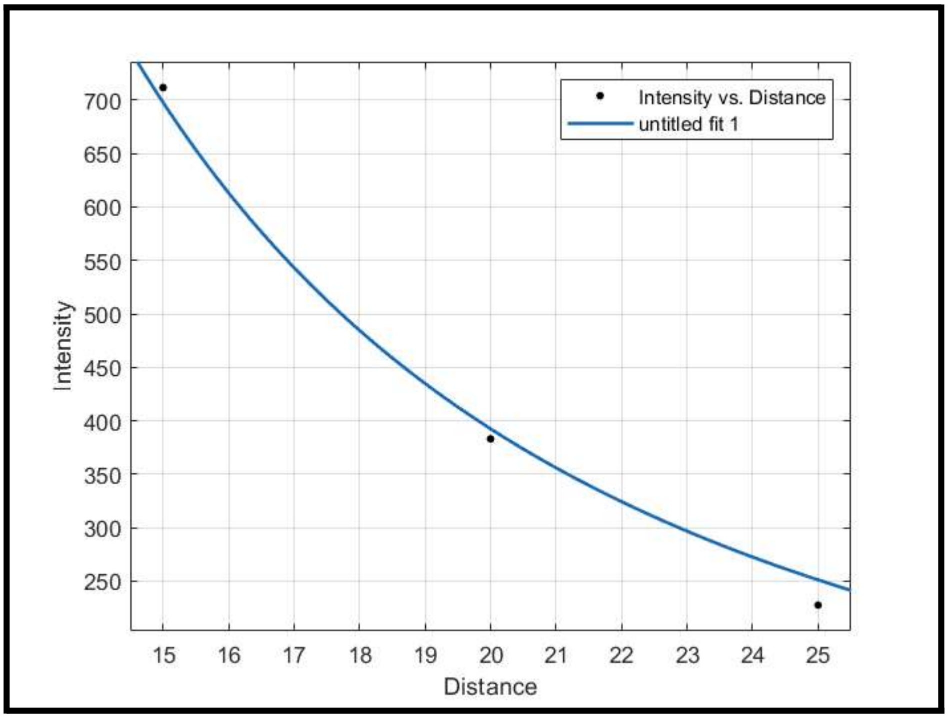


Figure : Best fit for intensity vs distance

General model:
f(x) = a/x^2
Coefficients (with 95% confidence bounds):
a = 1.57e+05 (1.406e+05, 1.735e+05)
Goodness of fit:
R-square: 0.9932

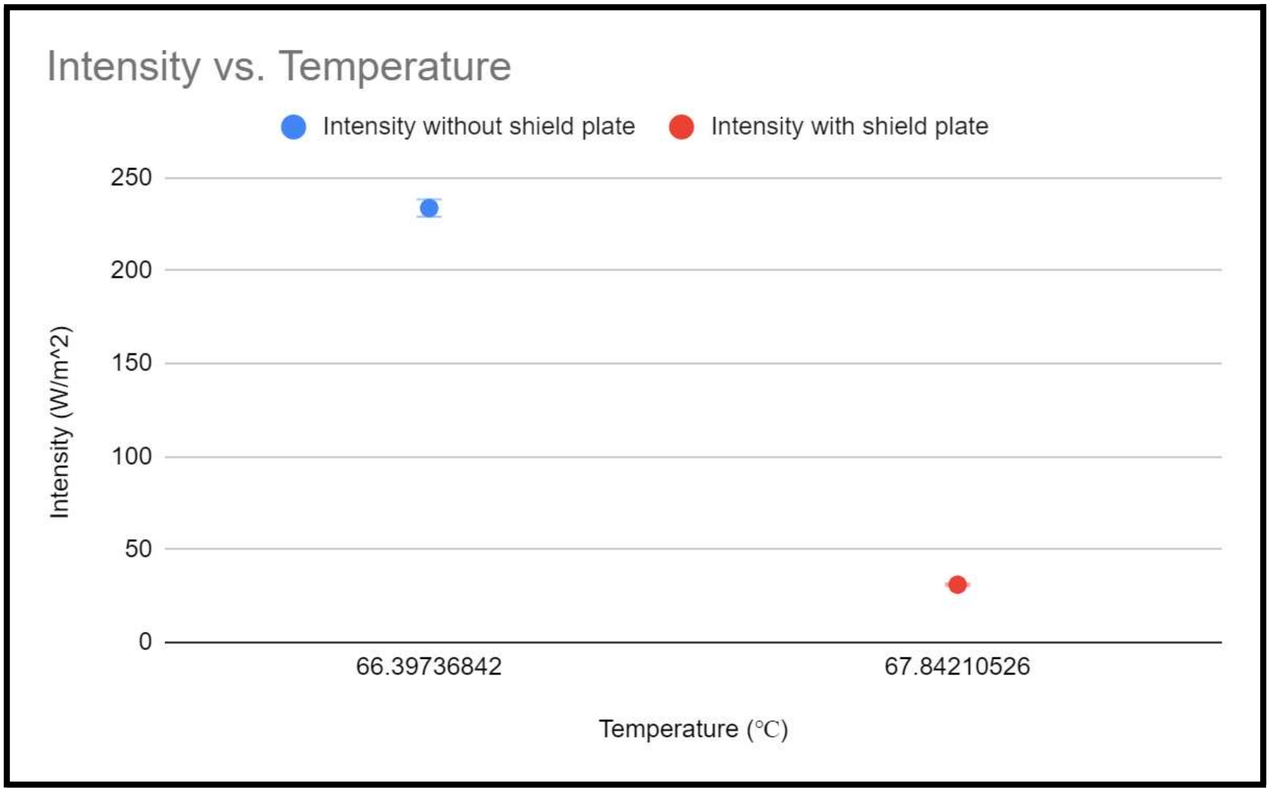
Intensity |q| α $\frac{1}{|distance|^2}$

Intensity |q| $= \frac{constant}{|distance|^2}$

- This fit for the distance vs intensity data shows that the intensity varies approximately as a function of $1/R^2$, as the goodness of fit is quite high.

3. Variation in intensity radiation with and without shield plate

We placed the heat source (ST 3) in between the radiometer and plate (ST 7). The distance between the new black plate (ST 3) and the heat source is y = 15 mm



For this experiment, we used a shield plate between plate and heated source. It was seen that the intensity decreased after using a shield plate for the approximately same temperature. This is because the solid body (or plate) absorbs some of the energy radiated from the source and hence decreases the radiation energy reached to the rightmost plate.

Emissivity is the ratio of radiation emitted by a surface and radiation emitted by a black body at the same temperature. Emissivity depends on wavelength of radiation, surface temperature and surface roughness. However, in most of the engineering applications, emissivity is assumed as constant.

Emissivity shows how closely the real body and black body are related in terms of energy radiated. Objects with lower emissivities radiate less energy from its surface than as compared to black body, for the same wavelength and temperature.
So if an object with low emissivity is used as a radiation shield, most of the energy will be absorbed by the body itself and that type of body can be considered as a good radiation shield.

6. ***Conclusion:***

- It is demonstrated here that the heat transfer from a heater surface is a combination of heat losses due to natural convection and radiation.
- In this experiment, we investigated the two fundamental tenets of radiation-based heat transfer. First is the Stefan-Boltzmann Law which says that energy radiated per unit cross-sectional area of the object is directly proportional to the fourth power of absolute temperature of the object. The second is the inverse square law, according to which the intensity varies as a square function of distance.
- From the graph, we can say that the radiation intensity decreases with increasing distance and more significantly.
- The experiment is not conducted in an evacuated medium. So the energy radiated is also absorbed by the medium particles and hence causing the errors in radiation intensity values. It can be said that energy is lost due to convection.