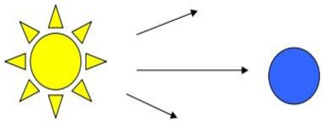
RADIATION HEAT TRANSFER EXPERIMENT

1. Object

The purpose of this experiment is to study the technical details and test parameters of radiation heat transfer.

2. Introduction

Radiation, energy transfer across a system boundary due to a ΔT, by the mechanism of photon emission or electromagnetic wave emission.



Because the mechanism of transmission is photon emission, unlike conduction and convection, there need be no intermediate matter to enable transmission. The significance of this is that radiation will be the only mechanism for heat transfer whenever a vacuum is present.

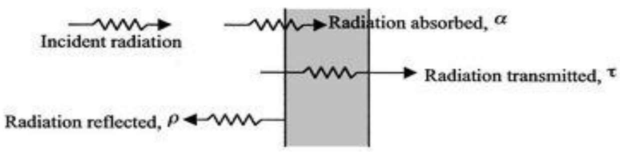
All bodies radiate energy in the form of photons moving in a random direction, with random phase and frequency. When radiated photons reach another surface, they may be absorbed, reflected or transmitted. The behavior of a surface with radiation incident upon it can be described by the following quantities:

α : Absorptance - fraction of incident radiation absorbed

ρ : Reflectance - fraction of incident radiation reflected

τ : Transmittance - fraction of incident radiation transmitted

The following figure shows these processes graphically.



From energy considerations the three coefficients must sum to unity as shown below.

$$\propto + \rho + \tau = 1$$

Reflective energy may be either diffuse or specular (mirror-like). Diffuse reflections are independent of the incident radiation angle. For specular reflections, the reflection angle equals the angle of incidence.

3. Theory

3.1 Stefan-Boltzmann law

Stefan-Boltzmann law states that for a black body

$$q_b = \sigma(T_s^4 - T_a^4)$$

Where

q_b : Energy radiated by a blackbody per unit area, (W/m^2)

σ : The Stefan-Boltzmann constant, (σ= 5.67·10^{-8} W/(m^2 · K^4))

T_s : Surface temperature of the heated plate, (K)

T_a : Surrounding temperature including the radiometer, (K)

The reading on the radiometer will be related to the radiation emitted by the plate through a constant factor *F*

$$F = \frac{q_r}{q_b}$$

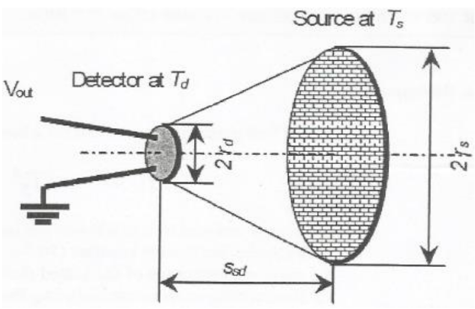
q_r : Radiation received by the radiometer, (W/m^2)

F : View factor, (-)

3.2 Radiation intensity

The radiation received by the radiometer is connected to the radiation emitted by the source through the view factor *F* defined as fraction of energy emitted per time unit by a surface intercepted by the other surface. In this case we have

$$q_b = F\sigma(T_s^4 - T_a^4)$$



$$F_{sd} = \frac{2\pi r_d^2}{r_s^2 + r_d^2 + s_{sd}^2 + \sqrt{(r_s^2 + r_d^2 + s_{sd}^2)^2 - 4r_s^2 r_d^2}}$$

The view factor *F* depends on only geometrical parameters.

3.3 Emissivity of radiating surfaces

The Stefan-Boltzmann law states that

$$q_b = \varepsilon F\sigma(T_s^4 - T_a^4)$$

Where ε is the emissivity of the radiating surface and $\varepsilon = 1$ for a black body.

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

$$\varepsilon = \frac{R}{F\sigma(T_s^4 - T_a^4)}$$

3.4 Radiating energy

Considering the simple case in which a small hot surface at temperature T_a and area A_a is surrounded by a quite wide cold surface at temperature T_b and area A_b, the radiating energy exchange (Q_{ab}) between two black surfaces is given by

$$Q_{ab} = A_a F_{ab} \sigma(T_a^4 - T_b^4)$$

This simple equation can be applied to the radiation from the heated plate (T_a/A_a) to the surrounding environment at ambient temperature (T_a). The radiometer is actually a small area of the ambient at temperature T_a.

3.5 Lambert's cosine law for light

The Lambert law for diffused radiation states that the radiant intensity along a beam is directly proportional to the cosine of the angle between the beam and a line perpendicular to the radiating surface.

$$l_\phi = l_0 cos\phi$$

Where

l_0 **:** Radiant intensity in perpendicular direction to the surface i.e. for $\phi = 0°$, (lux)

l_ϕ **:** Radiant intensity at angle ϕ in respect to normal direction, (lux)

3.6 Lambert's law of absorption

The Lambert law of absorption states that the luminous intensity of light (l_f) decreases exponentially with the distance *t* that it enters an absorbing medium with a linear absorption coefficient, α. The light intensity (l_f) of the beam striking the absorbing filter is given by

$$l_f = l_0 e^{-\alpha t}$$

Where

l_0 **:** Light intensity of the incident beam, (lux)

l_f **:** Light intensity after crossing the filter, (lux)

t **:** Filter thickness, (m)

α **:** Absorbing capacity of the filter material, (-)

The light intensity is reduced due to the light absorption by the material. The absorbed quantity depends on the thickness t of the material and the absorbing quality of the material.

In practice, part of the light is reflected on the front surface of the filter and does not cross the same filter. So it is necessary to detect this value of reflected light when the absorption inside the filter is considered. The equation written above must be corrected to include this reflected loss (l_r) as follows:

$$l_f = (l_0 - l_r)e^{-\alpha t}$$

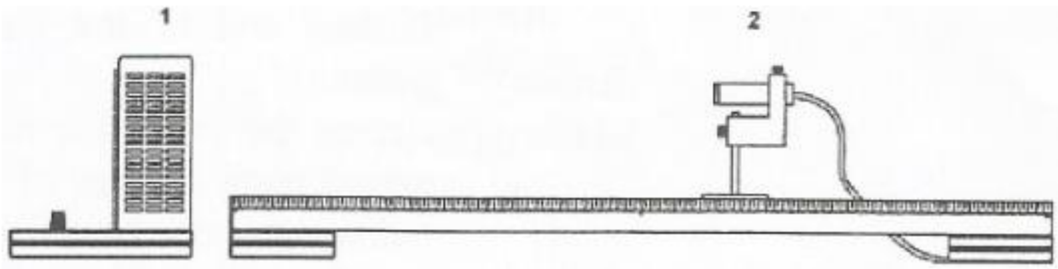
4. Experiments to be Performed

The test unit will be introduced in the laboratory before the experiment by the relevant researching assistant.

4.1 Radiometer experimental tests

4.1.1 Stefan-Boltzmann law

Aim of the experiment: To compare the obtained value of *F* at different surface temperatures of the heated plate and comment the validity of the Stefan-Boltzmann relation.



Disposition heated plate (1) and radiometer (2) on the track.

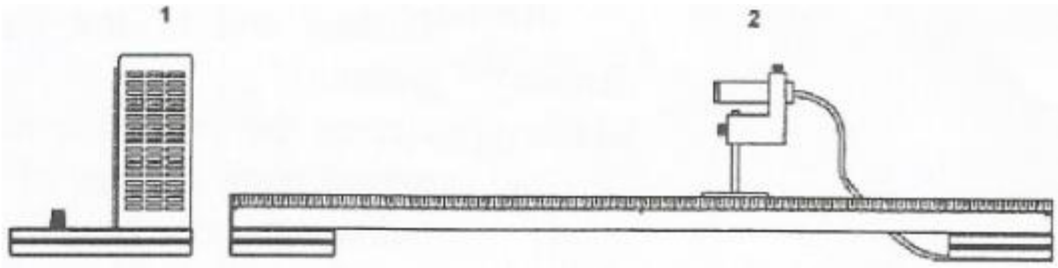
The necessary data for calculations will be recorded to the table given below.

T_s (K)	T_a (K)	%	Q_b (W)	Q_r (W)	F (-)

Where T_s the surface temperature of the heated plate, T_a is the ambient temperature, % the percental of the dimmer, Q_b the energy emitted by the heated plate, Q_r the radiometer reading, and *F* the view factor.

4.1.2 Radiant intensity

Aim of the experiment: To compare the calculated values of q_r with the readings measured with the radiometer R_c and to check the congruence, δ.



Disposition heated plate (1) and radiometer (2) on the track.

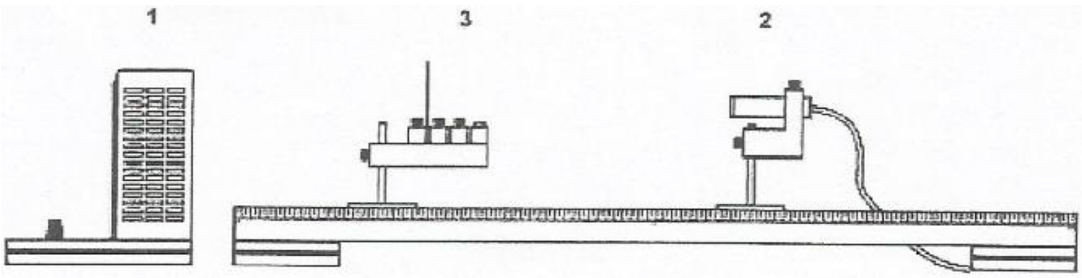
The necessary data for calculations will be recorded to the table given below.

x (m)	F (-)	Q_b (W)	$Q_{r,calc}$ (W)	R_c (W/m^2)	δ

4.1.3 Emissivity of radiating surface

Aim of the experiment 1: To see that the temperature of the heat source changes when plates of different emissivity are set in front of it.

Aim of the experiment 2: To compare the results obtained from each test and explain the differences in terms of combinations of emissivity. The emissivity of a surface affects the heat transfer from the surface or at the surface and so it affects the heat transfer to or from adjacent surface.



Disposition heated plate (1), radiometer (2), and plate holder (3).

Black painted surface

T (K)	$T_s^4 - T_a^4$ (K^4)	R (%)

White painted surface

T (K)	$T_s^4 - T_a^4$ (K^4)	R (%)

Polished painted surface

T (K)	$T_s^4 - T_a^4$ (K^4)	R (%)

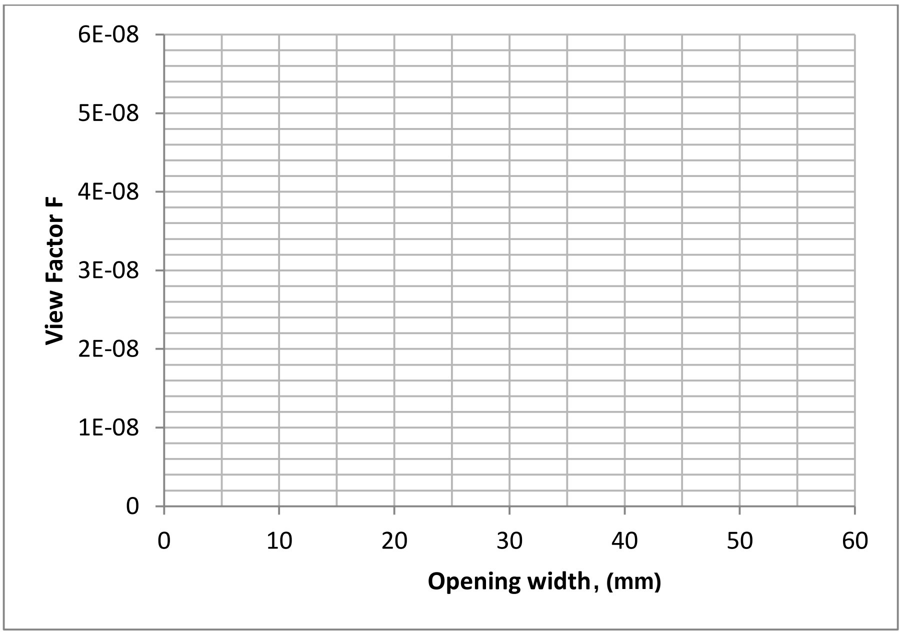
Test no	Plate type	Plate type	Plate type	ε
1	Black plate	Polished plate		
2	Black plate	Black plate		
3	Black plate		Black plate	
4	Black plate	Polished plate	Black plate	
5	Polished plate			
6	Polished plate	Black plate		
7	Polished plate		Black plate	

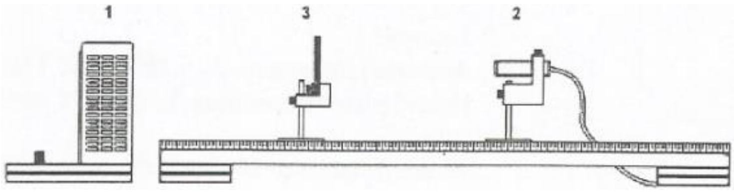
$$\varepsilon = \frac{R}{F\sigma(T_s^4 - T_a^4)}$$

4.1.4 Radiating energy

Aim of the experiment: To plot a graph of the view factor *F* vs. the amplitude of the opening w.

w (mm)	Q_r (W)	Q_b (W)	$F = Q_r/Q_b$





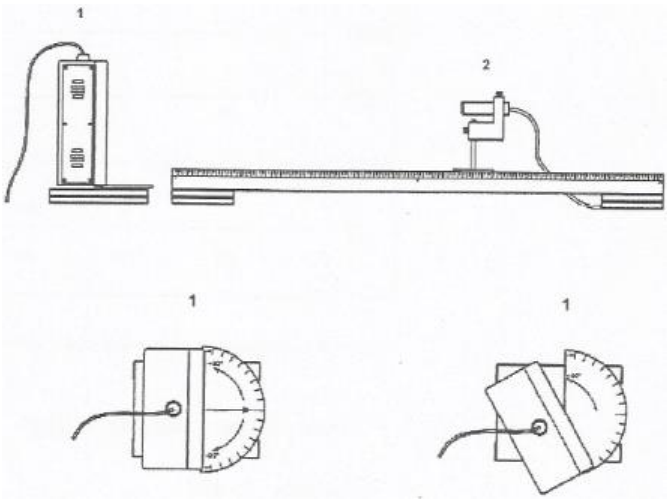
Disposition heated plate (1), radiometer (2), and accessory with cork plates (3).

4.2 Luxmeter experiments

4.2.1 Lambert's cosine law for light

Aim of the experiment: To see that the results follow the cosine relation shown below.

$$l_{\phi} = l_0 cos\phi$$



Disposition light source (1), luxmeter (2), and top view of the light source (1) with rotation from -90° to +90°.

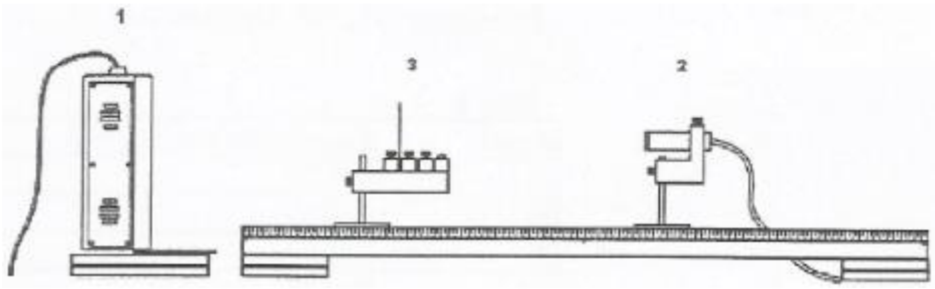
The necessary data for calculations will be recorded to the table given below.

Angle (°)	Luminosity from theory (lux)	Luminosity from calculation (lux)
10		
20		
30		
40		
50		
60		
70		
80		
90		
- 10		
- 20		
- 30		
- 40		
- 50		
- 60		
- 70		
- 80		
- 90		

4.2.2 Lambert's law of absorption

Aim of the experiment: To check the Lambert's law of absorption stating that the light intensity (l_f) of the beam after entering the absorption filter is given by

$$l_f = l_0 e^{-\alpha t}$$



Disposition light source (1), luxmeter (2), and filters holder (3).

Test no	Filter 1	Filter 2	Filter 3
1	Light filter		
2	Medium filter		
3	Dark filter		
4	Light filter	Light filter	
5	Medium filter	Medium filter	
6	Dark filter	Dark filter	
7	Light filter	Medium filter	Dark filter

5. The Report

Your laboratory reports must include the followings;

a) Cover,

b) A short introduction, a schematic view of experimental setup by hand drawing and the aim of the all experiments,

c) All the necessary calculations using measured data,

d) Discussion of your results and a conclusion.