SCUPI

Sichuan University - Pittsburgh Institute

ME 1042

Thermal Fluids Lab

Radiation Heat Transfer

Revised
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Mechanical Engineering Department

Goal: To verify that the total radiation emitted by a heat source is proportional to the fourth power of its absolute temperature (Stefan-Boltzmann Law) and the effect emissivity has on measured emission.

Equipment Needed:
FILR T630sc Infrared Camera
Hot Plate
304 Stainless Steel samples
PLA samples
Black tape
Type K Surface Thermocouple
Omega MDSi8 Temperature Controller

1 Introduction and Basic Theory

The Stefan-Boltzmann Law states that the total emission from a blackbody (E_b) is proportional to the fourth power of its absolute temperature (T).

$$E_b = \sigma T^4$$

where σ is a physical constant known as the Stefan-Boltzmann constant. (This value can be found using many textbooks and Web sources).

This law enables us to calculate the amount of radiation emitted in all directions over every wavelength of a blackbody simply by knowing its temperature. Of course, we are not dealing with perfect emitters, nor can we assume that we are close in most cases. The Stefan-Boltzmann Law can be confirmed by plotting the total experimental irradiation values versus heat source temperature on a log-log scale. This should be a linear curve whose slope should verify the Stefan-Boltzmann law.

1.1 *Emissivity*

Emissivity (ε) is the way that we deal with an imperfect emitter. It is a value between zero (perfect absorber) and one (blackbody) that is indicative of the surfaces relative ability to emit radiation. In reality, emissivity is based on the temperature, wavelength and angle of emission. However, in practice an emissivity is typically found that is averaged over all possible directions and wavelengths. It is introduced into the radiation equation as follows:

$$E = \varepsilon \sigma T^4$$

Typically, we see emissivity expressed as a constant that is simply a property of the surface. This is not completely correct as the emissivity of a surface can change with temperature just as the properties of a material can change. This can alter data to a measurable degree if either the measurements are sensitive or the emissivity change is great. Thus, we will examine this effect as well in this lab.

There will be uncertainty associated with the temperature measurements. Although we typically assume that the surroundings act as a blackbody, this is not the case for the emitter. One can determine the emissivity by comparing experimental radiation with what could be expected from theory:

$$\varepsilon = \frac{E_T}{E_{theory}}$$

where E_{theory} is defined as:

$$E_{theory} = \sigma T_{HS}^4$$

1.2 *Incident Radiation*

The detection of radiative intensity occurs for all incoming radiation from the heat source and its surroundings. Therefore we must account for both the radiation of the heat source as well as the ambient effects.

The total radiation (E_T) measured is simply the sum of both the ambient radiation (E_{amb}) and the measured heat source radiation (E_{HS}):

$$E_T = E_{HS} + E_{amb}$$

The ambient radiation must be determined based on the ambient temperature (T_{amb}, typically ~20 ℃):

$$E_{amb} = \sigma T_{amb}^4$$

Radiation measured by a sensor from all surroundings is called Irradiation, which is dependent upon emission, reflection and spectral distribution. Total irradiation measured by a sensor is the total radiation incident per unit area from all directions and at all wavelengths.

2 Experimental Procedure

The experiment will be broken up into three investigative components. We will experimentally measure temperature of the surface of our samples as a result of heat conduction. We will then observe the effects of emissivity and finally consider temperature dependence through the Stefan-Boltzmann relation.

2.1 *Radiative temperature measurement from a conductively heated source*

1. Locate each type of sample. There should be two aluminum samples and 2 PLA samples. One of each sample type should have black tape covering a surface with the other having a totally exposed surface.

2. With the TA's help, set up the infrared camera with correct temperature, humidity, distance, etc. Sett the emissivity as 0.95, which is the value for the black rubber tape.

3. With TA's assistance, stick a K-type thermocouple (TC) on the hot plate, and connect the TC to OMEGA MDSi8 Temperature Reader.

4. Turn on the hotplate and set the temperature to 50℃ (the hotplate surface temperature will ultimately be lower than this). Wait about 5 minutes for the hotplate temperature to reach its intended value and stabilize.

5. While waiting for the hot plate to heat up, become familiar with the infrared camera by learning to take an infrared photo of a defective container. Simply analyze the temperature distribution of the infrared photo.

6. Once the hotplate is ready, place all four samples on its surface, spaced out uniformly.

7. Take infrared photos of the hot plate (at a tilt angle) at these time points: 30s, 90s, 150s, 270s, 390s and note the thermocouple temperature as well.

8. Analyze the samples with black tape in the infrared images. Use Table 1 below as a template for your record keeping.

Table 1: Experimental results table for conductive heating measurements

Heat Time	Thermocouple Temperature(℃)	Aluminum Image Temperature(℃)	PLA Image Temperature(℃)
30 s			
90 s			
150 s			
270 s			
390 s			

2.2 *Determination of emissivity*

9. With the samples still on the hot plate, capture 4 new infrared images 15 seconds apart under the same settings from the previous experimental step. Also note the thermocouple temperature at the same time interval.

10. Adjust the emissivity value to 1 (black body value) and determine the radiative emission for each image for the exposed surface samples. Use Table 2 as a template for your record keeping.

Table 2: Experimental results table for emissivity investigation.

	Aluminum		PLA	
Time Step	Black tape sample Temperature(°C)	Emissivity	Black tape sample Temperature (°C)	Emissivity
15 s				
30 s				
45 s				
60 s				

2.3 *Radiative emission at different temperatures*

11. Set the conditions as the previous experimental step.

12. Capture infrared images 15 seconds apart around the thermocouple region. Also note the thermocouple temperature at the same time interval.

13. Repeat the above steps for the temperature values shown in Table 3. As you change the hotplate temperature, allow the hotplate to reach a steady temperature value.

14. Analyze the images and determine the temperature and peak emission for the hotplate.

Note: The infrared camera generates ***irradiance*** and can convert it to ***radiance*** by multiplying by Steradian. Do this with the TA's instruction.

Table 3: Stefan-Boltzmann Law experimental results table.

Heat Source T (°C)	Thermocouple T (°C)	Peak Emission (W/m^2)	T^4 (K^4)
50			
70			
90			
110			

3 For the Report

Your discussion points will cover each of the 3 experimental investigations from laboratory. For each topic area use the following information to complete your reports. The form of the report is an extended memo. This should include, theory of radiation heat transfer, a brief introduction and explanation of experiments. Be sure to discuss the results in a separate discussion section and make your final conclusions in a separate conclusion section.

3.1 *Radiative temperature measurement from a conductively heated source*

- Please briefly describe what you observed in relation to "heat conduction" during this experimental step.
- Explain the temperature difference between different samples under different heat up times.

3.2 *Radiative temperature measurement from a conductively heated source*

- Why is there a temperature difference between the samples with and without black tape?
- How do emissivity values differ for each of the materials tested?

3.3 *Radiative emission at different temperatures*

In order to fully convey your understanding of the subject matter under this experimental section, the following tables and plots should be included in your lab report

A. **Log-log plot used to verify the Stefan-Boltzmann Law.** Make sure to label and point out any important characteristics. Determine the slope of this curve. Does it make sense? Keep in mind that you should first take the log of the data (both temperature and irradiance) and then find the slope of the resulting values.
B. **A non-log scale plot of the same data** to demonstrate the trend of the data. Be sure to include error bars on all experimental data. This should also include a curve fit of the data. You should use this to compare your best fit to the prediction from theory.
C. **A plot of the emissivity as a function of the temperature.** If appropriate, propose a curve fit to help explain the trends. Note that the plot of emissivity should also show error bars, which will define the upper and lower bound of uncertainty for each data point (see part (D)).
D. **A table showing the equations used to calculate uncertainty in emissivity and listing uncertainty in emissivity for each temperature point**. This is a propagation of uncertainty analysis. Your task is to determine the uncertainty in ε based on the experimental uncertainties of the irradiance and temperature readings, the ambient reading, and all other quantities used including E_{theory}.

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