## 6.3 Thermal Radiation

### 6.3.1 Introduction

The purpose of this experiment is to display radiation heat transfer. A heater enclosed in a vacuum radiates thermal energy to its enclosure. Through an understanding of Stefan-Boltzmann's law and real surface behavior, a comparison between real and ideal behavior is made.

### 6.3.2 Stefan-Boltzmann Law

This section briefly discusses the emission and absorption of radiation heat transfer. All bodies that have temperature emit thermal radiation. The ideal maximum energy that can be emitted from a surface is known as Stefan-Boltzmann's law

$$E_b = \sigma T^4 \tag{1}$$

where $E_b$ [W/m$^2$] is the emissive power, $\sigma$ is the Stefan-Boltzmann's constant, and $T$ is the body's absolute temperature. The value of $\sigma$ is 5.6697 x $10^{-8}$ W/m$^2$-K$^4$ . A blackbody is an ideal surface that emits this amount of energy. A blackbody is not only an ideal emitter but it is also an ideal absorber. All the energy incident upon a blackbody is absorbed. The blackbody emits and absorbs over all wavelengths and all directions.

A real surface does not emit ideally. Considering the emission from a real surface over all directions and wavelengths, the emissivity is the ratio of the actual energy emitted by the surface divided by the emissive power of a blackbody at the same temperature.

$$\varepsilon = \frac{\dot{q}''}{\sigma T^4} \tag{2}$$

where $\dot{q}''$ is heat transfer flux [W/m$^2$] emitted.

### 6.3.3 Description of Apparatus

The apparatus for this experiment is shown in Fig. 1. It consists of a cylindrical electric heater mounted inside a bell jar which can be evacuated when needed. The dimensions of the heater are 13.49 cm in length and 1.27 cm diameter. The power generated by the heater is controlled by a Variac, the heater powerstat. The power is measured by the wattmeter. The heater’s temperature is measured by three differently located chromel-alumel thermocouples. The inner and outer surface temperatures of the belljar are measured by chromel-alumel thermocouples. If natural convection within the jar is to be minimized, the air enclosed by the jar must be withdrawn by a vacuum pump to its maximum value. To keep the jar cool, there are air ducts which direct airflow over the belljar.

### 6.3.4 Safety Guidelines

- Do not exceed the recommended power requirement to the electric heater for each power increment.
- Cooling air flow over the exterior surface of the glass jar must be on while running the experiment.

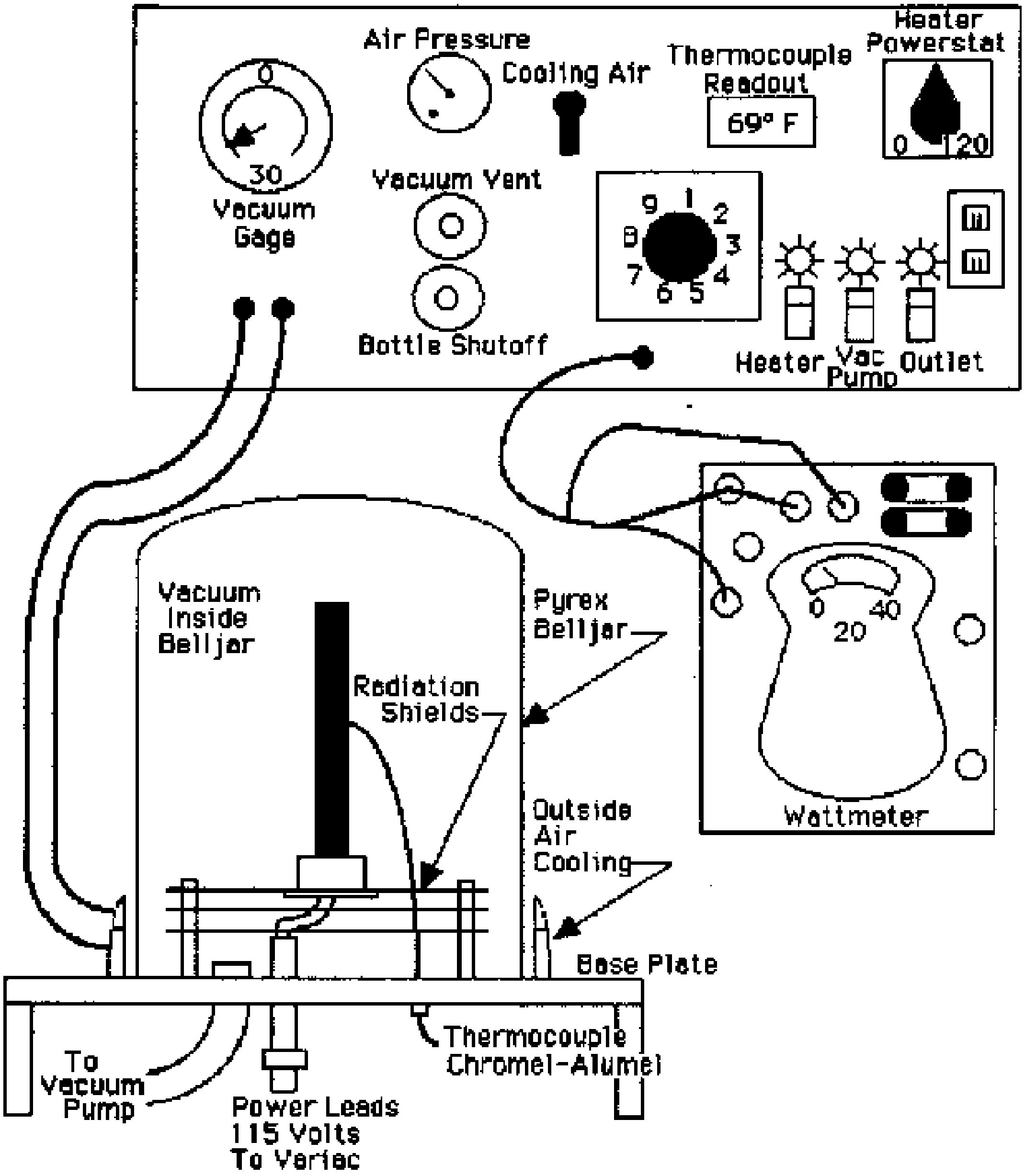

Figure 1: Test Set-up for Experiment.

## Radiation Worksheet

1. List the objectives of the experiment.
2. Open the vent valve (Never turn on vacuum pump when this valve is closed) and open the bottle shut off valve.
3. Turn on the vacuum pump.
4. Shut the vent valve and watch the vacuum gauge reach to its maximum. The gauge units are inches of mercury. Close the bottle shut-off valve. Record the vacuum value.

Pressure ________________ in of Hg

5. Turn on cooling air flow.
6. Turn heater powerstat to zero reading.
7. Turn heater switch on.
8. Turn the dial to read all initial temperature readings from the thermocouple digital meter.
9. Set the dial knob at 10 W and verify the power with the wattmeter reading. Keep increasing power until the wattmeter's reading is 10 W. See Note*.
10. Record all thermocouple readings every 10 min until the system reaches steady state. Record data in given tables.
11. Continuously monitor heater temperatures. See Note*.
12. Record power input to the heater at steady state: use 10, 20, 30, and 40 W. See Note*.

***Note**: Do not exceed 40 W or the surface temperature of 527 C (980 F). Add the amount of cooling air to cool the jar's temperature.

13. After data are collected, shut off all power. Eliminate vacuum in belljar. Maintain airflow until heater temperature has significantly dropped.

14. Use only the steady state values to perform the following steps.
15. Plot the theoretical blackbody radiation, $E_b$, as a function of the measured heater surface temperature, $T_h$.
16. Estimate the emissivity of the heater for the different surface temperatures assuming only radiation occurs between the heater and the belljar. The equation to determine the emissivity is

$$\dot{q} = A\varepsilon\sigma\left(T_h{}^4 - T_e{}^4\right) \tag{3}$$

where A is the heater surface area. Use the following space to show the calculation for determining the emissivity at 10 W.

Derivation:

17. Estimate the emissivity of the heater for the different surface temperatures assuming radiation and convection occur between the heater and the belljar. The equation to determine the emissivity is

$$\dot{q} = A\varepsilon\sigma\left(T_h{}^4 - T_e{}^4\right) + hA\left(T_h - T_e\right) \tag{4}$$

The natural convection heat transfer coefficient, h, can be calculated from a known correlation. Such a correlation is often found in any undergraduate heat transfer text.[1] For laminar flow

$$h = 1.42\left(\frac{\Delta T}{L}\right)^{0.25} P^{0.5} \qquad for\ 10^4 < Gr_L \Pr < 10^9 \tag{5}$$

and for turbulent flow

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[1] Ozisik, Heat Transfer, A Basic Approach, McGraw-Hill, 1985, Table 9-6, pg. 448.

$$h = 1.31(\Delta T)^{1/3} P^{2/3} \qquad \qquad for \;\; 10^{9} < Gr_{L} \Pr < 10^{13} \qquad (6)$$

where $\Delta T$ is the temperature difference between the heater surface and the air temperature inside the jar, $P$ is the air pressure in atmospheres, $L$ is the vertical cylinder's length in meters, and $h$ is the heat transfer coefficient in units, W/m$^2$-C. $Pr$ is the Prandtl number. $Gr_L$ is the Grashof's number defined as

$$Gr_L = \frac{g\beta \, \Delta T L^3}{\nu^2} \qquad (7)$$

where $g$ is the gravitational constant, $\beta$ is the volumetric coefficient of thermal expansion, and $\nu$ is the fluid viscosity. The volumetric coefficient of thermal expansion for an ideal gas is the inverse of the absolute temperature.

| Time [min] | Jar Outside Temp. [1] [F] | Heater Middle Temp. [2] [F] | Heater Top Temp. [3] [F] | Heater Bottom Temp. [4] [F] | Jar Inside Temp. [5] [F] | Ambient Air Temp. [6] [F] | Wattmeter [W] |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | |
| 10 | | | | | | | |
| 20 | | | | | | | |
| 30 | | | | | | | |
| 40 | | | | | | | |
| 50 | | | | | | | |
| 60 | | | | | | | |
| 70 | | | | | | | |
| 80 | | | | | | | |
| 90 | | | | | | | |
| 100 | | | | | | | |
| 110 | | | | | | | |
| 120 | | | | | | | |
| 130 | | | | | | | |
| 140 | | | | | | | |
| 150 | | | | | | | |

Table 1:  Data for 10 W Setting.

| Time [min] | Jar Outside Temp. [1] [F] | Heater Middle Temp. [2] [F] | Heater Top Temp. [3] [F] | Heater Bottom Temp. [4] [F] | Jar Inside Temp. [5] [F] | Ambient Air Temp. [6] [F] | Wattmeter [W] |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | |
| 10 | | | | | | | |
| 20 | | | | | | | |
| 30 | | | | | | | |
| 40 | | | | | | | |
| 50 | | | | | | | |
| 60 | | | | | | | |
| 70 | | | | | | | |
| 80 | | | | | | | |
| 90 | | | | | | | |
| 100 | | | | | | | |
| 110 | | | | | | | |
| 120 | | | | | | | |
| 130 | | | | | | | |
| 140 | | | | | | | |
| 150 | | | | | | | |

Table 2:  Data for 20 W Setting.

| Time [min] | Jar Outside Temp. [1] [F] | Heater Middle Temp. [2] [F] | Heater Top Temp. [3] [F] | Heater Bottom Temp. [4] [F] | Jar Inside Temp. [5] [F] | Ambient Air Temp. [6] [F] | Wattmeter [W] |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | |
| 10 | | | | | | | |
| 20 | | | | | | | |
| 30 | | | | | | | |
| 40 | | | | | | | |
| 50 | | | | | | | |
| 60 | | | | | | | |
| 70 | | | | | | | |
| 80 | | | | | | | |
| 90 | | | | | | | |
| 100 | | | | | | | |
| 110 | | | | | | | |
| 120 | | | | | | | |
| 130 | | | | | | | |
| 140 | | | | | | | |
| 150 | | | | | | | |

Table 3:  Data for 30 W Setting.

| Time [min] | Jar Outside Temp. [1] [F] | Heater Middle Temp. [2] [F] | Heater Top Temp. [3] [F] | Heater Bottom Temp. [4] [F] | Jar Inside Temp. [5] [F] | Ambient Air Temp. [6] [F] | Wattmeter [W] |
|---|---|---|---|---|---|---|---|
| 0 | | | | | | | |
| 10 | | | | | | | |
| 20 | | | | | | | |
| 30 | | | | | | | |
| 40 | | | | | | | |
| 50 | | | | | | | |
| 60 | | | | | | | |
| 70 | | | | | | | |
| 80 | | | | | | | |
| 90 | | | | | | | |
| 100 | | | | | | | |
| 110 | | | | | | | |
| 120 | | | | | | | |
| 130 | | | | | | | |
| 140 | | | | | | | |
| 150 | | | | | | | |

Table 4:  Data for 40 W Setting.

## Discussion of Results and Conclusion