BLACKBODY RADIATION LAB

Objectives

The objectives of this experiment are:

1. To become familiar with blackbody radiation and its relation to the emission temperature,

2. To become acquainted with a pyroelectric radiometer system that is designed for the measurement of radiation,

3. To measure radiation emitted by a blackbody at various temperatures using a detector positioned in different locations relative to the emission source, and

4. To determine the blackbody temperature from the measured radiation.

Introduction

The total emissive power of a blackbody E_b is determined from the Stefan-Boltzmann law

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

where the Stefan-Boltzmann constant σ has the value

$$\sigma = 5.670 \text{ x } 10^{-8} \text{ W/m}^2\text{-K}^4 . \tag{2}$$

Equation (1) describes the total amount of energy emitted in all directions and at all wavelengths based on the blackbody temperature T. Since the emission is diffuse, the total intensity of the blackbody emission is

$$I_b = \frac{E_b}{\pi} \tag{3}$$

Referring to Fig. 1, the amount of the blackbody intensity that is intercepted by a detector is dependent on the radiation source area A_s, the detector area A_d, the spacing between the source and detector r, and the angles of the source and detector defined from the line between the source and detector. The particular relationships are defined in terms of the differential areas and the differential solid angle $d\omega$, where

$$d\omega_{d-s} = \frac{dA_n}{r^2} \tag{4}$$

and $$dA_n = dA_d \cos\theta_d . \tag{5}$$

If dA_s and dA_d are treated as finite areas, then eqs. (4) and (5) become

$$\omega_{d-s} \approx \frac{A_n}{r^2} \text{ and} \tag{6}$$

$$A_n \approx A_d \cos\theta_d \tag{7}$$

Still using the previous assumption, the radiation heat transfer q_{s-d} from the source that is measured by the detector is expressed in terms of the intensity of the blackbody emission

$$q_{s-d} \approx I_b A_s \cos\theta_s \omega_{d-s} \tag{8}$$

Equations (6) through (8) define the relationship between the temperature of the blackbody source and the radiation energy measured at the detector.

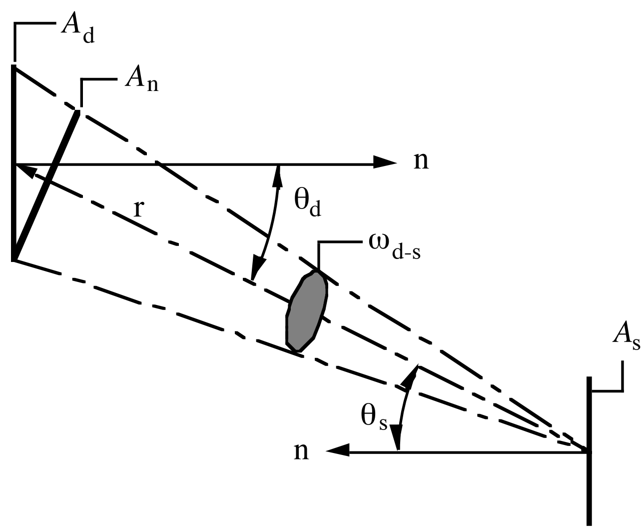

Fig. 1 Typical geometry for source detector arrangement

Experimental Apparatus

An Oriel Pyroelectric Radiometer System combined with an Optical Chopper from Oriel are the primary pieces of equipment needed for this radiation experiment. The radiometer system includes the blackbody source that may be set to a wide range of temperatures and a detector head with detector area A_d = 1 mm^2. The unit may be set to fast, medium, or slow response, which varies the system response time from 0.2 to 10 seconds. Set the response time to slow, as the unit becomes unstable at other settings. A multiplier is used to select the desired system sensitivity in watts. The system needs to be calibrated to obtain accurate readings; the calibration will be completed before any students groups conduct an experiment. A digital panel meter will display the detector signal (0.000 to ± 1.999 times the multiplier setting in watts). An analog panel meter also displays the detector signal and is useful for system alignment.

The chopper is a fixed frequency beam modulator that operates at a nominal 19 Hz (true frequency is 18 2/3 Hz). A pulley/belt set may be used to allow conversion to a 93 Hz nominal frequency (true frequency is 93 1/3 Hz). A 4-section blackened blade is driven by a synchronous motor. The rotating blade is enclosed in a housing with a 25 mm diameter aperture that is adjustable through 180° and may be fixed in place. As shown in Fig. 2, the chopper is placed between the source and detector. The detector head toggle switch should be in the proper position to match the chopper configuration (HI for 93 Hz, LO for 19 Hz). Fig. 2 also indicates the areas and angles used to predict the radiation heat flux measured by the detector.

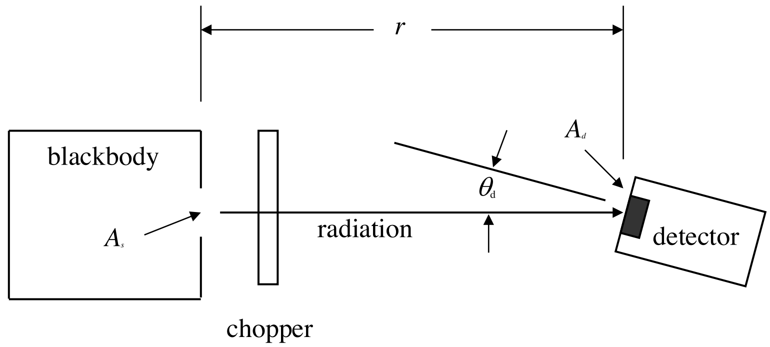

Fig. 2 Schematic of blackbody radiation apparatus

Procedure

1. The Lab Technician should have already set the chopper frequency to the appropriate value. Plug in the power supply for the blackbody fan.

2. There are 3 control variables in this experiment, T, A_s, and r. The effects of these variables on $q_{s\text{-}d}$ may be examined one at a time by fixing 2 of the control variables and varying the remaining one. For each set of control variables, the radiation intersected by the detector should be measured and recorded using the Oriel radiometer. Begin by setting the emission temperature T using the temperature controller for the blackbody. A temperature in the range from 300 to 900°C is suggested. Locate the detector approximately 9 in normal to the blackbody with θ_d = 0. Now vary A_s by rotating the large silver ring attached to the blackbody outlet. Seven different aperture diameters d, measured in inches, are available.

3. Set the aperture diameter to 0.6 in and place the detector such that $\theta_d = 0$. Vary r in the range from 8 to 12 in (use 1 in increments) and record all data at steady state.

4. Set the aperture diameter to 0.6 in and place the detector such that $r = 9$ in and $\theta_d = 0$. Increase the setting on the temperature controller by 200°C. As the temperature indicated by the digital thermometer passes through selected temperature values, read and record the detector signal. 20°C increments are recommended for the radiation readings.

5. Set the temperature controller to 300°C and leave the temperature controller on. The blackbody will cool and be ready for the next group.

Required Plots

1. For each data set, compare the measured radiation to the predicted value. To do this, create a plot of theoretical radiative heat transfer, q_{theory}, from equation (8) versus the measured radiation heat transfer, $q_{measured}$, from the radiometer. Plot q_{theory} on the y-axis and $q_{measured}$ on the x-axis; use markers for all points (do not forget the correct units). On the same figure, plot the 1:1 line, i.e., a line passing through the origin with a slope of 1. If the measurements agree exactly with the theory, then all data points show fall on the 1:1 line. The deviation of the data from this line indicates the accuracy and precision of the theory.

2. For each data set, use the measured radiation heat transfer from the radiometer, $q_{measured}$, and the values of the other control variables to calculate the temperature of the blackbody, T_{body}. Create a plot of the calculated temperature, T_{body}, versus the measured temperature, $T_{measured}$, that was fixed during the experiment. Plot T_{body} on the y-axis and $T_{measured}$ on the x-axis; use markers for all points. On the same figure, plot the 1:1 line.

3. Verify that the heat rate is a function of T^4 for a fixed aperture diameter of 0.6 in, a fixed distance of r=9 in, and a fixed detector orientation of $\theta_d=0^o$. To do this, plot $q_{measured}$ (on the y-axis) versus $T^4_{measured}$ (on the x-axis) for the data from Procedure Step 4; use markers for all points. The resulting relationship should be linear. Perform a curve fit to find the equation of this linear relationship. Overlay the curve fit on the data using a solid black line. Include a legend that indicates "data" for the markers and the actual equation with calculated slope and intercept for the curve fit line.

4. Verify that the radiation intercepted by the detector is proportional to $1/r^2$, where r is the separation distance between the source and detector. To do this, plot $q_{measured}$ (on the y-axis) versus $1/r^2$ (on the x-axis); use markers for all points. The resulting relationship should be linear. Perform a curve fit to find the equation of this linear relationship. Overlay the curve fit on the data using a solid black line. Include a legend that indicates "data" for the markers and the actual equation with calculated slope and intercept for the curve fit line.

5. Verify that the radiation intercepted by the detector is proportional to d^2, where d is the aperture diameter. To do this, plot $q_{measured}$ (on the y-axis) versus d^2 (on the x-axis); use markers for all points. The resulting relationship should be linear. Perform a curve fit to find the equation of this linear relationship. Overlay the curve fit on the data using a solid black line. Include a legend that indicates "data" for the markers and the actual equation with calculated slope and intercept for the curve fit line.

References

1. Incropera, F.P. and Dewitt, D.P., Introduction to Heat Transfer, John Wiley & Sons, New York, 1985.
2. Instruction Manual, Oriel Optical Chopper - Model 7509, Oriel Corp., Stamford, CT.
3. Instruction Manual, Oriel Pyroelectric Radiometer System - Model 7080, Oriel Corp., Stamford, CT.