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Total normal emittance of dolomitic limestone

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INTRODUCTION

FLUIDIZED-bed combustors are well known for high rates of heat transfer to immersed boiler tubes. The total heat transfer coefficient, h_w, between immersed boiler tubes and a fluidized-bed combustor is approximately given by [1]

$$h_w = h_{wc} + h_{wcv} + h_{wr} \tag{1}$$

where h_{wc} is the particle convective component, h_{wcv} the gas convective component, and h_{wr} the radiative component of the heat transfer coefficient. The particle convective component of the heat transfer coefficient is due to unsteady state conduction between the boiler tube surface and the solid particles directly adjacent to it and the convection of the cooled particles to the bulk of the bed. The gas convective component is due to the augmentation of the heat transfer in the gas gaps between the particles and the heat transfer surface, and between neighboring particles by convective mixing of gas. The radiative component represents the heat exchange by radiation and is important for bed temperatures above 900 K [1].

Because fluidized bed coal combustors operate at temperatures much higher than 900 K, a number of models have been proposed to estimate the radiative component [2]. However, the use of the models to calculate h_{wr} requires the knowledge of the emittance of the bed material. One of the commonly used bed materials for a fluidized-bed combustor burning high-sulfur coal is dolomitic limestone. Since the information about the emittance of this material is not available in the literature, we have measured the total normal emittance of dolomitic limestone as a function of temperature by the integral blackbody comparison method [3, 4]. In the blackbody comparison method the emittance is determined by comparing the radiation from the sample to the radiation from a blackbody having the same surface area and temperature.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experimental apparatus used to measure the normal total emittance of dolomitic limestone consists of a furnace assembly, an optical set-up, an electronic set-up, and a d.c. power supply [5]. The furnace assembly is shown in Fig. 1. The fixture is primarily made of aluminum and is used to hold the furnace in a vertical position. Two ceramic caps are used to prevent direct contact of the tubular furnace with the aluminum plates of the fixture.

The details of the furnace are shown in Fig. 2. It has five distinct regions. Its central region is a silicon carbide tube connected at both ends with silicon carbide rods impregnated with silicon. The two ends of the furnace are metallized with aluminum. The silicon carbide tube which is 10.2 cm long constitutes the heating section of the furnace. An accurately machined slot (12.7 x 6.5 mm) through the walls in the middle of the tube serves as the blackbody. A groove (19.1 x 6.5 x 1.2 mm) ultrasonically machined along the surface of the silicon carbide tube and having the same width as the blackbody slot is used for placing the sample. However, its length is longer to allow for the removal of the sample as well as to facilitate the thermocouple insertion at the base of the sample. Two holes are drilled in the middle of the tube to host the thermocouples for the measurement of the blackbody temperature. The current is supplied to the heating section via two flexible aluminum strips which are fastened to the aluminized ends of the furnace with two steel clamps. A d.c. power supply with a current/voltage regulation of 0.01% is used to heat the furnace.

The optical system is shown in Fig. 3. It consists of a 1.5 x 6 mm slit, a toroidal mirror (TM) and a light chopper. The electronic set-up consists of a pyroelectric detector with

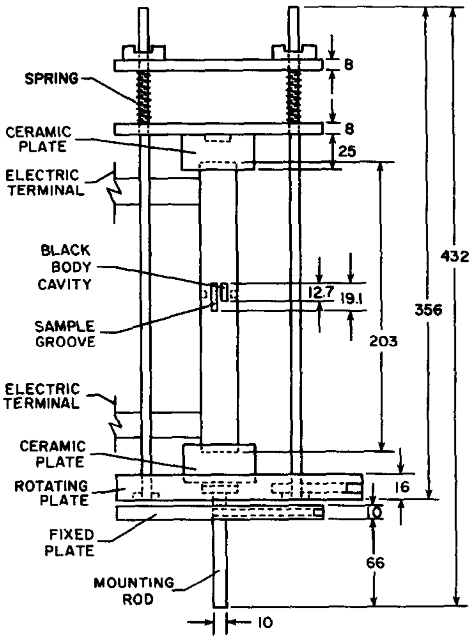

FIG. 1. Furnace assembly for the measurement of total normal emittance. Insulation and cylindrical cover are not shown in the sketch. All dimensions are shown in mm.

NOMENCLATURE

h_w	total heat transfer coefficient
h_{wc}	particle convective component of the heat transfer coefficient
h_{wcv}	gas convective component of the heat transfer coefficient
h_{wr}	radiative component of the heat transfer coefficient
T	temperature
T_b	blackbody temperature
T_s	sample surface temperature.
Greek symbol	
ε_n	total normal emittance.

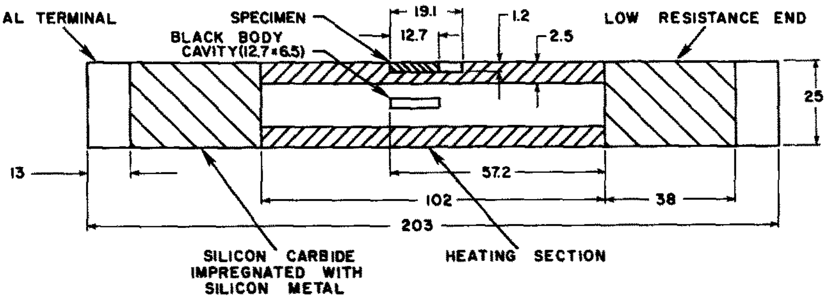

FIG. 2. Details of the silicon carbide furnace. All dimensions are in mm.

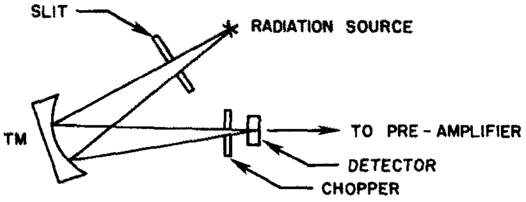

FIG. 3. The schematic of the optical set-up.

a flat response in the spectral range from 1 to 20 μm, a preamplifier, a lock-in amplifier and an A/D converter.

The dolomitic limestone is pulverized into fine powder with 95% of particles having diameters between 2 and 40 μm. The composition of dolomitic limestone after having been exposed to a temperature of 1030 K for 16 h is shown in Table 1. A piece of quartz cut to the same dimensions as the blackbody is attached to the sample groove using a high thermal conductivity glue. A thin layer of the same glue is then applied to the top surface of quartz and dolomitic limestone powder is generously sprinkled over the glue layer. A glass plate is used to gently compress the powder on the quartz to ensure that a thick layer of limestone is formed. A visual examination of the surface using a low-power microscope has not indicated any seepage of the white glue when seen against the background of the colored powder.

A 30-gage platinum vs platinum–10% rhodium thermocouple (ANSI type S) is attached to the bottom of the quartz using the high thermal conductivity glue for measuring the sample temperature. Another thermocouple of the same kind is inserted through one of the small holes in the furnace into the hollow region of the cylinder to read the temperature of the blackbody.

Table 1. Composition of dolomitic limestone

$CaMg(CO_3)_2$	51%
MgO	17%
SiO_2	10%
$Ca(OH)_2$	12%
$CaCO_3$	10%

The furnace is wrapped with high temperature insulation leaving only the sample and the blackbody opening uncovered. The insulation in turn is covered with aluminum foil to minimize the heat radiated by the insulation which would otherwise affect the results. The furnace is then placed inside the fixture which is mounted on an optical bench. The d.c. power supply is connected to the furnace.

A slit (1.5 × 6 mm) is placed in front of the fixture at the same height as the blackbody opening and centered with it. The optical components are arranged so that the radiation from either the blackbody or the sample whichever is rotated in front of the slit, passes through the slit, strikes the mirror (TM) and is brought to a focus at the center of the pyroelectric detector. A chopper between the mirror and the detector modulates the radiation. The electrical signal generated at the detector is fed to an A/D converter through a pre-amp and a lock-in amplifier. The data thus collected gives the intensity of the radiation.

The furnace is heated to a certain temperature and after thermal equilibrium is reached, the blackbody and sample temperatures are measured with the thermocouples. For temperatures above 980 K an optical pyrometer is used as a check on the values recorded by thermocouples. The blackbody is rotated in front of the slit and adjusted by rotating back and forth until maximum intensity is observed as indicated by the output of the A/D converter. This process is repeated several times and an average of these (maximum) values is determined. The furnace is now rotated so that the sample is in front of the slit. The furnace is again adjusted as above and the average intensity of radiation from the sample is determined. The ratio of the average value for the sample to the average value for the blackbody yields the total normal emittance of the sample at the appropriate temperature. Since the blackbody and the sample were not at the same temperature in a given run, it was necessary to correct the emittance value due to this difference. This was achieved by multiplying the above calculated value by T_b^4/T_s^4 where T_b is the blackbody temperature and T_s is the corresponding sample temperature during a given run.

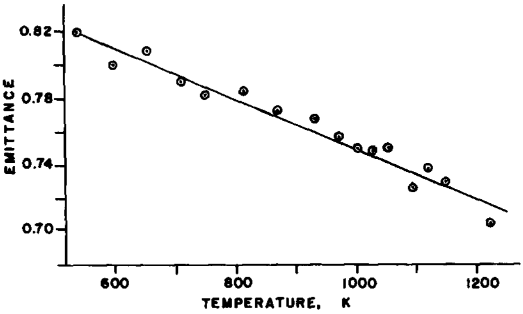

FIG. 4. Total normal emittance of dolomitic limestone as a function of temperature.

RESULTS AND DISCUSSION

The total normal emittance of dolomitic limestone was measured over the temperature range of 539–1223 K. The results are shown in Fig. 4. It is observed that the emittance of dolomitic limestone decreases as the temperature increases. Specifically the value of the total normal emittance, ε_n, falls from 0.819 to 0.704 as the temperature increases from 539 to 1223 K. The data in Fig. 4 indicate a linear relationship. Using a least squares fit it is found that emittance of dolomitic limestone as a function of temperature can be written as

$$\varepsilon_n = 0.90 - 1.505 \times 10^{-4} T \qquad (2)$$

where T is in kelvin. This correlation represents the experimental data with a maximum error of 1.71%. The maximum and the most probable errors in the values of the emittance range from -5.4 to 6.5 and from -3.8 to 4.0%, respectively. This error is mainly due to uncertainty in the measurement of the specimen and the blackbody temperatures and the degree of blackness of the blackbody. The reproducibility of ε_n is $\pm 1.6\%$.

A literature survey revealed that the information about the emittance of limestone is limited [6–10]. Since all these results except those reported by Singham [9] were obtained at room temperature, only the data of Singham [9] are compared with the present data. The values of emittance reported by Singham [9] are 0.83 and 0.75 at 533 and 811 K, respectively. The predicted values of ε_n from equation (2) are 0.82 and 0.78 at these temperatures. Although there is a good agreement between these two sets of data one should be cautioned to the possibility that this may just be a coincidence. It may be noted that the composition of limestone to which the values of Singham [9] refer is not given. However, the agreement in the results is encouraging for the range of temperatures covered.

CONCLUSION

The total normal emittance of dolomitic limestone is found to vary linearly with temperature. Specifically the total normal emittance decreases from 0.819 to 0.704 as the temperature increases from 539 to 1223 K. The results are well represented by equation (2).

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