JULY 1994

ECN-RX--94-059

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MEASUREMENT OF RADIANT PROPERTIES OF CERAMIC FOAM

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TO BE PUBLISHED IN THE PROCEEDINGS OF EUROTHERM SEMINAR NO. 37 ON HEAT TRANSFER IN RADIATING AND COMBUSTION SYSTEMS-2, SALUGGIA, ITALY, OCTOBER 5-7, 1994

This paper will be published in the Proceedings of the Eurotherm Seminar No.37 on Heat Transfer in Radiating and Combustion Systems-2.
The seminar will be held in Saluggia, Italy on October 5-7, 1994

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MEASUREMENT OF RADIANT PROPERTIES OF CERAMIC FOAM

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Petten, The Netherlands

ABSTRACT

An experimental facility is described for the measurement of the normal spectral and total emissivity and transmissivity of semi-transparent materials in the temperature range of 600 °C to 1200 °C. The set-up was used for the measurement of radiation properties of highly porous ceramic foam which is used in low NO_x radiant burners. Emissivity and transmissivity data were measured and are presented for coated and uncoated ceramic foam of different thicknesses.

1. INTRODUCTION

In the fossil fuels research program of the Netherlands Energy Research Foundation (ECN), low-NO_x burners, based on ceramic foam, have been developed and successfully introduced [1, 2]. The burners are fired with premixed gas/air. An important feature is that a part of the combustion energy is released as infrared radiation from the burner surface. The research program is directed towards the development of burners for new applications using suitable porous ceramic materials and the optimization of the combustion behaviour. The experimental program is supported by the development of a mathematical model [3] which includes chemical reactions and heat transfer for the prediction of burner performance and stability.

The ceramic material is an alumina-silica; highly porous (up to 92%), and with pore diameters up to 1 mm. The porous foam is used in approximately 15 mm thick plates of flat or curved form. Top coatings are applied for enhancing the combustion behaviour. The premixed gas/air mixture is supplied from one side and ignited on the other side. Depending on the flow and fuel ratio of the gas/air mixture the burner will act as a radiant burner or as a (blue) flame holder. In the radiant situation a very steep temperature gradient exists across the thickness of the plate, since the entrance gas/air is at room temperature and the burner side surface can be up to 1300 °C.

Being a new material, not all the physical and radiation properties of the ceramic foam are known. Although massive, non-porous ceramics have been extensively researched in the 60's [4], the physical character of the foam, being a highly porous reticulated material, introduces more difficulties in the experimental determination of radiant properties. A specific feature of this kind of dielectric material is that it also has a semi-transparent character. So far, data on the emissivity and transmissivity of these kinds of porous ceramics have not been reported in literature.

To measure the temperature dependent spectral normal and total normal emissivity and transmissivity of ceramic foam it is necessary to establish a measuring

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method, measuring instruments and a technical facility. For this study it was of particular interest to determine the emissivity and transmissivity characteristics as a function of the thickness of the material. These data then permit calculations to be made of the effective emissivity and transmissivity of ceramic plates with temperature-profiles based on local measurements and calculations.

The benefits of the accurate determination of the emissivity and transmissivity of the material as a function of wavelength and temperature include, amongst other things, the;

- application of radiation thermometry to measure the surface temperature;
- calculation of the heat balance and of the heat transfer by radiation within the ceramic foam and between the foam and the gaseous environment;
- contribution of data for the verification of the mathematical model.

2. EXPERIMENTAL FACILITY

Several approaches have been introduced previously and described in the literature for the experimental determination of radiation properties [4, 5]. Typical classification depends on desired parameters, temperature-range and material properties. For high temperature measurements it is necessary to detect a signal from the isothermally heated sample without cooling it. For ceramic materials several methods have been proposed, but they are difficult to use in our case because of the specific properties of the ceramic foam and the need to measure as a function of thickness. Typical constraints are the high porosity and the semi-transparent character.

Our experimental set-up is based on the rotating sample approach [6], together with radiometric detection using the ratio-method [4]. The set-up (figure 1) consists of a well-insulated laboratory resistance tube furnace, closed with a bottom and top plug. Both plugs, of 200 mm inner diameter, contain resistance elements for additional heating. In the top plug two water cooled tubes are constructed. One holds a black body cavity which is mounted in the furnace part. The other tube is used for viewing the sample. Two samples of 45 mm diameter can be mounted in the wings of a propeller like holder, enabling the samples to be rotated under the viewing tube. A water cooled cold-trap with separate top shield passes through the bottom plug and is positioned under the sample viewing tube. By moving aside the top shield and positioning the cold-trap under the sample it is possible to eliminate transmittance of radiation through the sample. This permits discrimination between emittance and transmittance characteristics.

Detection of the sample and black-body signal is performed by a liquid nitrogen cooled MCT detector mounted on top of the furnace. The signal from each tube is passed through a ZnSe lens, which closes the tube. The inside of the tubes with appropriate L/d are coated with soot from a rich acetylene flame to reduce grazing reflection. Signal modulation is performed using an optical chopper. Spectral resolution is realized using narrow band interference filters in the range from 1 to 15 µm. To improve the reduction of background signal an aperture is used in front of the detector.

Sample rotation permits passing the sample under the tube with minimum influence due to cooling. To minimize reflection effects from the inside of the furnace the sample can be adjusted by minimising the distance to the tube. For the same reason the cold-trap can be lifted just below the sample when making combined transmittance- and emittance measurements. The sample presence is optically triggered and an electronic timing circuit permits correct signal processing. Primary signal processing is performed by using a digital storage oscilloscope. A gated integrator and Boxcar averager set-up is used for averaging integrated signals.

The performance of the set-up has been thoroughly tested with regard to temperature stability, temperature distribution, etc. [10]. Further testing has been performed using samples of non-transparent platinum foil and semi-transparent high grade massive alumina of different thicknesses. From the initial results it turned out that the signal from the black-body tube was not representative. This was caused by a lower temperature of the tube relative to that of the sample. The measuring procedure was modified by using the signal of a separate calibrated black-body reference source. Using the same measuring configuration as during sample measurement, ie. viewing tube, lens, chopper, aperture, etc., the signal of the black-body reference source is measured at specific sample temperatures and used for rationing. Final measured data of the platinum foil agree very well with data available from the literature [7]. An example of data at 600 °C is given in figure 2. For the semi-transparent alumina (Coors AD995, thickness 4 mm) the agreement [8] is satisfactory (figure 3). Measured data for the lower wavelengths (up to ca. 4 µm) tend to be higher. Data above 4 µm are, however, somewhat lower.

3. MEASUREMENTS

Measurements were carried out on two kinds of 60 pores per inch ceramic foam samples: the original uncoated material and the same spray-coated material with a black surface. The samples were machined in thicknesses of 1, 2, 3, 4, 7, 8 and 12 mm. To ensure smooth surfaces the samples were impregnated with wax prior to machining. The wax was removed afterwards. Measurements of the spectral and total emissivity and transmissivity were performed at temperatures of 600, 750, 900 and 1050 °C. The emissivity was measured using the cold trap to exclude transmitted radiation. The transmissivity was then deduced from this measurement and the measurement without the cold trap, allowing for radiation from, and transmitted radiation through, the sample.

4. RESULTS AND DISCUSSION

Figures 4 to 7 represent the spectral and total normal emissivity and transmissivity data for the coated and uncoated ceramic of different thicknesses at 750 °C. From these results it was observed that the spectral emissivity of the foam material showed a similar behaviour to that of a solid ceramic. The spectral emissivity data showed a significant increase of emissivity in the lower wavelength range for the coated material compared to the uncoated material. The influence of thickness was most apparent on the transmissivity data in the same lower wavelength range as for the uncoated foam. Scatter in the data may occur due to the random surface structure of the samples. Results at the other temperatures show a similar behaviour.

An example of the temperature dependence of the spectral emissivity of coated and uncoated data is given in figures 8 and 9 for a thickness of 4 mm. At higher temperatures an increase is noted specifically in the region of wavelengths below 4 µm. The temperature dependent total emissivity, as depicted in figures 10 and 11, shows a slight increase with temperature, although at 900 °C a local peak can be observed. The increasing character cannot directly be translated from the spectral behaviour. For non-metallic materials a decrease is expected.

More results are presented in [9, 10]. The results need further interpretation. For use in the previously mentioned analytical model [3] the data must be transformed to effective emissivities.

5. CONCLUSIONS

A test facility for the measurement of the thermal properties of transparent materials was designed, constructed and successfully tested. Acceptance measurements show good agreement with reference materials. Measurements on ceramic foam materials of different thicknesses were performed in the temperature range from 600 °C to 1050 °C. The results show an increase of the spectral emissivity in the wavelength range of 1 to 5 µm due to the surface coating. Further treatment of the data is necessary for use in the calculation-model.

ACKNOWLEDGEMENT

Sponsored by the ECN basic-research program a portion of this work constitutes part of a PhD study by one of the authors. Furthermore the authors wish to thank Mr. Yuri Roest of the Hogeschool, Alkmaar, The Netherlands, for his technical support during the execution of the measurement program.

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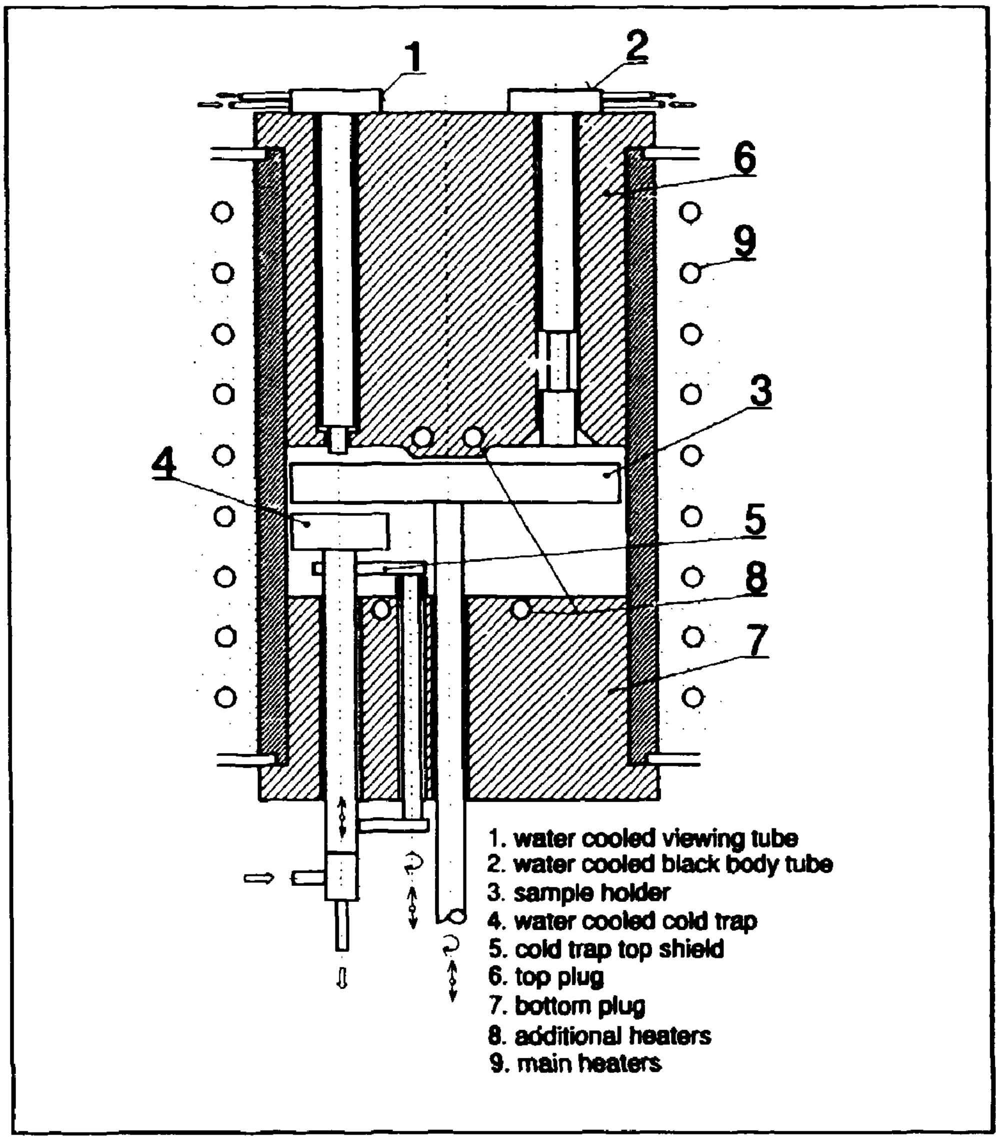

Figure 1 Rotating specimen furnace, as designed and build by ECN.

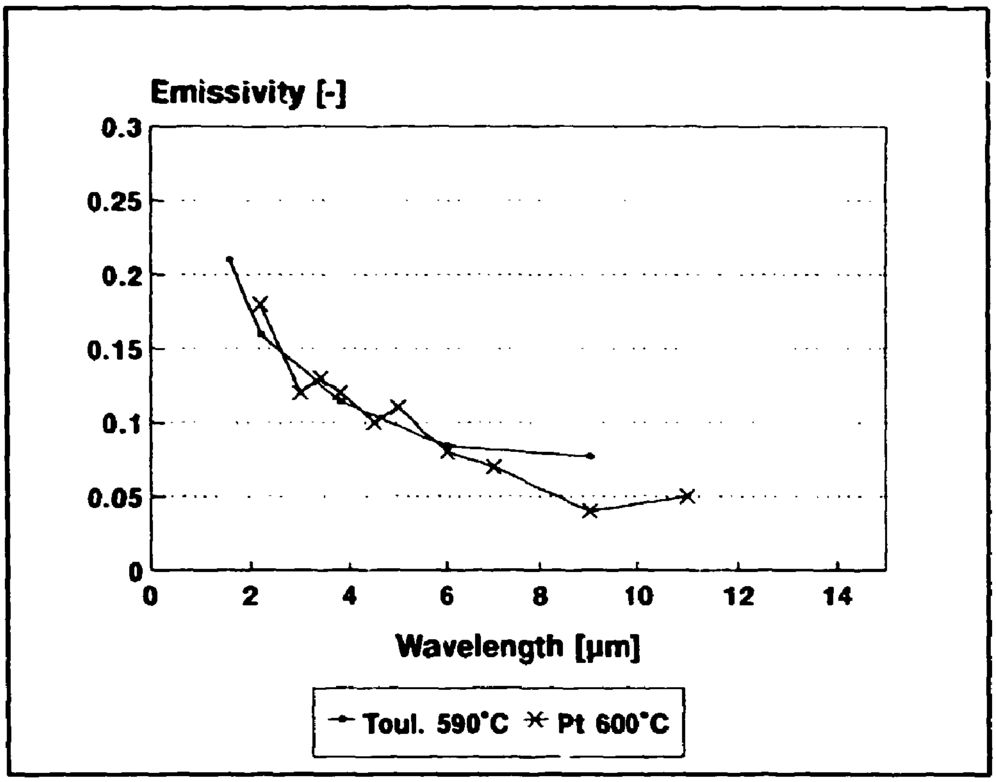

Figure 2 Emissivity of platinum versus literature at T=600 °C.

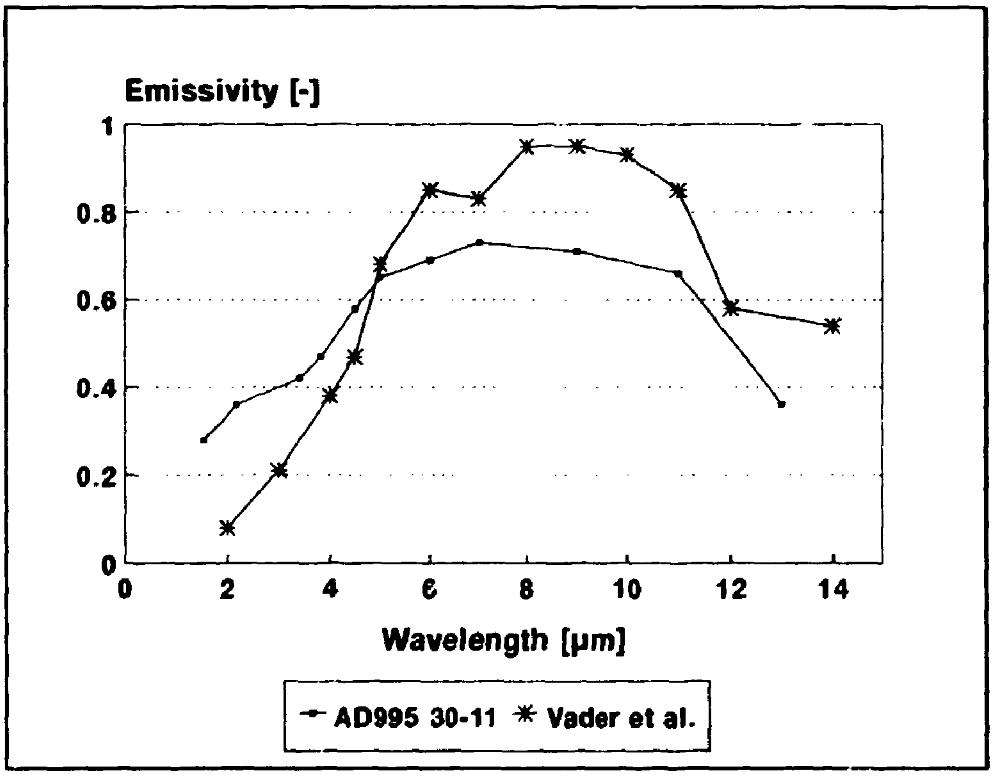

Figure 3 Emissivity of Coors versus literature at T=600 °C.

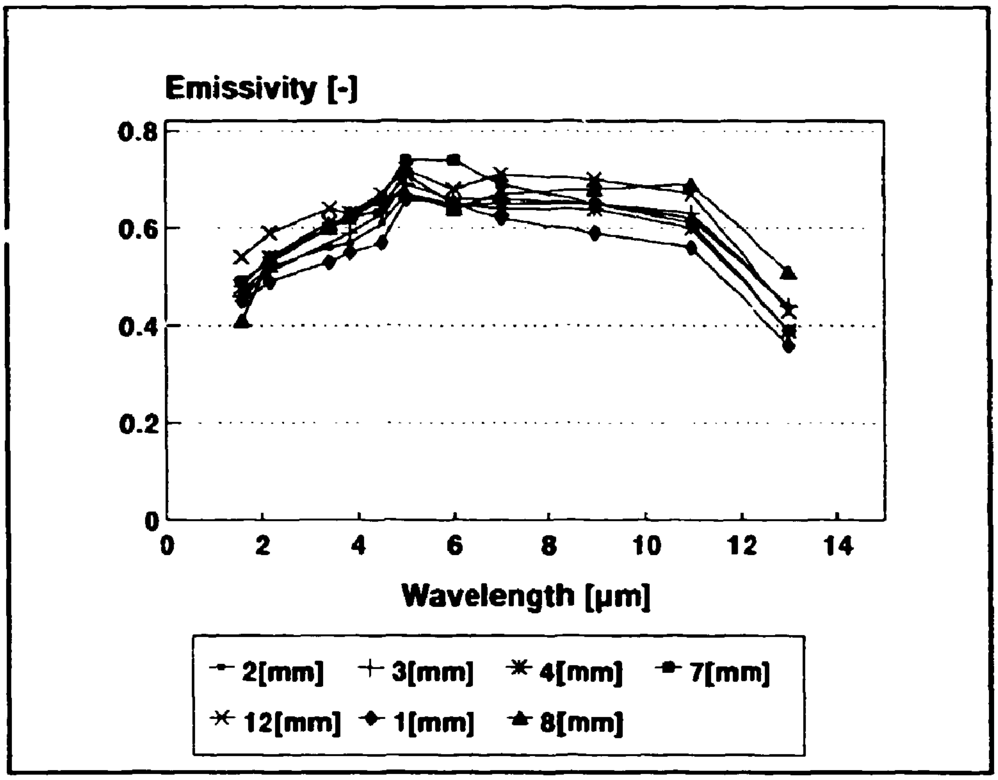

Figure 4 Emissivity of coated ceramic foam at T=750 °C.

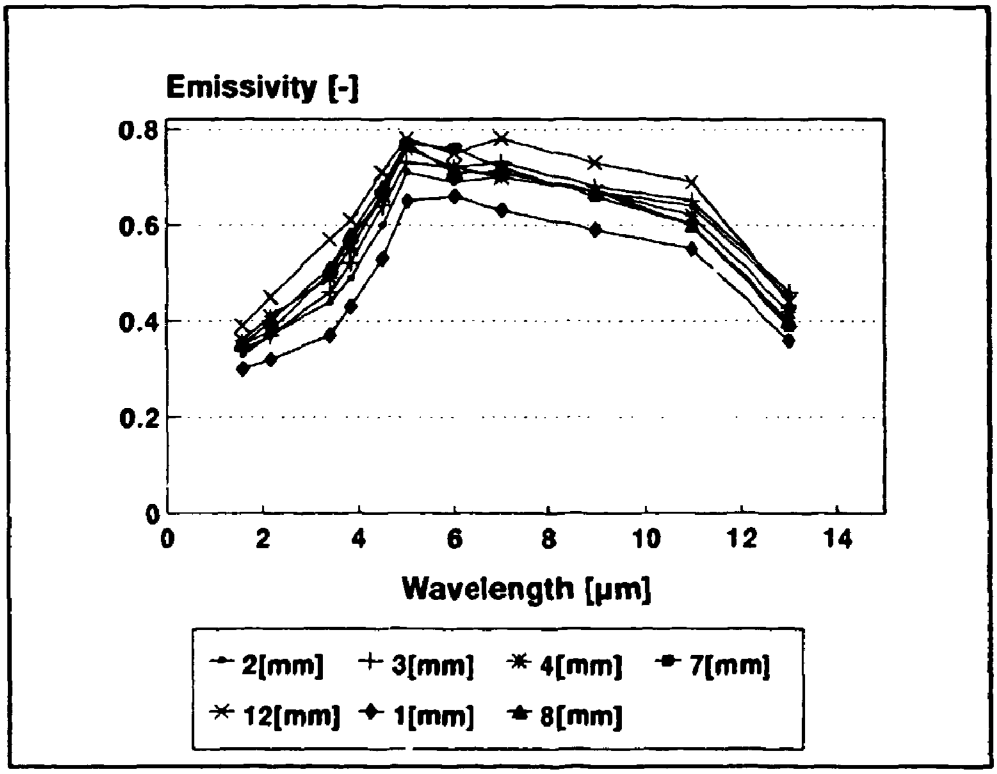

Figure 5 Emissivity of uncoated ceramic foam at T=750 °C.

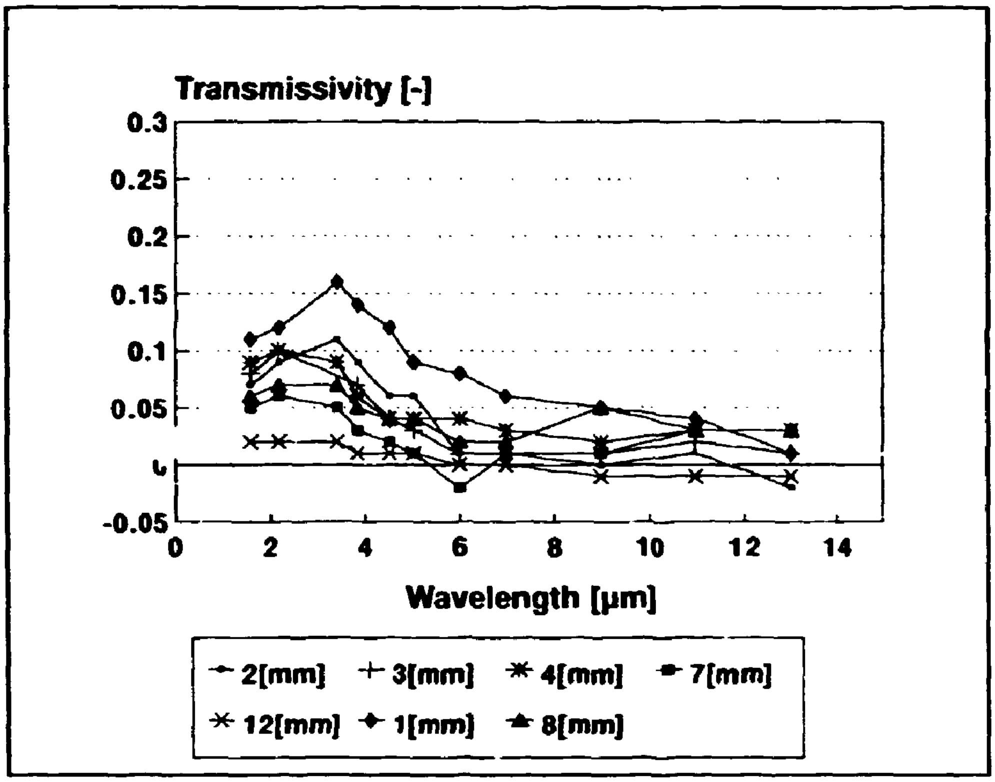

Figure 6 Transmissivity of coated ceramic foam at T=750 °C.

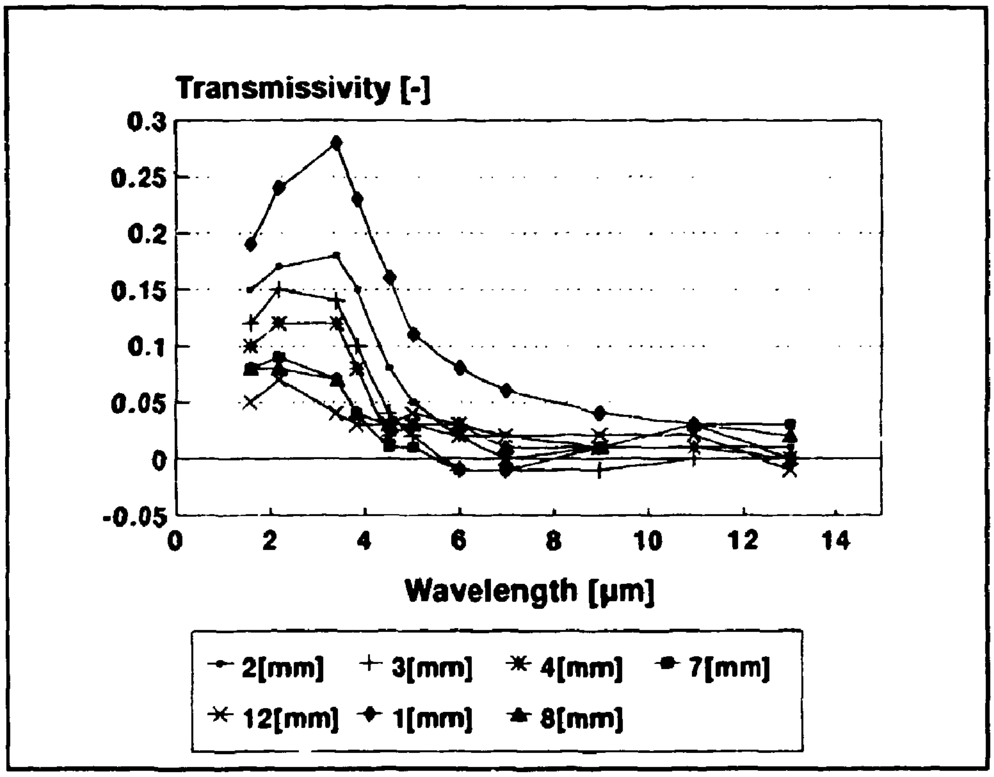

Figure 7 Transmissivity of uncoated ceramic foam at T=750 °C

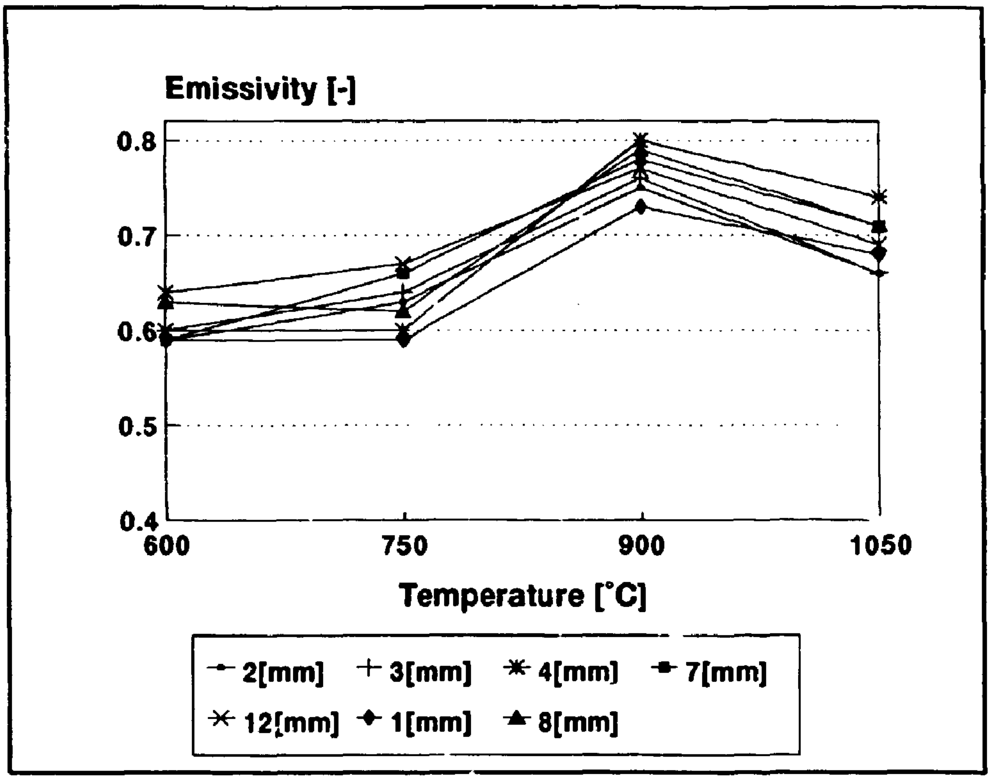

Figure 8 Total emissivity of coated ceramic foam.

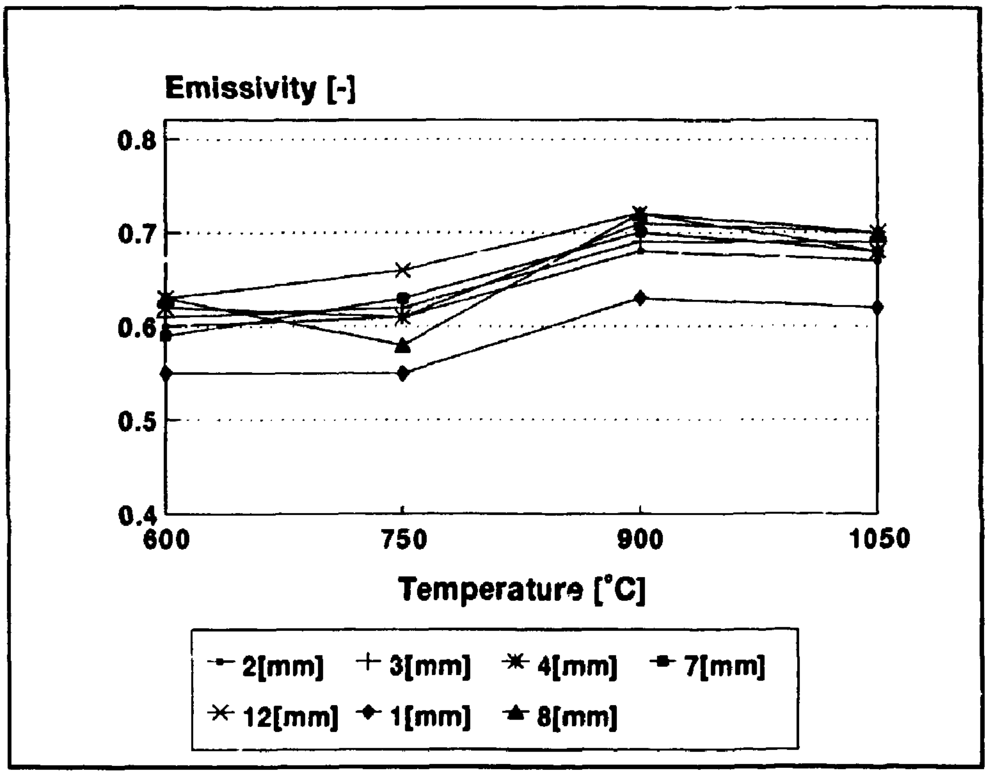

Figure 9 Total emissivity of uncoated ceramic foam.