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EXPERIMENTAL STUDY ON EFFECTIVE THERMAL CONDUCTIVITY OF FOAMS USING TRANSIENT PLANE HEAT SOURCE METHOD

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ABSTRACT

Thermal Probe Method (TPM) using transient plain source widely used to determine the effective thermal conductivity (ETC) of two phase materials. In this method, ETC of sample is determined by varying the concentration by varying thickness of the sample. The heating coil supplied with DC power is the source of heat which is in contact with surface of the sample. It is heated to temperature range between 80°C - 90°C and temperature is measured using J-type of thermocouple which is contact with the centre of the heating coil. The raise in temperature has been recorded for every 2 seconds by using lab VIEW and data acquisition system (DAQ) which is interfaced with the computer. The reliability of experimental setup has been carried out and the experimental error of 2% has been obtained which is well within the limit. The graph is plotted between in (time) VS temperature and slope is obtained at the mid-range of graph. The calculation is made by Fourier law of heat conduction and thermal conductivity is obtained for samples. The results shows that increase in concentration of the material resulted in increase in thermal conductivity.

KEYWORDS

Transient plain heat source, Effective thermal conductivity, Two phase materials and Concentration.

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INTRODUCTION

The consumption of energy is expected to rise by 71 percent between 2003 and 2030[1], so energy resources should be used efficiently for the expansion in energy consumption. In some sector, energy requirements are primarily used for space heating and cooling in houses, consisting of approximately 60% of usage[2]. In order to save energy, thermally qualified building designs have become increasingly necessary. This allows residents to improve thermal comfort due to constant fluctuations in outdoor climate conditions[3].

Porous systems such as Polyurethane foam (PU foam), Synthetic foam and Latex Rubber foam are commercially available for thermal insulation as excellent energy savers. Inside the porous system, the air trapped confers low thermal conductivity. Nihal Sarier, *et al*[4] developed PU foam through the integration of n-hexadecane and n-octadecane which is having good insulation properties against temperature changes. Chaudhary[5] and Ramvir Singh, *et al*[6] studied thermal conductivity and thermal diffusivity of samples using transient plane heat source (TPS) simultaneously. TPS method of determining thermal conductivity encompasses a very wide range (i.e. from cryogenic temperatures to high temperatures) and is also useful for measuring specimens present in different forms and sizes.

G. Labudova, *et al*[7] investigated and demonstrated that the variability of the calculation of thermal conductivity is about ±3.3% for 68% confidence level. The measurement of liquids and gases has been successfully used in this standard hot wire test process and also to solids with considerable variability to measure the thermal conductivity. Computed micro-tomography (µCT) and computed tomography (CT) developed by Solorzano *et al*[8] is a nondestructive technique to characterize the cellular structure. Foam characteristics such as cell size, cells shape, anisotropy of pores, local density, etc. can be measured by using these techniques. Thermal conductivity depends heavily on density, and because of this, the TPS method can differentiate between homogeneous and inhomogeneous zones of metallic foams.

The thermal conductivity of porous wicks was obtained by Jiyuan Xu, *et al*[9] and found that thermal conductivity was influenced not only by the porosity, but also the pore size distribution. It is inferred that for the same porosity, wicks with smaller pore size and more centralised distribution of wicks illustrates much lower thermal conductivity. The thermal conductivity of an insulation material was analysed by Alessandro Franco, *et al*[10] and found that lateritic materials does not only depend on its density, temperature and moisture content, it also relies on the atomic and molecular structure of the material, porosity, anisotropy, structural faults and defects.

The effective thermal conductivity (ETC) of foam neoprene was predicted by Erick Bardy, *et al*[11] based on semi empirical correlation for different ambient presses. The effective thermal conductivity of foam neoprene given by this empirical correlation which is a function of increasing ambient pressure can be determined if the constituent thermal conductivities are known (air and rubber).

The determination of effective thermal conductivity of polyurethane foam and latex rubber foam is reported in this paper by using the transient plane heat source method for different concentrations.

Experimental setup

The experimental arrangement (Figure No.1) consists of a sample container with various concentrations of different thicknesses. The heating coil in the experimental setup is supplied with DC power which is in contact with surface of the sample. It is heated to temperature range of 80°C - 90°C and measured by using J-type thermocouple which is contact with the centre of the heating coil. The thermocouple is interconnected with the Lab VIEW software to calculate temperature over a period of time.

After placing samples (Figure No.2-3) in sample container, the heater wires are connected to DC power supply. Figure No.1 shows the measurement of temperature using thermocouple.

Thermal Conductivity Calculations

For measurements of thermal conductivity, the output from the Lab VIEW is used. From the time (x) - temperature (T) table obtained, a new table of ln x- T entries is calculated. With the values a graph (Figure No.5-8) is drawn for in X Vs T and the slope of the graph at the required temperature has been found out. According to the theory of the transient plane source[12] on which the configuration is built, the slope of the graph should be equal to

$$\text{Slope (m)} = \left[\frac{P_0}{\pi^{\frac{3}{2}}\,a\,k}\right] \quad (1)$$

Where,

p_o - Amount of heat delivered to the heating coil per unit length in Watts.

k - ETC of two-phase material in W/m K
a - Heating coil radius in meter (0.035m)
m - Slope in °C (Temperature in °C vsln (time))

The effective thermal conductivity is determined from the Eq. 1 by knowing the amount of heat supplied and the slope of the graph. Reliability test has been conducted for the experimental set up on glycerin to validate the experimental setup. Results show that the errors in the experimental configuration were found to be 2% which is acceptable range.

RESULTS AND DISCUSSION

Through putting the foam sample in the sample container, the concentration of foam can be found and it is compressed to vary the concentration. It is possible to find out the concentration of any sample by,

Concentration = 1- porosity (2)

$$\text{Porosity} = \frac{Volume of fluid}{Volume of specimen} = \frac{V_S - V_{SC}}{V_S} \quad (3)$$

Where,
V_s - Volume of specimen = $\Pi R^2 H$
V_{sc} - Volume of specimen in compressed condition = $\Pi R^2 h$
R - Radius of the foam
H - Height of the foam
h - Height of the foam in compressed condition

The graph plotted for temperature range 32°C to 93°C and in (Time in Sec) which is actual time taken for the rise in temperature. The slope (m) is obtained at mid-range in order to avoid the initial lag error and final axial loss error. Similar graphs can be ploted for Latex rubber foam and Synthetic foam for the same concentration. By using Eq. 1, thermal conductivity of foams with varying concentration can be obtained and listed in Table No.1.

Table No.1: Effective thermal conductivity of different foam at various concentrations

S.No	Sample	Porosity	Concentration	Effective thermal conductivity (W/m °C)
1	Polyurethane foam	0.9000	0.1000	0.0472
		0.8667	0.1333	0.1093
		0.8000	0.2000	0.1117
		0.6000	0.4000	0.1371
2	Latex rubber foam	0.8529	0.1471	0.0991
		0.8039	0.1961	0.1051
		0.7059	0.2941	0.1209
		0.4118	0.5882	0.1830

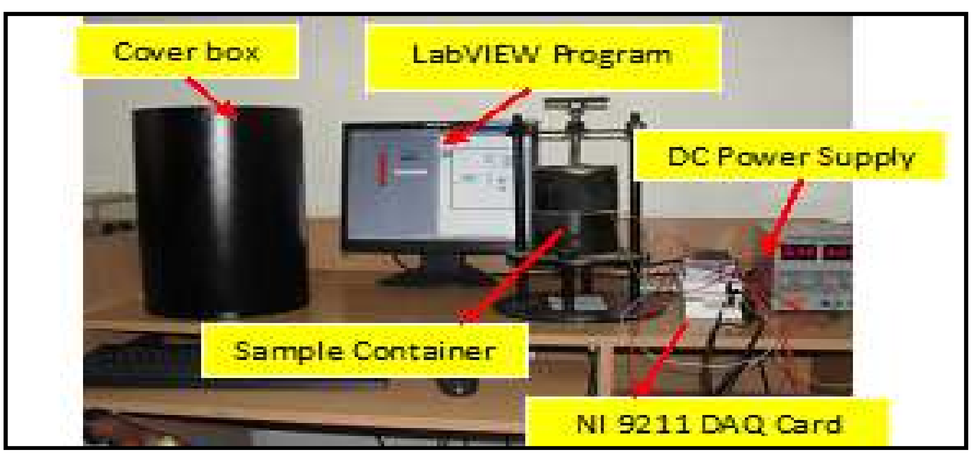

Figure No.1: Experimental setup for transient heat plane source

Figure No.2: Polyurethane Foam Sample

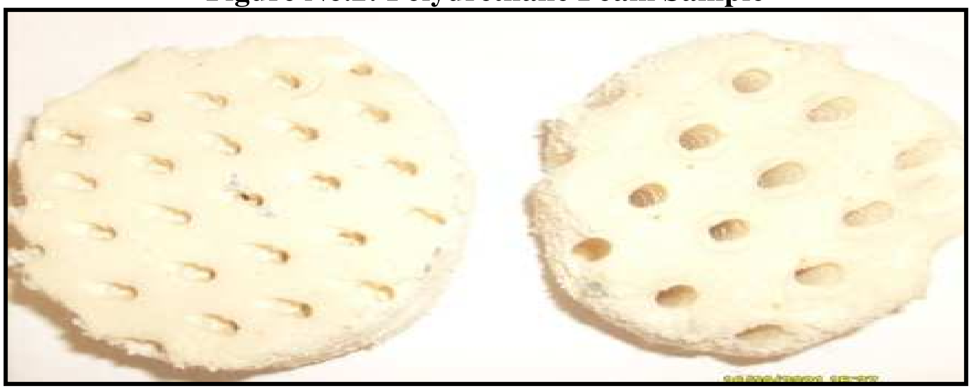

Figure No.3: Latex rubber foam sample

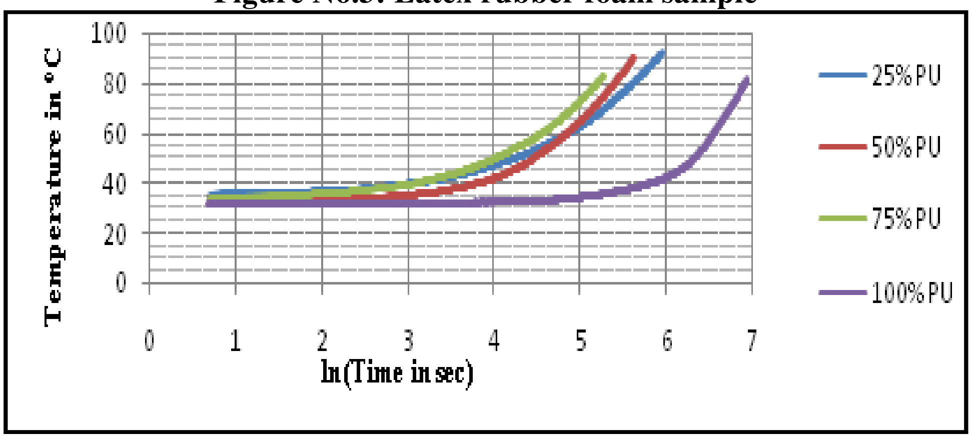

Figure No.4: Temperature in °C vsln (Time in Sec) for various concentration of Polyurethane foam

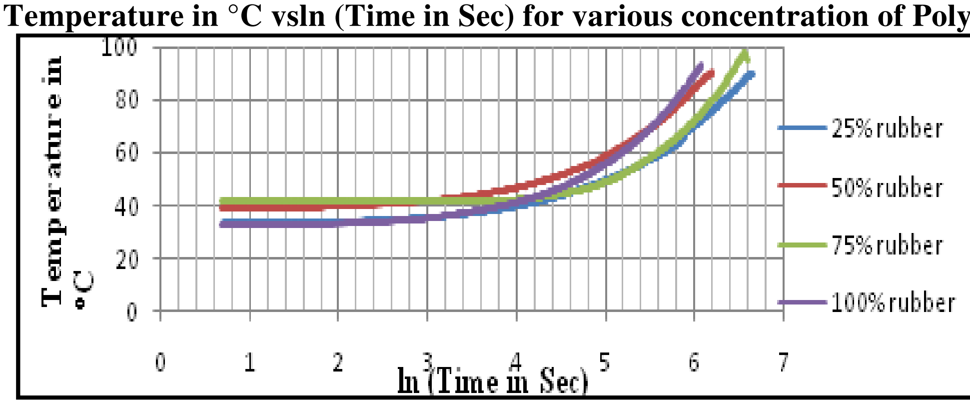

Figure No.5: Temperature in °C vsln (Time in Sec) for various concentration of Rubber foam

CONCLUSION

Based on the transient plane source principle, an experimental set-up for determining the effective thermal conductivity of two-phase materials has been developed. Polyurethane foam and latex rubber foam were tested and found that the effective thermal conductivity of the foam is changing due to a change in the sample concentration. The explanation behind the increase in thermal conductivity was due to the suspended gas evacuation within the porous system (i.e. low thermal conductivity due to air). Evacuation of gas gradually results in gradual increase in thermal conductivity.

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CONFLICT OF INTEREST

We declare that we have no conflict of interest.

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