INVESTIGATION 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 LabVIEW and data acquisition system (DAQ) which is interfaced with the computer. The calculation has been made by Fourier law of heat conduction and thermal conductivity are obtained for different samples. The result shows that the increase in concentration of the material results in increase in thermal conductivity.

***Keywords** - Transient plain heat source; Effective thermal conductivity; Two phase materials; Concentration*

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1. INTRODUCTION

Energy utilization is predicted to increase by 71% from 2003 to 2030 [1], so energy resources should be used efficiently for the expansion in energy consumption. Energy requirement in certain sector are mainly used for space heating and cooling in buildings, comprising approximately 60% of usage [2]. Thermally competent building designs have become increasingly important for energy saving. This enables to improve thermal comfort for residents from constant fluctuations in outdoor climatic conditions [3].

Commercially, porous system such as Polyurethane foam (PU foam), Synthetic foam, Latex Rubber foam are widely used for thermal insulation as excellent energy savers. The air trapped inside the porous system confers low thermal conductivity. Nihal Sarier et al [4] developed PU foam by incorporating *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 simultaneously using transient plane heat source (TPS). TPS method of determining thermal conductivity covers a very broad range (i.e. from cryogenic to high temperatures) and is also useful for measurement on specimens available in various forms and sizes.

G. Labudova et al [7] investigated and shown that the uncertainty of the thermal conductivity measurement is about ±3.3% for 68% confidence level. In this standard hot wire test method has been successfully applied to the measurement of liquids and gases and also to solids with considerable variability to measure the thermal conductivity. E. Solorzano et al [8] developed computed micro-tomography (μCT) and computed tomography (CT) as 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 strongly depends on density and due to this fact the TPS method can distinguish homogeneous and inhomogeneous zones of metallic foams.

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

Erick Bardy et al [11] predicted the effective thermal conductivity of foam neoprene at varying ambient pressure based semi empirical correlation. This empirical correlation gives the effective thermal conductivity of foam neoprene, as a function of increasing ambient pressure can be determined if the constituent thermal conductivities are known (air and rubber).

This paper reports to determine the effective thermal conductivity of polyurethane foam, synthetic foam, and latex rubber foam by using transient plane heat source method for various concentrations.

2. EXPERIMENTAL SETUP

Experimental setup (Fig. 1) consists of sample container with provision to vary concentration by varying thickness. The heating coil is supplied with DC power 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 thermocouple which is contact with the centre of the heating coil. In this set up, thermocouple is interfaced with LabVIEW program to measure temperature over a period of time.

After placing samples (Figs. 2-4) in sample container, the heater wires are connected to DC power supply. Fig.1 shows the measurement of temperature using thermocouple.

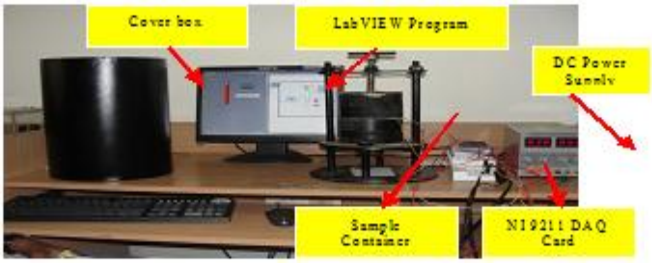

Fig.1. Experimental Setup for Transient Heat Plane Source

Fig.2. Polyurethane Foam Sample

Fig.3. Latex Rubber Foam Sample

Fig.4. Synthetic Foam Sample

2.1 Thermal Conductivity Calculations

The output from the LabVIEW is used for thermal conductivity calculations. From the time (x) - temperature (T) table, a new table of ln x-T can be obtained. With the values, a plot of **ln X Vs T** can be drawn. The slope of the plot at the required temperature can be found out for determination of thermal conductivity. According to the transient plane source theory [12], based on which the set-up is designed, the slope of the graph should be equal to

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

Where, p_o = Amount of heat supplied to the heating coil per unit length in Watts, k = Effective thermal conductivity of two-phase material in W/m K, a = Radius of heating coil in meter (0.035 m), m = Slope [Temperature in °C vs ln (time)].

Knowing the amount of heat supplied and the slope of the graph, the effective thermal conductivity is calculated from the Eq. 1. 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 setup found to be very less i.e. 2%, which is acceptable range.

2.2 Results and Discussion

The concentration of foam can be found by placing the foam sample in sample container and it is compressed to vary the concentration. Concentration of any sample can be found out by

$$\text{Concentration} = 1\text{- porosity} \qquad (2)$$

$$\text{Porosity} = \frac{Volume\ \ of\ fluid}{Volume\ \ of\ specimen} = \frac{V_s - V_{sc}}{V_s} \qquad (3)$$

Where V_s = Volume of specimen = $\Pi R^2 H$, V_{sc} = Volume of specimen when fully compressed = $\Pi R^2 h$, R = radius of the foam, H = height of the foam, h = height of the foam when it is fully compressed.

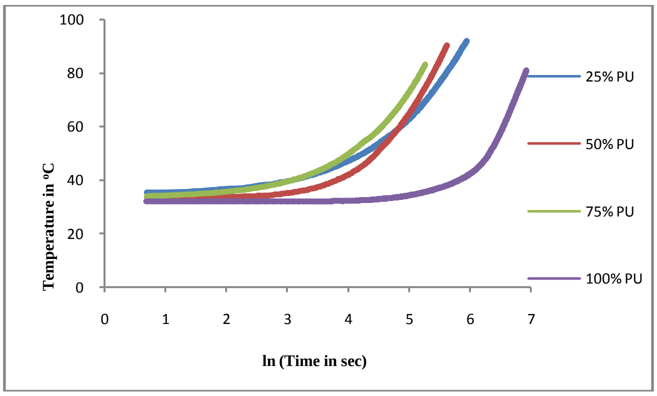

Fig.5. Temperature in °C vs ln (Time in Sec) for various concentration of Polyurethane foam

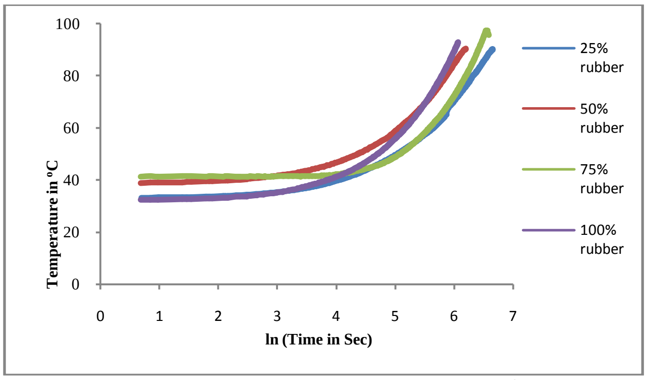

Fig.6. Temperature in °C vs ln (Time in Sec) for various concentration of rubber latex foam

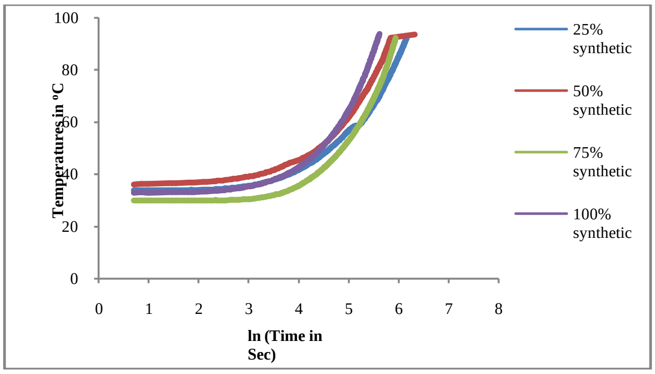

Fig.7 Temperature in °C vs ln (Time in Sec) for various concentration of synthetic foam

The plot between Temperature in °C and ln (Time in Sec) has been obtained for various foams with different concentration in the temperature range of 32°C to 93°C. The slope (m) is obtained at mid-range in order to avoid the initial lag error and final axial loss error. The thermal conductivity of various foams with varying concentration can be obtained by using Eq. (1) and listed in Table 1.

Table 1 Effective Thermal Conductivity of Different Foams at various Concentrations

Sample	Porosity	Concentration	Effective Thermal Conductivity (W/m °C)
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
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
Synthetic foam	0.8346	0.1654	0.0776
	0.7759	0.2241	0.0997
	0.6693	0.3307	0.1027
	0.3385	0.6615	0.1117

3. CONCLUSIONS

An experimental set-up for determining the effective thermal conductivity of two-phase materials has been fabricated based on transient plane source theory. Various two phase materials were tested and found that the effective thermal conductivity of the foam changes due to change in concentration of the sample. The reason behind for increase in thermal conductivity was due to evacuating gas suspended inside the porous system (i.e. since air low thermal conductivity). Gradual evacuation of gas results in gradual increase in thermal conductivity.

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