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Influence of Density and Concentration on Effective Thermal Conductivity of two Phase Materials using Square Guarded hot plate Apparatus

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Abstract

In this present work, performance study on two-phase materials based on density, temperature difference at various load under the steady state condition is experimentally analysed to estimate the Effective Thermal Conductivity (ETC) using square guarded hot plate apparatus (SGHP). The experimentally determined ETC value shows an excellent agreement with the available theoretical data.

Keywords: Effective thermal conductivity (ETC), square guarded hot plate apparatus (SGHP), two-phase materials.

Introduction

A two-phase material is one which there are distinct parts of the material that have different chemical or physical structure. The word “phase” refers to the particular arrangement of atoms in a material[1]. The two-phase materials consist of continuous and dispersed phases and are grouped in several distinct systems based on their characters. The two phase systems are generally made of solid-fluid composition with a variety of shape and size. Use of two-phase materials is regarded as one of the most effective means of energy conservation and energy efficiency in building and industrial sectors. The effective thermal conductivity of two-phase materials is an important property to determine heat transfer characteristics. The two-phase systems have considerable importance in engineering applications such as heat exchangers, nuclear reactors, solar collectors, cryogenic insulations and food materials.

The parameters influencing the effective conductivity of two-phase systems are thermal conductivities of the dispersed and continuous phases and their conductivity ratio α. Besides primary parameters, many secondary parameters that influencing conductivity are contact resistance, heat transfer through radiation, pressure, and geometrical configuration. The geometrical factors include particle size, shape, location and orientation[2].

There are two methods available to estimate the ETC of two-phase materials. They are steady state and unsteady state method. Unsteady state method has been widely used for determining ETC of two-phase materials due to its simple technique, less time consumption and low cost of instrumentation. But the accuracy of this method is less in comparison with steady state method. Guarded hot plate method[3,4] is one the standard steady state methods for determining ETC of two-phase materials even though it is time consuming.

The analytical model for measuring ETC of two-phase materials have been described[5].

Thermal conductivity of any material is defined Fourier law[6]. According to Fourier law, for one-dimensional heat conduction the appropriate relation that defines the thermal conductivity is

$$k = \frac{Q \times L}{\Delta T \times A} \qquad (1)$$

Here ΔT represents absolute value of temperature difference across the thickness L of the medium.

Guarded hot plate method: The guarded hot plate method is the widely used for measuring the thermal conductivity of insulation materials. The standard steady-state guarded hot plate (GHP) method is recognized by the American Society of Testing and Materials[3] and International Organisation for Standardization[4]. This method is suitable for flat specimen, which is suitable for one-dimensional axial heat flow[7]. Test specimens can range from low density super insulation materials to metals and ceramics with high thermal conductivity. The guarded hot plate apparatus is essentially classified into two types, circular and square. The square guarded hot apparatus is simple and efficient compared to circular hot plate apparatus.

Material and Methods

The various components of Square Guarded Hot Plate (SGHP) apparatus are, stack system, coolant pump, radiator, pipe heater, control panel, DC and AC supply for main and auxillary heaters respectively. Stack system consists of a main heater, two auxillary heaters and coolant blocks. Two samples of identical size are arranged symmetrically between the assembly consisting of main and auxillary heaters shown in figure-1. The two heaters are energized by independent power supplies with suitable controllers. Heat transfer from the lateral edges of the sample is prevented by the guard packed by a thick layer of insulation all along the periphery. The two faces of the samples are maintained at different temperature by heaters on one side and cooling water circulation on the other side. Identical one-dimensional temperatures fields are setup in the two samples.

In guarded hot plate apparatus, the ETC is computed from the measured power input, specimen thickness, effective area and temperature difference between hot and cold plates. In practical systems, there may be temperature variations in the hot and cold plates, radial heat flow in the specimen and temperature fluctuations to add uncertainty in the measurement of thermal conductivity. Since it is a two-phase material, there is a random distribution of dispersed particles. So temperature of the specimen should be measured at more than one location (say 16). There are 16 thermocouples in the main heater. The auxillary heaters and the coolant blocks have 2 thermocouples each. So a total of 24 thermocouples are used.

Test Specimen: The test is conducted for the specimen, polyurethane foam. Foam is a substance that is formed by trapping gas in a liquid or solid in a divided form, i.e. by forming gas regions inside liquid or solid regions, leading to different kinds of dispersed media. Some typical applications in which the polyurethane foams are used in food preservators and insulation.

The standard dimension of PU foam specimen is 300mm × 300mm x 45mm and different densities of PU foam selected are 23, 32 and 40 kg/m^3. The three parameters which are considered for testing are density, temperature difference and load condition. The temperature difference is suitably varied from 10^{o}C to 30˚C.

The three different load conditions are no load, half load and full load. Load conditions are expressed in terms of concentration. Applied load results in change in the volume of the specimen. The load condition and the concentration of the specimen are related by

$$\text{Concentration}, \nu = \frac{\text{Volume of fluid phase}}{\text{Total volume}} \qquad (2)$$

In no load condition, there is no load acting on the specimen and hence the thickness of the specimen remains unchanged as 45 mm. So the concentration (ν) of the specimen at no load condition is zero. In half load condition, the thickness of the specimen is compressed to half of its initial thickness. In full load condition, the thickness of the specimen is compressed to its maximum possible extent. It has exceptional thermal properties and boasts a 'k' value of between 0.018 - 0.023 W/m K at normal conditions for density 30kg/m^3.

Model calculation: Material (Density 23 kg/m^3)
Temperature at various points from temperature indicator: For main heater: (T in $^{\circ}$C)
$T_1 = 44$, $T_8 = 45$, $T_2 = 45$, $T_9 = 45$, $T_3 = 45$, $T_{10} = 44$, $T_4 = 45$ $T_{11} = 46$, $T_5 = 45$, $T_{12} = 44$, $T_6 = 45$, $T_{13} = 45$, $T_7 = 46$ $T_{14} = 45$

Average main heater temperature: $T_{avg} = 44.9375 = 45^0$C, For top auxillary heater (values from indicator): $T_{15} = 35^0$C, $T_{16} = 35^0$C, Average top heater temperature: $T_{avg} = 35^0$C, Temperature difference $\Delta T = 45 - 35 = 10^0$C $= 10$ K, Area of the specimen, $A = 300 \times 300$ mm, $= 0.09$ m^2
Thickness of the specimen, $L = 0.045$ m
Thermal conductivity, $k = \frac{Q \times L}{\Delta T \times A}$
Heat power input, $Q = (V \times I) = (6 \times 0.152)$
$Q = 0.912$ W (for 2 specimens)
For a single specimen, $Q = 0.456$ W

$$k = \frac{0.456 \times 0.045}{10 \times 0.09}$$

$$k = 0.0228 \text{ W/m K}$$

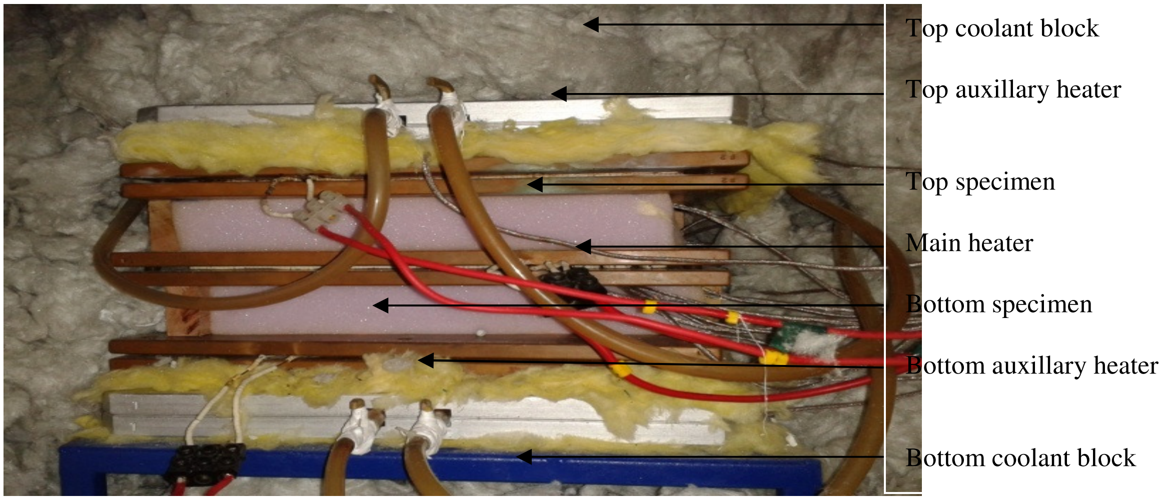
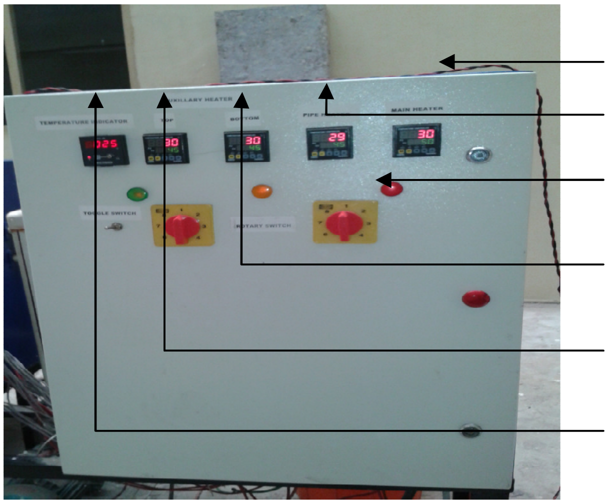


Figure-1
Guarded Hot Plate Apparatus



Temperature controller for main heater

Temperature controller for pipe heater

Rotary switch

Temperature controller for bottom auxillary heater

Temperature controller for top auxillary heater

Temperature indicator

Results and Discussion

The conductivity ratio (α) is defined as the ratio of thermal conductivity of the solid phase (k_s) to the thermal conductivity of fluid phase (k_f). Here the fluid phase is the air present in the void space. For polyurethane foam conductivity ratio (α) is less than 1, (i.e) $k_s < k_f$. As density increases, there is a shrinkage of void space. This results in evacuation of air from the foam. Hence, the volume of fluid phase decreases. The thermal conductivity takes place mainly through the solid phase. Thus, increase in density results in decrease in effective thermal conductivity as shown in figure- 13.

When the load applied on the Polyurethane foam increases, there is evacuation of air from the voids. This results in decrease in the concentration of fluid phase. Thus, decrease in concentration of the fluid phase results in decrease in the effective thermal conductivity as shown in figure- 12.

Conclusion

The effect of density, temperature difference and different load conditions on the ETC of the polyurethane foam have been experimentally investigated under steady state condition. The experimental effective thermal conductivity values are in close range with the theoretical values. From the results, it is proved that the evacuation of the air in the void space reduces the effective thermal conductivity of the system.

References

1. Andrew Skipor, Ph.D., Argonne national laboratory, Two-Phase Materials, **(2004)**
2. Cengel Y.A., Heat transfer-A Practical Approach, Tata McGraw-Hill Publishing Company Limited, Revised Edition **(2002)**
3. ASTM C 177-97, "Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the guarded hot plate apparatus", Annual book of ASTM Standards, 04-06, West Conshocken
4. ISO 8302, Thermal insulation-determination of steady state area of thermal resistance and related properties-guarded hot plate apparatus (International Organisation for Standardization, Geneva, Swizerland) **(1991)**
5. Senthil Kumar A.P., Karthikeyan P. and Prabhu Raja V., Empirical Correlation of Various Inclusions on the Effect of Primary and Secondary Parameters for Estimation of Effective Thermal Conductivity (ETC) of Two Phase Materials, *Res. J. Recent Sci*., **1(1)**, 22-32 **(2012)**
6. Kothandaraman C.P. and Subramanyan S." Heat and Mass Transfer Data Book", New Age International Publishers, Seventh Edition **(2010)**
7. Zarr R.R., History of the Guarded-Hot-Plate Apparatus at NIST available on the internet at http://www.bfrl.nist.gov/863/hotplate, Gaithersburg MD: National Institute of Standards and Technology **(1997)**
8. Senthilkumar A.P., Prabhu Raja V. and Karthikeyan P., Comparison of Geometry Dependent Resistance Models with Conventional Models for Estimation of effective Thermal Conductivity of Two-Phase Materials, *Heat Mass Transfer – Springer*, 46(11-12), 1379-1394 **(2010)**

Table-1
Experimental values of ETC for Polyurethane Foam

Test No.	ρ Kg/m^3	Load condition	ν %	ΔT K	Voltage V	Current A	Q W	k W/mK
1	23	No	0	10	6	0.15	0.912	0.0228
2	23	No	0	15	7.5	0.188	1.392	0.0232
3	23	No	0	20	8.5	0.223	1.896	0.0237
4	23	No	0	25	9.5	0.254	2.44	0.0244
5	23	No	0	30	10.5	0.282	2.964	0.0247
6	23	Half	50	10	7	0.17	1.184	0.0148
7	23	Half	50	15	8.5	0.216	1.836	0.0153
8	23	Half	50	20	9.5	0.265	2.528	0.0158
9	23	Half	50	25	11	0.294	3.24	0.0162
10	23	Half	50	30	12.5	0.316	3.96	0.0165
11	23	Full	77.77	10	8	0.207	1.656	0.0092
12	23	Full	77.77	15	9	0.247	2.241	0.0083
13	23	Full	77.77	20	11	0.29	3.168	0.0088
14	23	Full	77.77	25	12.5	0.325	4.095	0.0091
15	23	Full	77.77	30	13.5	0.372	5.076	0.0094
16	32	No	0	10	5.5	0.13	0.72	0.018
17	32	No	0	15	6.5	0.166	1.08	0.018
18	32	No	0	20	7.5	0.195	1.464	0.0183
19	32	No	0	25	8.5	0.22	1.89	0.0189
20	32	No	0	30	9	0.255	2.304	0.0192
21	32	Half	50	10	5.5	0.126	0.688	0.0086
22	32	Half	50	15	6.5	0.162	1.056	0.0088
23	32	Half	50	20	7.5	0.198	1.488	0.0093
24	32	Half	50	25	8.5	0.223	1.9	0.0095
25	32	Half	50	30	9	0.262	2.376	0.0099
26	32	Full	71.11	10	6	0.16	0.983	0.0071
27	32	Full	71.11	15	7	0.176	1.246	0.006
28	32	Full	71.11	20	8	0.207	1.661	0.006
29	32	Full	71.11	25	9	0.237	2.111	0.0061
30	32	Full	71.11	30	9.5	0.275	2.616	0.0063
31	40	No	0	10	5	0.135	0.676	0.0169
32	40	No	0	15	6.5	0.158	1.02	0.017
33	40	No	0	20	7.5	0.191	1.352	0.0169
34	40	No	0	25	8	0.217	1.74	0.0174
35	40	No	0	30	9	0.236	2.124	0.0177
36	40	Half	50	10	5	0.125	0.608	0.0076
37	40	Half	50	15	6	0.154	0.924	0.0077
38	40	Half	50	20	7	0.18	1.28	0.008
39	40	Half	50	25	8	0.207	1.64	0.0082
40	40	Half	50	30	8.5	0.231	1.992	0.0083
41	40	Full	66.66	10	5	0.127	0.612	0.0051
42	40	Full	66.66	15	5	0.12	0.6	0.005
43	40	Full	66.66	20	7	0.167	1.152	0.0048
44	40	Full	66.66	25	8	0.199	1.59	0.0053
45	40	Full	66.66	30	8.5	0.23	1.98	0.0055

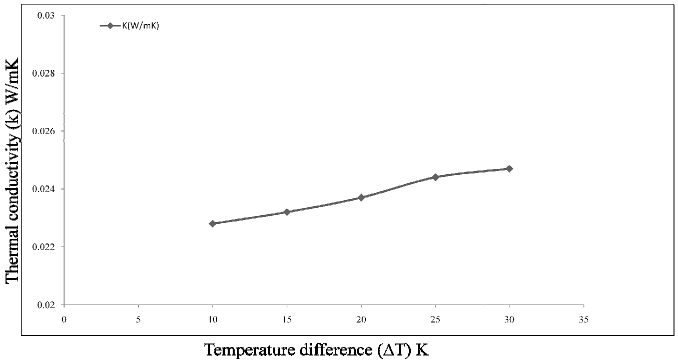


Figure-3
Experimental ETC for ρ = 23kg/m^3 at no load condition

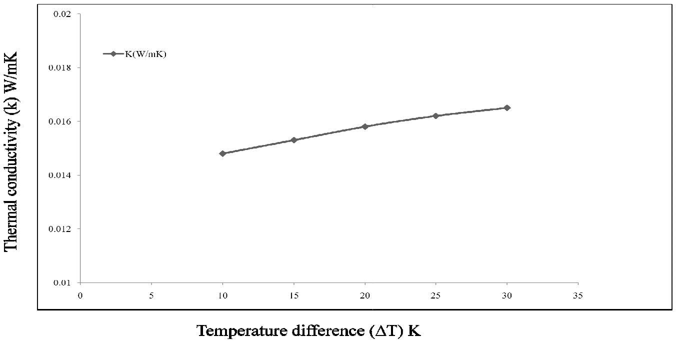


Figure- 4
Experimental ETC for ρ = 23kg/m^3 at half load condition

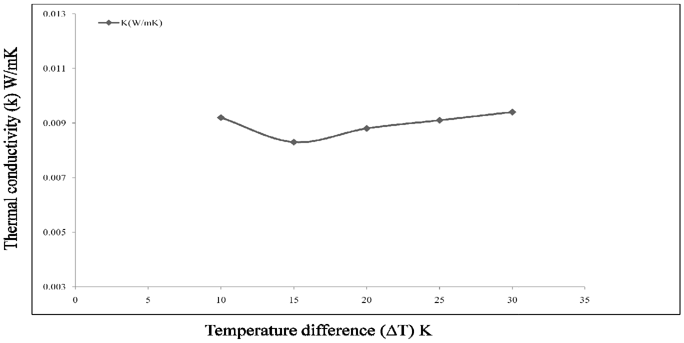


Figure- 5
Experimental ETC for ρ = 23kg/m^3 at full load condition

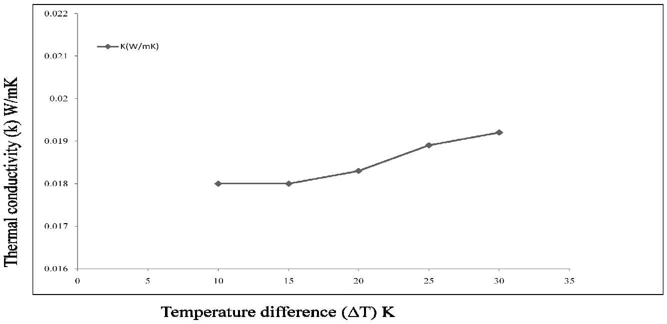


Figure-6
Experimental ETC for ρ = 32kg/m^3 at no load condition

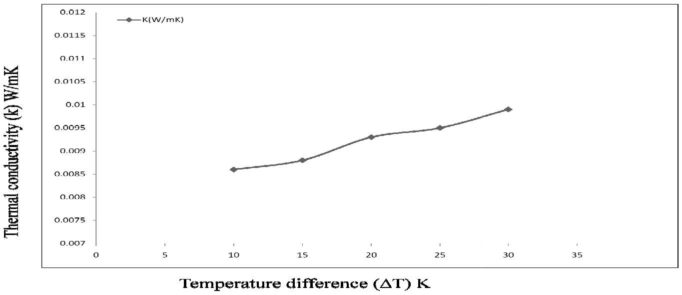


Figure-7
Experimental ETC for ρ = 32kg/m^3 at half load condition

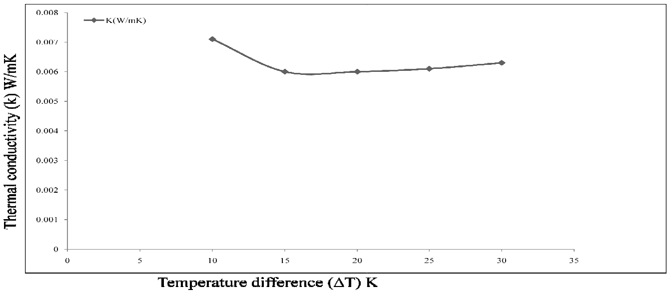


Figure- 8
Experimental ETC for ρ = 32kg/m^3 at full load condition

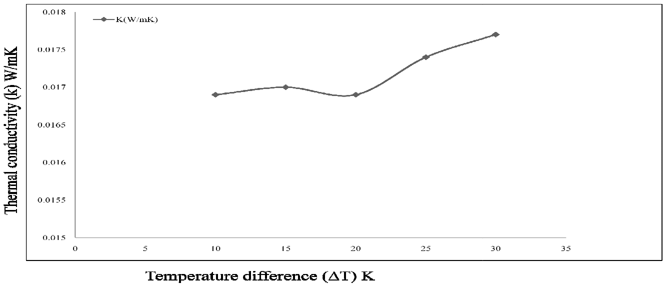


Figure- 9
Experimental ETC for ρ = 40kg/m^3 at no load condition

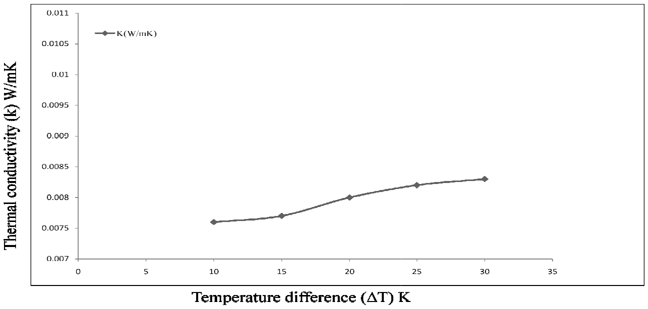


Figure- 10
Experimental ETC for ρ = 40kg/m^3 at half load condition

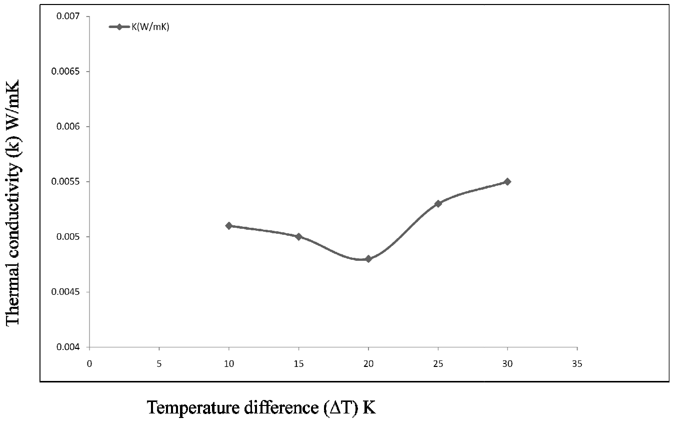


Figure- 11
Experimental ETC for ρ = 40kg/m^3 at full load condition

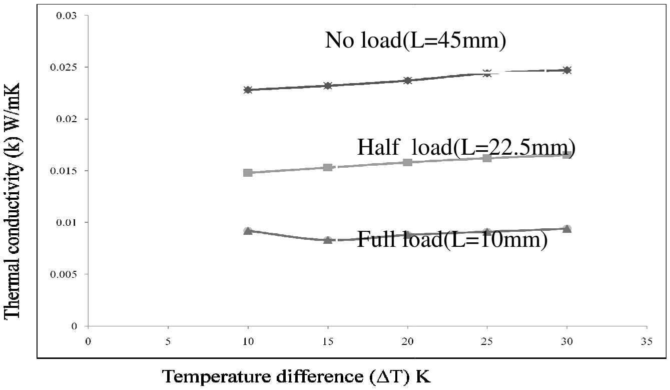


Figure- 12
Comparison of ETC with temperature difference for no load, half load and full load conditions for a constant density (ρ=23kg/m^3)

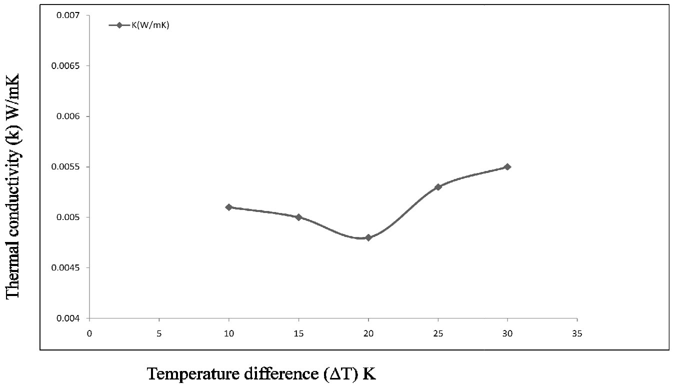


Figure-11
Experimental ETC for ρ = 40kg/m^3 at full load condition

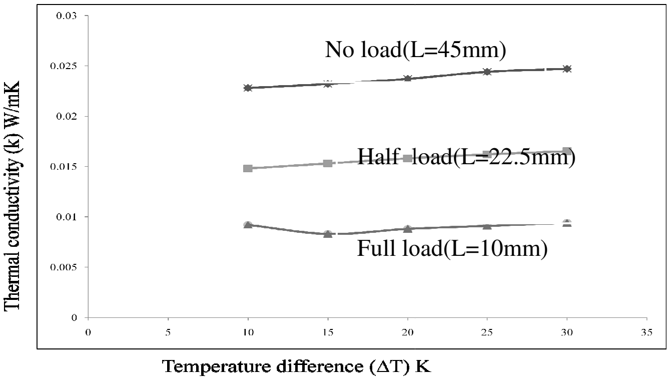


Figure- 12
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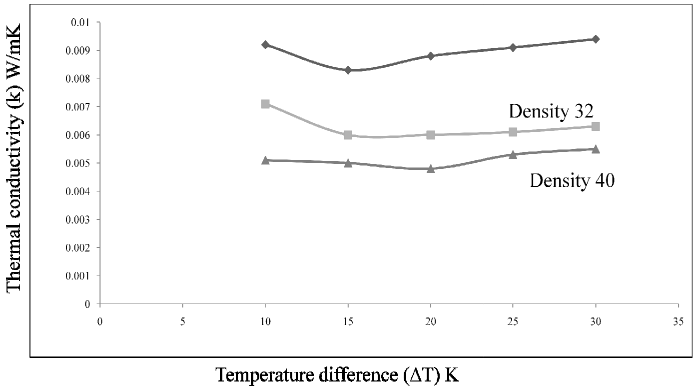

Figure-13
Comparison of ETC with temperature difference for three densities for a constant full load condition

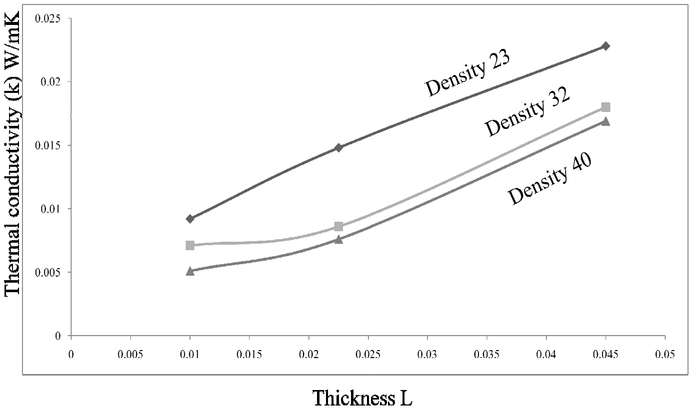

Figure-14
Comparison of ETC with thickness for three densities for a constant temperature difference (ΔT=10 K)