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Modelling and Prediction of Effective Thermal Conductivity of Two-Phase System With Interfacial Layer

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Abstract

The effective thermal conductivity, the semi-empirical theoretically model often used are generally based network combinations of the series and parallel models. In general the effective thermal conductivity of open cell foam material is much higher than that of granular material of the same component due to the enhanced effective heat transfer by the inner netlike morphology of the foam material. We developed a numerical expression for two phase systems being comprised by contribution from both the phase with the interfacial layer. A new correlation term θ are introduced for a resistor model to determine effective thermal conductivity of two phase porous system, As a porous medium is neither composed of slabs parallel nor perpendicular to the heat flux, it is proposed to use slab inclined at an angle θ with the heat flux. Best fitting relation θ in terms of the thermal conductivity are presented here.

Keywords: Effective Thermal Conductivity (ETC); Series And Parallel Resistors ; Angle Of Inclination; Interfacial Layer.

Introduction

The effective thermal conductivity of two phase mixtures, where the two phases have different thermal conductivities has attracted the attention of theorists ever since the pioneering work of more than one hundred year ago [1-2]. Theoretical modeling and prediction for two-phase systems is a challenging task for engineers, mathematicians and physicists. Dependence of the ETC (effective thermal conductivity) of these material on porosity shape, grain size, packing of the particles is also a matter of concern to engineers, architects, and physicists. The importance of two phase material like soil, ceramics, granular materials, emulsion, silica aerogels, foamed polymers, metal foam like their application in high performance cryogenic insulation. The parameter of fluids, such as the size, volume fraction, the thickness of the interfacial layer, are shown to play important roles in the enhancement of thermal conductivity.

Several models have been proposed for modeling and predicting the effective thermal conductivity of highly porous two phase systems, which have been summarized and reviewed in publications [3-8]. Calmidi and Mahajan [9] presented a one dimensional thermal conduction model by considering the porous structure as two dimensional array of hexagonal cells. Boomsma and Poulikakos [10] proposed a one dimensional heat conduction model based on a three dimensional tetrakaidecahedral frame description of the structure. R. Singh and H.S. Kasana [11] independently developed models utilizing geometrical estimate for calculation of ETC for metallic foam saturated with a fluid. Bhattacharya et al. [12] has extended the analysis of Calmidi and Mahajan [9] with a circular intersection. Zhang et al [21] develop a randomly mixed model to predict the effective thermal conductivity of moist porous media.

In this paper we developed a suitable expression for predicting the static ETC for highly porous two phase systems. In order to incorporate varying individual geometries and non-linear flow of heat flux lines generated by the different conductivity of the constituent phases. The irregular shape have been assumed to be distributed randomly in the continuous medium. The resistor model has been applied to determine ETC of the unit cell, thermal resistors formed out of the phases, in the form of parallel slabs, are considered, further the slabs are taken to be inclined angle θ to the direction of the heat flow. The expression for θ has been obtained, using curve fitting technique.

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Theory

In the literature [15-20] one find that the ETC of a composite is an additive property . Considering various components as resistors one can take combinations of such resistors to predict effective thermal conductivity. This is a common practice adopted to predict ETC from the thermal conductivity of the constituent phases. Accepting the similarity, A relation is proposed here in the following manner.

consider a two phase medium made up of solid material (subscript s); a fluid (subscript f) and interfacial layer between solid and fluid (subscript sf) filling the pore space having volume fractions ϕ_s , ϕ_f , ϕ_{sf} respectively . The matrix is supposed to be made up of layers oriented parallel and perpendicular to the direction of heat flow, alternately as depicted in fig. 1 .

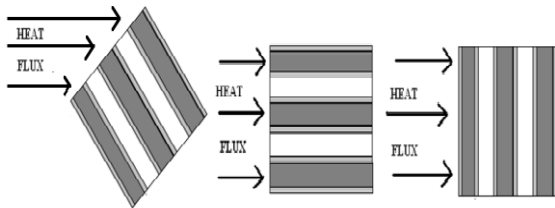


Fig. 1. Configuration of the resistors in a two phase system with inclined angle θ .

The thermal conductivity of resistors arranged in parallel layers $\lambda_{||}$ is given by the weighted arithmetic mean and that of perpendicular layers λ_{\perp} by weighted harmonic mean. The corresponding expressions are

$$\lambda_{||} = \phi_f \lambda_f + \phi_s \lambda_s + \phi_{sf} \lambda_{sf} \quad (1)$$

$$\lambda_{\perp} = \frac{\lambda_f \lambda_s \lambda_{sf}}{\phi_f \lambda_s \lambda_{sf} + \phi_s \lambda_f \lambda_{sf} + \phi_{sf} \lambda_f \lambda_s} \quad (2)$$

Where λ_s thermal conductivity of solid phase, λ_f is thermal conductivity of fluid phase, λ_{sf} is the thermal conductivity of interfacial layer , ϕ_s is volume fraction of solid phase , ϕ_f is volume fraction of fluid phase , ϕ_{sf} is volume fraction of interfacial layer.

In Esq. (1) and (2) $\lambda_{||}$ and λ_{\perp} represent the upper and lower bounds of the effective thermal conductivity for a mixture. Thus $\lambda_{||} = (\lambda_e)_{\max}$ and $\lambda_{\perp} = (\lambda_e)_{\min}$.

It is known that a two phase system is neither composed of slabs parallel to the heat flux nor perpendicular to it , yet the concept of the slabs is capable of predicting the maximum and minimum limits of the effective thermal conductivity . Therefore, it is proposed that the slabs of the continuous and dispersed phases, inclined to the heat flux, may represent the effective thermal conductivity of the system.

Now, let us assume the continuous and dispersed phases in form of the parallel slabs (equivalent resistors) , which make an angle ' θ ' with the direction of heat flux . Let us also assume that effective thermal conductivity has a direction along the slabs. As the slabs are neither parallel nor perpendicular to the heat flux , we resolve the effective thermal conductivity in two components, one parallel to the heat flux (say λ_{pl}) and the other perpendicular to it (say λ_{pr}).

The two components should be such that,

- (i) For $\theta = 0$, the component λ_{pl} reduces to $\lambda_{||} = (\lambda_e)_{\max}$ and λ_{pr} reduces to $\lambda_{\perp} = 0$.
- (ii) For $\theta = \pi/2$, the component λ_{pl} reduces to $\lambda_{||} = 0$ and λ_{pr} reduces to $\lambda_{\perp} = (\lambda_e)_{\min}$.

These considerations lead to the conditions that the components should be ,

$$\lambda_{pl} = (\lambda_e)_{\max} \cos \theta \quad (3)$$

$$(\lambda_{pr}) = (\lambda_e)_{\min} \sin \theta \quad (4)$$

Hence , the effective thermal conductivity is given by ,

$$\lambda_e = (\lambda_{pl}^2 + \lambda_{pr}^2)^{1/2} \quad (5)$$

Eqs. (3) to (5) suggest that an increase in the angle θ will increase λ_{pr} and decrease λ_{pl} components. The net result will be a decrease in effective thermal conductivity. On the other hand, decrease in θ will have a reverse effect and effective thermal conductivity will be increase.

From Eqs. (3) to (5), we get

$$\lambda_e = (\lambda_{||}^2 \cos^2 \theta + \lambda_{\perp}^2 \sin^2 \theta)^{1/2} \quad (6)$$

$$\lambda_e = \frac{[(\phi_f \lambda_f + \phi_s \lambda_s + \phi_{sf} \lambda_{sf})^2 \cos^2 \theta + (\frac{\lambda_s \lambda_f \lambda_{sf}}{\phi_f \lambda_s \lambda_{sf} + \phi_s \lambda_f \lambda_{sf} + \phi_{sf} \lambda_s \lambda_f})^2 \sin^2 \theta]^{1/2}}{\cos^2 \theta} \quad (7)$$

The angle of inclination of the slabs ' θ ' , the ETC of any system can be obtained .

Therefore, rearranging Eq. (7) , we get

$$A \sin^2 \theta + B = 0 \quad (8)$$

Where

$$A = [\lambda_s^2 \lambda_f^2 \lambda_{sf}^2 - \{\phi_f \lambda_s \lambda_{sf} + \phi_s \lambda_f \lambda_{sf} + \phi_{sf} \lambda_s \lambda_f\}^2] \{ \phi_f \lambda_f + \phi_s \lambda_s + \phi_{sf} \lambda_{sf} \}^2 \text{ and } B = \{ \phi_f \lambda_s \lambda_{sf} + \phi_s \lambda_f \lambda_{sf} + \phi_{sf} \lambda_s \lambda_f \}^2 \cdot [\phi_f \lambda_f + \phi_s \lambda_s + \phi_{sf} \lambda_{sf}]^2 - \lambda_e^2 .$$

The experimental results show that ETC depends upon various characteristics of the system. The most prominent among them are the non uniform shape of the particles, the random packing of the phases and the non-uniform flow of heat flux lines in the phases. For the practical utilization of Eq. (7) , we have to calculate the value of angle θ using data given in literature.

Result and Discussion

The theoretical model discussed above on two phase systems , for which the characteristics of the constituent phases , including thermal conductivities of solid phase , fluid phase and interfacial layer , porosity and the experimental results for the ETC have been cited in the literature [18,19] . First of all , angle θ is calculated from a large number of experimental data reported in the literature , by putting the value of thermal conductivity of constituent phases and as in Eq. (7) . A curve has been plotted between $\sin^2 \theta$ and $\phi_f^{2/5} \ln (\lambda_s / \lambda_f)$. The plot of $\phi_f^{2/5} \ln (\lambda_s / \lambda_f)$ versus $\sin^2 \theta$ are shown in fig. 1-2 . It is found that $\sin^2 \theta$ (for Solid-air , emulsion, suspension, granular, and solid-solid two phase systems) increases roughly linearly with increasing $\phi_f^{2/5} \ln (\lambda_s / \lambda_f)$) and found that $\sin^2 \theta$ (for Al-water , reticulated vitreous carbon (RVC)-air, reticulated vitreous carbon (RVC)-water system) decreases roughly linearly with increasing $\phi_f^{2/5} \ln (\lambda_s / \lambda_f)$. The expression

$$\sin^2 \theta = C_1 \phi_f^{2/5} \ln (\lambda_s / \lambda_f) + C_2 \quad (9)$$

best -fitted curve obtained from fig. 2-6. where C_1 and C_2 are constant. These constants for different type of materials. The values of these constants for Solid-air , emulsion, suspension, granular, and solid-solid two phase systems are 0.71302 and -0.34192,

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for Al-water system constant are -0.68041 and 4.41243 ,for reticulated vitreous carbon (RVC)-air system constant are -27.33255 and 158.58627 , for reticulated vitreous carbon (RVC)-water system constant are -24.29331 and 64.09428 respectively.

On putting (9) as the porosity correction term in (7) we have calculated values of effective thermal conductivity for a large number of samples reported in the literature . Tables 1-4 show a comparison of experimental results of effective thermal conductivity and calculated values from (7) . The average deviation is 1.75% for solid-air, emulsion , suspension, granular , and solid-solid two phase systems shown in table-1 and for metal and non metal foams the average deviation is 3.03% shown in table -2, respectively. The constant C₁ and C₂ in (9) are different for metal foams.

In the present model , $\lambda_{sf} = 2\lambda_f$ (i.e. $K_{layer} = 2k_f$) , the same value as that given by Leong et.al. [22] is used in the calculation of the thermal conductivity. we have used curve fitting technique and found that expression

$$\phi_{sf(solid-solid)} = 2.91879 \cdot 10^{-29} \cdot \left(\ln \frac{\lambda_s}{\lambda_f}\right) * \left(\ln \frac{\lambda_s}{\lambda_f}\right) - 8.67747 \cdot 10^{-29} \cdot \left(\ln \frac{\lambda_s}{\lambda_f}\right) + 0.009 \quad (10)$$

$$\phi_{sf(Al/water,RVC/water,air)} = 42.05607 \cdot \left(\ln \frac{\lambda_s}{\lambda_f}\right) * \left(\ln \frac{\lambda_s}{\lambda_f}\right) - 23.27741 \cdot \left(\ln \frac{\lambda_s}{\lambda_f}\right) + 2.76588 \quad (11)$$

the values of ϕ_{sf} are shown in table 1-2 for solid-solid , aluminum- water, reticulated vitreous carbon (RVC) –air, reticulated vitreous carbon (RVC) –water .Now it good agreement with the experimental data.

In Figs.6-10, experimental results of the ETC for the same samples are shown with computed values using Eq.(7) and with the models (10-12 &18-19) . It is found that ETC calculated using Eq. (7), gives closer results then R.singh et.al. model [11] and is comparable with Bhattacharya et.al. model [12]. Comparing our correlation using Eq.(7) to the experimental data shows that our model follows the curve of the data points very well as in Fig.6-10.The average deviation from experimental values for the models has also been computed ,it is found that R.Singh et.al. model has 7.28% error, and our model we found that 1.75% for solid-air, emulsion , suspension, granular , and solid-solid two phase systems (table-3). When we use Eq (7) then we found that for metal and nonmetal foam ,two phase systems of ETC computed our model is 3.03% compare with R.singh et.al has 4.17% , Jyoti Rani et.al has 5.62% , Bhattacharya et.al. has 10.18% , and Boosma et.al. has 26.11% (shown table-4) deviation is least for our empirical proposition when we use Eq.(7) in the calculation of ETC.

Table 1
Comparison of ETC values for two phase systems using Eq. (7).The thermal conductivity is in W m⁻¹ K⁻¹

S.No	Type of sample	ϕ_s	λ_s	λ_f	ϕ_f	ϕ_{sf}	λ_{sf}	λ_{exp}	λ_{theo}	%error
1	Cu/solder ²⁵	0.0124	398	78.1	0.9786	0.009	156.2	79.8	79.93	0.16
2	Cu/solder ²⁵	0.0136	398	78.1	0.9774	0.009	156.2	80	80.07	0.09
3	Cu/solder ²⁵	0.0507	398	78.1	0.9403	0.009	156.2	85.2	84.74	0.54
4	Cu/solder ²⁵	0.0996	398	78.1	0.8914	0.009	156.2	92.4	91.85	0.60
5	Cu/solder ²⁵	0.0195	398	78.1	0.9715	0.009	156.2	80.8	80.77	0.04
6	Cu/solder ²⁵	0.0263	398	78.1	0.9647	0.009	156.2	81.7	81.60	0.13
7	Cu/solder ²⁵	0.0286	398	78.1	0.9624	0.009	156.2	82	81.88	0.14
8	Cu/solder ²⁵	0.1029	398	78.1	0.8881	0.009	156.2	92.7	92.37	0.36
9	Cu/solder ²⁵	0.2377	398	78.1	0.753	0.009	156.2	115.4	117.76	2.04
10	Cu/solder ²⁵	0.0848	398	78.1	0.9062	0.009	156.2	90.2	89.58	0.69
11	Cu/solder ²⁵	0.1586	398	78.1	0.8324	0.009	156.2	102	101.88	0.12
12	Cu/solder ²⁵	0.2516	398	78.1	0.7394	0.009	156.2	118	120.83	2.40
13	Cu/solder ²⁵	0.2894	398	78.1	0.7016	0.009	156.2	125	129.60	3.68
14	Cu/solder ²⁵	0.291	398	78.1	0.7	0.009	156.2	125	129.98	3.98
15	cellosize/flexol ²⁶	0.3	0.616	0.161	0.691	0.009	0.322	0.235	0.26	10.22
16	cellosize/polypropylene glycol ²⁷	0.3	0.55	0.15	0.691	0.009	0.3	0.234	0.24	2.02
17	Water/mineral Oil ²⁷	0.4	0.611	0.149	0.591	0.009	0.298	0.292	0.28	2.51
18	Water/Oil solvent ²⁷	0.4	0.607	0.173	0.591	0.009	0.346	0.312	0.31	0.10
19	Water/mineral Oil ²⁷	0.4	0.611	0.149	0.591	0.009	0.298	0.293	0.28	2.85
20	cellosize/polypropylene glycol ²⁶	0.1	0.551	0.15	0.891	0.009	0.3	0.182	0.18	3.12
21	cellosize/polypropylene glycol ²⁶	0.1	0.577	0.154	0.891	0.009	0.308	0.18	0.18	0.68
22	cellosize/polypropylene glycol ²⁶	0.1	0.551	0.15	0.891	0.009	0.3	0.182	0.18	3.12
23	cellosize/polypropylene glycol ²⁶	0.1	0.577	0.154	0.891	0.009	0.308	0.18	0.18	0.68

Average deviation = 1.75%

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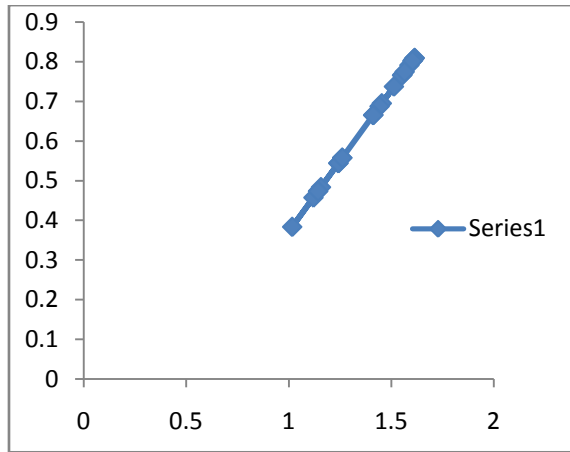


Fig. 2. . For Solid-air , emulsion, suspension, granular, and solid-solid two phase systems . Variation of $\text{Sin}^2\theta$ versus $\phi_f^{2/5} \ln(\lambda_s/\lambda_f)$. Squares are experimental data and the full line is the best fitted curve. X-axis on $\phi_f^{2/5} \ln (\lambda_s/\lambda_f)$ and Y-axis on $\text{Sin}^2\theta$.

Table 2.
Comparison of ETC values for two phase systems using Eq. (7).The thermal conductivity is in $\text{W m}^{-1} \text{K}^{-1}$

S.No	Type of sample	ϕ_s	λ_s	λ_f	ϕ_f	ϕ_{sf}	λ_{sf}	λ_{exp}	λ_{theo}	% error
1	Al/water	0.054	218	0.615	0.219	0.727	1.23	5.4	5.344924	1.02
2	Al/water	0.095	218	0.615	0.178	0.727	1.23	7.65	7.353736	3.87
3	Al/water	0.051	218	0.615	0.222	0.727	1.23	4.8	5.133812	6.95
4	Al/water	0.091	218	0.615	0.182	0.727	1.23	7.6	7.247555	4.64
5	Al/water	0.022	218	0.615	0.251	0.727	1.23	3.05	2.797368	8.28
6	Al/water	0.051	218	0.615	0.222	0.727	1.23	4.95	5.133812	3.71
7	Al/water	0.094	218	0.615	0.179	0.727	1.23	7.65	7.329331	4.19
8	Al/water	0.028	218	0.615	0.245	0.727	1.23	3.3	3.316506	0.50
9	Al/water	0.048	218	0.615	0.225	0.727	1.23	4.75	4.915983	3.49
10	Al/water	0.063	218	0.615	0.21	0.727	1.23	5.35	5.934353	10.92
11	RVC/air	0.0336	8.5	0.026	0.9654	0.001	0.052	0.164	0.165058	0.64
12	RVC/air	0.0256	8.5	0.026	0.9734	0.001	0.052	0.15	0.148697	0.87
13	RVC/air	0.0385	8.5	0.026	0.9605	0.001	0.052	0.17	0.167345	1.56
14	RVC/air	0.0319	8.5	0.026	0.9671	0.001	0.052	0.16	0.162782	1.74
15	RVC/water	0.0336	8.5	0.615	0.9654	0.001	1.23	0.73	0.733662	0.50
16	RVC/water	0.0256	8.5	0.615	0.9734	0.001	1.23	0.722	0.719205	0.39
17	RVC/water	0.0385	8.5	0.615	0.9605	0.001	1.23	0.743	0.73774	0.71
18	RVC/water	0.0319	8.5	0.615	0.9671	0.001	1.23	0.727	0.731378	0.60

Average deviation = 3.03%

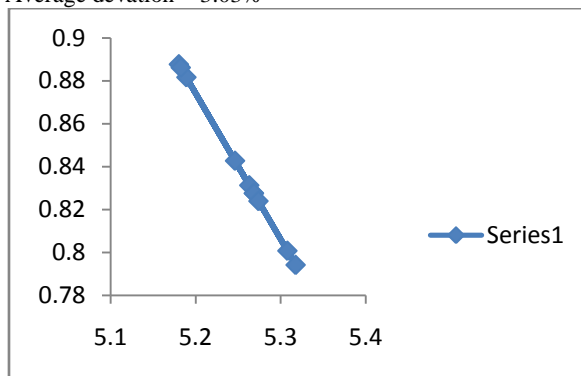


Fig. 3. . For Al/Water. Variation of $\text{Sin}^2\theta$ versus $\phi_f^{2/5} \ln(\lambda_s/\lambda_f)$. Squares are experimental data and the full line is the best fitted curve. X-axis on $\phi_f^{2/5} \ln (\lambda_s/\lambda_f)$ and Y-axis on $\text{Sin}^2\theta$.

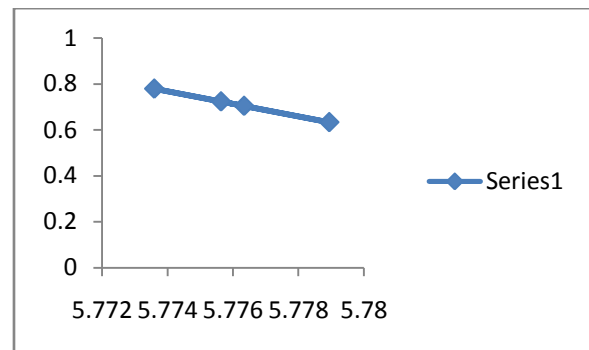


Fig. 4. . For RVC/air . Variation of $\text{Sin}^2\theta$ versus $\phi_f^{2/5} \ln(\lambda_s/\lambda_f)$. Squares are experimental data and the full line is the best fitted curve. X-axis on $\phi_f^{2/5} \ln (\lambda_s/\lambda_f)$ and Y-axis on $\text{Sin}^2\theta$.

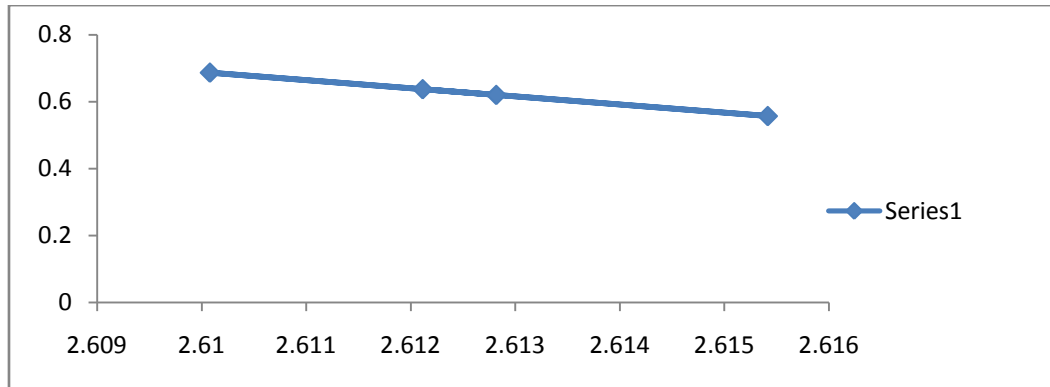


Fig. 5 . For RVC/water . Variation of $\text{Sin}^2\theta$ versus $\phi_f^{2/5} \ln(\lambda_s/\lambda_f)$. Squares are experimental data and the full line is the best fitted curve. X-axis on $\phi_f^{2/5} \ln(\lambda_s/\lambda_f)$ and Y-axis on $\text{Sin}^2\theta$

Table 3.
Comparison of ETC values for two phase systems using Eq. (7) and Jagjiwan Ram & R.singh.

S.No	Type of sample	Porsity	λ_{exp}	λ_{theo}	error	J.Ram &R.Singh	error
1	Cu/solder ²⁵	0.0124	79.8	79.93	0.16	79.73	0.09
2	Cu/solder ²⁵	0.0136	80	80.07	0.09	79.95	0.06
3	Cu/solder ²⁵	0.0507	85.2	84.74	0.54	86.84	1.92
4	Cu/solder ²⁵	0.0996	92.4	91.85	0.60	95.78	3.66
5	Cu/solder ²⁵	0.0195	80.8	80.77	0.04	81.05	0.31
6	Cu/solder ²⁵	0.0263	81.7	81.60	0.13	82.33	0.76
7	Cu/solder ²⁵	0.0286	82	81.88	0.14	82.75	0.91
8	Cu/solder ²⁵	0.1029	92.7	92.37	0.36	96.39	3.98
9	Cu/solder ²⁵	0.2377	115.4	117.76	2.04	123.52	7.04
10	Cu/solder ²⁵	0.0848	90.2	89.58	0.69	93.67	3.85
11	Cu/solder ²⁵	0.1586	102	101.88	0.12	106.97	4.87
12	Cu/solder ²⁵	0.2516	118	120.83	2.40	126.69	7.36
13	Cu/solder ²⁵	0.2894	125	129.60	3.68	135.78	8.62
14	Cu/solder ²⁵	0.291	125	129.98	3.98	136.18	8.94
15	cellosize/flexol ²⁶	0.3	0.235	0.26	10.22	0.28	17.45
16	cellosize/polypropyllene glycol ²⁷	0.3	0.234	0.24	2.02	0.26	9.40
17	Water/mineral Oil ²⁷	0.4	0.292	0.28	2.51	0.31	6.51
18	Water/Oil solvent ²⁷	0.4	0.312	0.31	0.10	0.26	17.31
19	Water/mineral Oil ²⁷	0.4	0.293	0.28	2.85	0.22	26.62
20	cellosize/polypropyllene glycol ²⁶	0.1	0.182	0.18	3.12	0.20	8.79
21	cellosize/polypropyllene glycol ²⁶	0.1	0.18	0.18	0.68	0.23	25.00
22	cellosize/polypropyllene glycol ²⁶	0.1	0.182	0.18	3.12	0.18	1.10
23	cellosize/polypropyllene glycol ²⁶	0.1	0.18	0.18	0.68	0.19	2.78
Average error					1.75		7.28

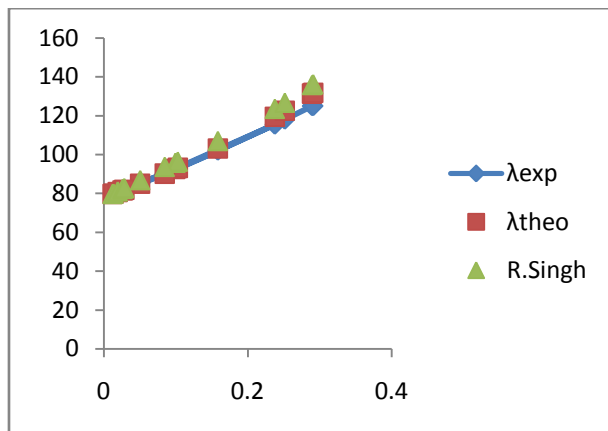


Fig:-6. Comparison of ETC values for two phase systems using Eq. (7) and Jagjiwan Ram and R.singh (S.no. 1-14).

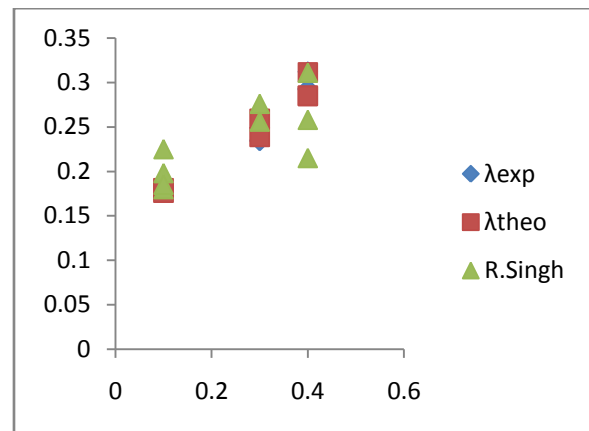


Fig :- 7. Comparison of ETC values for two phase systems using Eq. (7) and Jagjiwan Ram and R.singh (S.no. 15-23).

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Table 4.
Comparison of ETC values for two phase systems using Eq. (7)

S.No	Type of sample	λ_{exp}	$\lambda_{theo(our\ model)}$	Error	Jyoti	Error	J.Ram&R.Singh	Error	bhat	Error	boosma	Error
1	Al/water	5.4	5.345	1.02	5.36	0.74	5.477	1.4	4.746	12.1	3.753	30.5
2	Al/water	7.65	7.354	3.87	7.42	3	7.092	7.2	7.884	3.1	6.435	15.8
3	Al/water	4.8	5.134	6.95	5.18	7.91	5.271	9.8	4.516	5.9	3.551	26
4	Al/water	7.6	7.248	4.64	7.23	4.86	7.053	7.2	7.578	0.3	6.177	18.7
5	Al/water	3.05	2.797	8.28	3.28	7.54	2.797	8.2	2.297	24.6	1.475	51.6
6	Al/water	4.95	5.134	3.71	5.18	4.64	5.271	6.4	4.516	8.7	3.551	28.2
7	Al/water	7.65	7.329	4.19	7.37	3.66	7.085	7.3	7.808	2.1	6.371	16.7
8	Al/water	3.3	3.317	0.50	3.72	12.72	3.373	2.2	2.756	16.4	1.927	41.6
9	Al/water	4.75	4.916	3.49	5.01	5.47	5.054	6.4	4.287	9.7	3.346	29.5
10	Al/water	5.35	5.934	10.92	5.85	9.34	6.034	12.7	5.435	1.6	4.353	18.6
11	RVC/air	0.164	0.165	0.64	0.163	0.6	0.163	0.2	0.126	23	0.094	42.4
12	RVC/air	0.15	0.149	0.87	0.13	13.33	0.149	0.1	0.108	27.7	0.077	48.4
13	RVC/air	0.17	0.167	1.56	0.17	0	0.169	0.1	0.141	17.1	0.108	36.4
14	RVC/air	0.16	0.163	1.74	0.15	6.25	0.16	0.2	0.121	24.3	0.089	43.9
15	RVC/water	0.73	0.734	0.50	0.77	5.47	0.721	1.1	0.72	1.3	0.772	5.8
16	RVC/water	0.722	0.719	0.39	0.746	3.32	0.711	1.4	0.701	2.8	0.753	4.3
17	RVC/water	0.743	0.738	0.71	0.792	6.59	0.727	2.1	0.736	0.9	0.788	6.1
18	RVC/water	0.727	0.731	0.60	0.769	5.77	0.719	1	0.715	1.6	0.767	5.5
Average Error				3.03		5.62		4.17		10.18		26.11

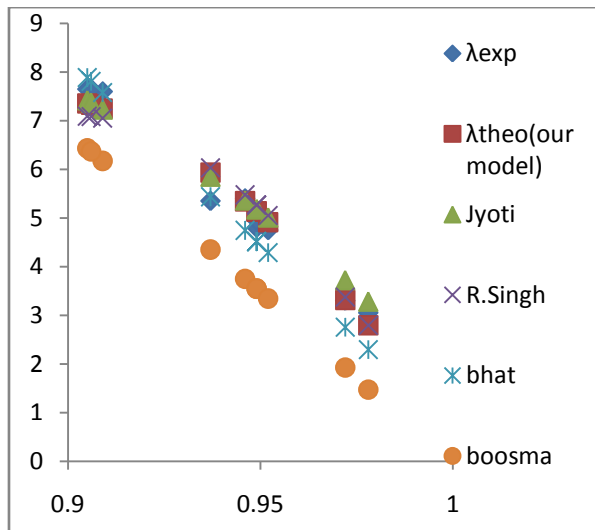


Fig :- 8. Comparison of ETC values for two phase systems Al/Water, using Eq. (7).

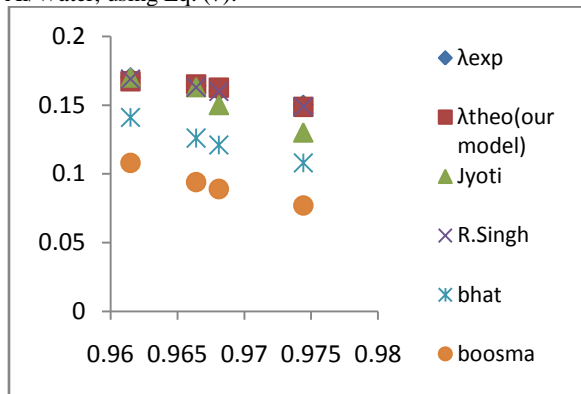


Fig :- 9. Comparison of ETC values for two phase systems RVC/air, using Eq. (7)

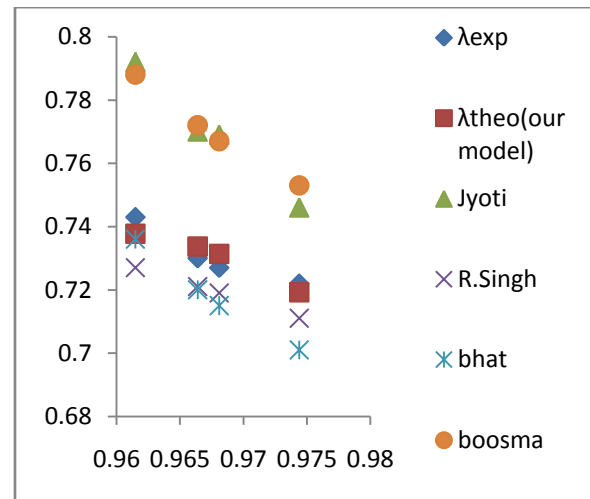


Fig :- 10. Comparison of ETC values for two phase systems RVC/water, using Eq. (7)

Conclusions

The empirical model proposed here is capable of predicting effective thermal conductivities close to the experimental values even for mixtures of higher conductivity ratio and high porosities, whereas one may find that other models give higher deviations in those situations. This model simple but powerful enough without compromising on the results. This clearly indicates that the slope of the curve as shown in fig. (2-5) strongly depends on the ratio of thermal conductivity of the constituent phases. The correlation presented here showed that the effective thermal conductivity stringly depends on the ratio of thermal conductivity of the constituents. other factors have small effect on the ETC. The parameter of fluid, such as the size, volume fraction, the thickness of the interfacial layer, are shown to play important roles in the enhancement of thermal conductivity. The model

predictions have been shown to be reasonable and are in good agreement with the available experimental data. It is expected that the experimentally validated model will be helpful in the evaluation of the effective thermal conductivity for foam like materials in the whole range of porosity.

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