Effective Thermal Conductivity of Porous Metal Foams by Introducing Interfacial Layer

Jyoti Rani[*,1], K. J. Singh[2]
[1]*SGN Khalsa PG College, Sri Ganganagar (MGSU, Bikaner), Rajasthan*
[2]*Govt. College, Suratgarh, Sri Ganganagar (Raj)*
[*]*E-mail: ranijyoti@yahoo.co.in*

Abstract

Metal foams have emerged as promising materials for use in heat sink and heat exchanger applications. But accurate prediction of ETC of porous metal foams has remained to be a challenging problem. Recent literature, Calmidi and Mahajan [1] and Boomsma and Poulikakos [2] have presented geometrical models for highly porous metal foams. We developed here a numerical expression for ETC based on resistor model for two-phase systems which is being comprised of contributions from both the phases with interfacial layer.

1. Introduction

In this paper, we have developed an empirical relation for estimation of ETC of highly porous metal foams. In order to incorporate varying individual geometries and non-linear flow of heat flux lines generated due to the difference in thermal conductivity of the constituent phases, a correlation term F and a weight factor W have been introduced. Parameter estimation technique has been used to optimise the values of F and W.

2. Formulation of the proposed model

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 *and* ϕ_{sf} respectively. Here we suppose that the matrix is to be made up of layers oriented parallel and perpendicular to the direction of heat flow, alternately as depicted in Fig. 1. The thermal conductivity of parallel layers $\lambda_\parallel$ is given by the weighted arithmetic mean and perpendicular layers $\lambda_\perp$ by weighted harmonic mean.The corresponding expressions are

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

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

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

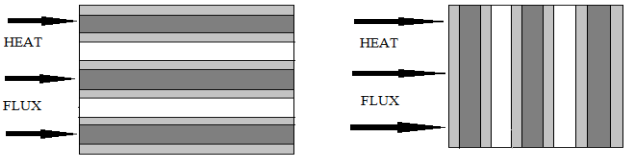

Figure. 1
Configuration of the resistors in a two-phase system.

As these relations do not predict the ETC of a real two-phase system correctly, so a different kind of weighted geometric mean is used as:

$\lambda_e = \left(\lambda_\parallel^F \lambda_\perp^{(1-F)}\right)$:where$(0 \le F \le 1)$ ...(3)

Eq. (3) is solved for F in terms of $\lambda_\parallel$, $\lambda_\perp$ *and* λ_e.

$$F = \frac{\ln\left[\phi_f \frac{\lambda_e}{\lambda_f} + \phi_s \frac{\lambda_e}{\lambda_s} + \phi_{sf} \frac{\lambda_e}{\lambda_{sf}}\right]}{\ln\left[\phi_f^2 + \phi_s^2 + \phi_{sf}^2 + \phi_f \phi_s \left(\frac{\lambda_f}{\lambda_s} + \frac{\lambda_s}{\lambda_f}\right) + \phi_f \phi_{sf} \left(\frac{\lambda_f}{\lambda_{sf}} + \frac{\lambda_{sf}}{\lambda_f}\right) + \phi_s \phi_{sf} \left(\frac{\lambda_s}{\lambda_{sf}} + \frac{\lambda_{sf}}{\lambda_s}\right)\right]} \quad \ldots(4)$$

The correlation term F is found to be a plot of F versus $R = \ln(\phi_f \lambda_s / \lambda_f)$ comes out to a straight line,having expression

$$F = 0.074 \ln\left(\phi_f \frac{\lambda_s}{\lambda_f}\right) + 0.216 \quad \ldots(5)$$

F is calculated using Eq. (5) and data available [4] for various systems. Plot of $\ln(\lambda_s/\lambda_f)$ versus ϕ_{sf} is found to be a parabolic in nature. In the present model, $\lambda_{sf} = 2\,\lambda_f$, the same value as that given by Leong et al. [5] is used in the calculation of the thermal conductivity. We have used curve fitting technique and found that the expression for ϕ_{sf} is

$$\phi_{sf} = -0.014\left(\ln\frac{\lambda_s}{\lambda_f}\right)^2 + 0.213\left(\ln\frac{\lambda_s}{\lambda_f}\right) - 0.285 \quad \ldots(6)$$

It is also interesting to see from Eq. (6) that the average value of ϕ_{sf} increases to a certain extent as

the ratio of thermal conductivity of the constituent phases increases, after that Φ_{sf} decreases as the ratio increases.

3. Results and Discussion

In above discussion we observed from experimental results that the expression (3) does not represent the true state of affairs of a real two-phase system. Thus for practical utilization, we have to modify ETC expression (3) by incorporating a constant W. A graph between W and the values of ETC has been plotted. Therefore, the most appropriate expression for ETC can be written as

$$\lambda_e = W\left(\lambda_{\parallel}^{F}\lambda_{\perp}^{(1-F)}\right) \quad ;0\leq F\leq 1 \qquad ...(7)$$

Weight factor W is calculated using Eq. (7) and data available [9] for various systems for several relationships and plotted with $\ln(\lambda_s/\lambda_f)$. Best fitted expression for was found to be

$$W = -0.021\left(ln\frac{\lambda_s}{\lambda_f}\right)^2 + 0.240\left(ln\frac{\lambda_s}{\lambda_f}\right) + 0.565 \qquad ...(8)$$

Fig. 2 and 3 shows the comparisons of the predicted ETC values by the present Eq. (7) for RVC-air and RVC-water foam system. In the present model, λ_{rvc} = 8.5 W/m K, λ_{air} = 0.026 W/m K, λ_{water} = 0.615 W/m K, $\lambda_{layer} = 2\lambda_{air}$ = 0.052 W/m K(in Fig. 2), $\lambda_{layer} = 2\lambda_{water}$ = 1.23 W/m K(in Fig.3) are used in the calculation of the thermal conductivity. In Figs. 2 and 3, we observe that when we remove weight factor than the average error is large (10.72%). The average error between calculated values by Eq. (7) of ETC with the experimental results is 5.17%.

4. Conclusions

From above discussion and presentation we easily predict that the ETC strongly depends on porosity and the ratio of thermal conductivity of the constituents.This work helped to clarify the impact of this key interfacial layer on the thermal analysis of metal foams. From above whole discussion, It is expected that the experimentally validated model Will be helpful in the evaluation of the ETC for foam like materials in the whole range of porosity.

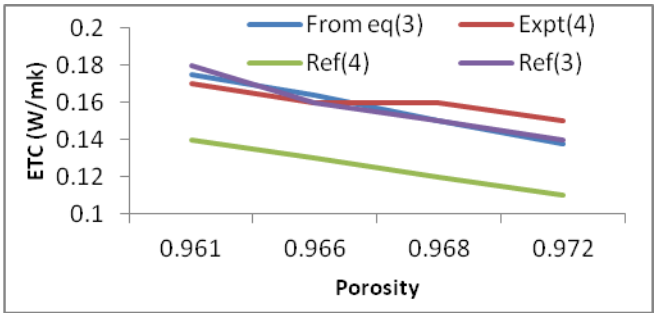

Figure. 2
Variation of ETC with porosity for RVC-air foams

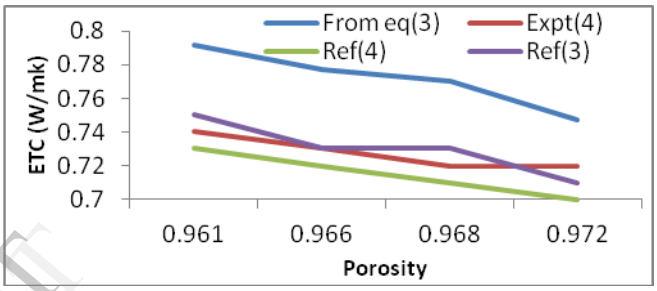

Figure. 3
Variation of ETC with porosity for RVC-water foams

5. References

[1] V. V. Calmidi, R. L. Mahajan, The Effective Thermal Conductivity of High Porosity Fibrous Metal Foams, ASME *J. Heat Transfer* **121** (1999)466.
[2] K. Boomsma, D. Poulikakos, On the Effective Thermal Conductivity of a Three Dimensionally Structured Fluid Saturated Metal Foams, *Int. J. Heat Mass Transfer* **44** (2001) 827.
[3] R. Singh, H. S. Kasana, Computational Aspects of Effective Thermal Conductivity of Highly Porous Metal Foams, Appl. Therm. Eng. **24** (13) (2004) 1841.
[4] A. Bhattacharya, V.V. Calmidi, R. L. Mahajan, Thermophysical Properties of High Porosity Metal Foams, *Int. J. Heat Mass Transfer* **45** (2002) 1017.
[5] K. C. Leong, C. Yang, S. Murshed, A Model for the Thermal Conductivity of Nanofluids - The Effect of Interfacial Layer *J. Nanopart.Res.***8**(2006)245.