

Computational Study of Conductive Heat Transfer in Porous Media by Finite Volume Method

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Abstract— A computational investigation has been carried out for accurate determination of heat transfer in metal foams in forced convective flows. The single-blow method was used, in which, the fluid temperature varies with distance and time and convective heat transfer becomes time-dependent. The method results in a transient and conjugate heat transfer phenomena between the foam and fluid. The conductive temperature data thus obtained from generated C program codes are then compared with the theoretical results to obtain the corresponding volumetric heat transfer coefficients between the fluid and foam solid surface. The volumetric coefficients thus determined are compared against available sets of experimental data, so as to examine the consistency among the reported experimental data.

Keywords- porous media, two energy method, single blow method, c program code

I. INTRODUCTION

A porous medium is a solid structure with interconnected voids. It is the region in space comprising at least two homogeneous material constituents, presenting identifiable interfaces between them in a resolution level, with at least one of the constituents remaining fixed or slightly deformable. In order to use porous media for convective heat exchanger applications, one must estimate the volumetric heat transfer taking place between the solid and fluid phases. Naturally, the local thermal equilibrium assumption must be discarded, and the two energy equation model must be used to determine the distinct temperatures of the fluid phase and solid phase, and the local volumetric heat transfer between the two phases. Thus, for engineering applications of porous media, the evaluation of the volumetric heat transfer coefficients is equally important as that of stagnant thermal conductivities.

II. LITERATURE REVIEW

Fu *et al.* [1] carried out exhaustive measurements and correlated the interstitial heat transfer coefficients of cellular materials, which indicates the linear dependency of the Reynolds number on the Nusselt number. A general correlation for the volumetric heat transfer coefficient was introduced by Kamiuto and Yee [2] for open cellular porous materials, who indicated the Reynolds number exponent for the Nusselt number being close to 0.8. They assembled experimental data reported by Younis and Viskanta [3], Ichimiya [4] and themselves, to find that all these experimental data for the volumetric heat transfer coefficient can be correlated fairly well using the strut diameter as a characteristic length for the open cellular materials. In recent years, some numerical attempts have been made to simulate the heat transport processes in foam materials (Zhiyong Wu [5], A. Kopanidis [6]). Kuwahara and Fumoto [7] conducted a series of three dimensional numerical experiments by assuming a macroscopically uniform flow through the metal foams, so as to estimate the interstitial heat transfer coefficient between the fluid and foam solid surface. Interstitial heat transfer coefficients are usually measured by the "single-blow method" (Liang and Yang [8]). The name "single-blow" is designated because a single fluid is employed in this method to heat the heat transfer surface. As illustrated in Fig. (1), in this method, inlet fluid temperature varies with time and convective heat transfer becomes time dependent, which results in a transient and conjugate heat transfer phenomena between the foam and fluid. A fluid flows steadily through a test core. Initially the fluid and the test core have the same uniform temperature. Then a fluid temperature variation is introduced at the inlet. Thereafter, the fluid and solid temperature histories at both inlet and outlet of the test core are measured continuously. These data are then compared with the theoretical results to obtain the corresponding interstitial heat transfer coefficients between the foam of solid surface and the fluid. Details of the method can be found in Wakao and Kaguei [9].

III. SINGLE BLOW METHOD

In this, an air supplied by the blower is constantly heated by the heater. Then the hot air is mixed well as it passes through a mixer and filter. Thus, the well-mixed hot air flows through the test specimen. The thermally steady state can be reached after supplying the heated air for 4 to 5 hours.

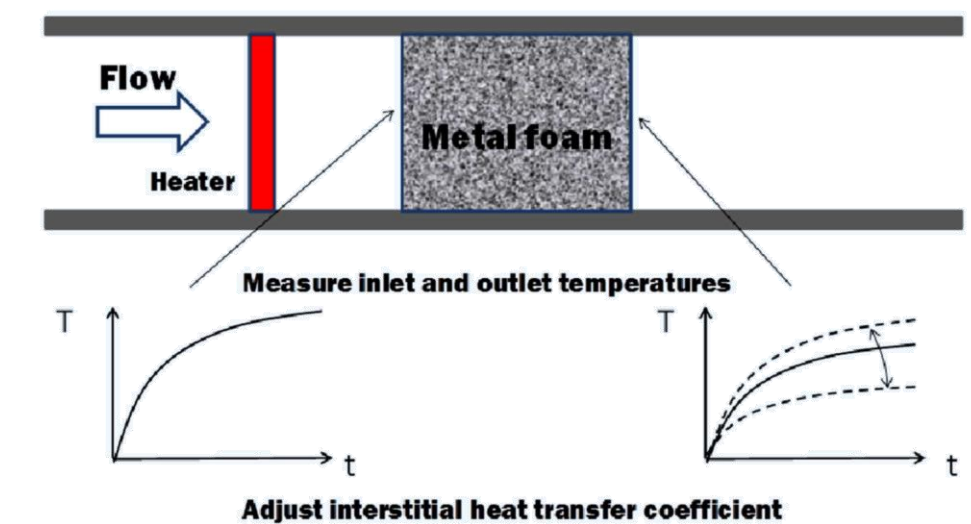


Figure 1: single blow method

Experimental Set-up:

The experimental set-up used in this study is schematically shown in Fig. (2).

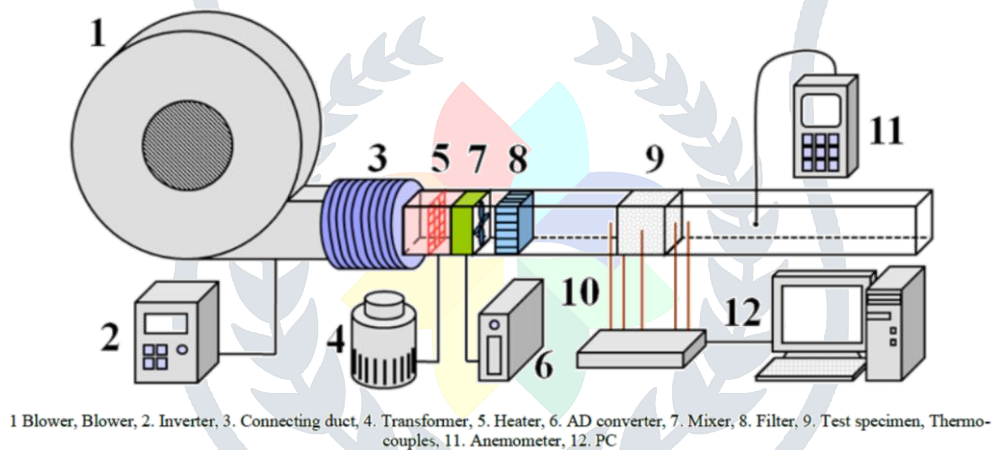


Figure 2: Experimental set-up.

In the present experimental set-up, the heat supply is suddenly cut to introduce a fluid temperature variation at the inlet. Then, the air and foam temperature variations at both windward and leeward sides are monitored as indicated in the figure. As prescribing the air and foam temperature variations at the inlet of the test specimen from the measurements, both air temperature $\langle T \rangle^f$ and foam temperature $\langle T \rangle^s$ at the leeward side are predicted and correlated with the temperatures predicted using the two-energy equation model:

$$\rho_f c_{pf} \left(\frac{\partial \langle T \rangle^f}{\partial t} + u_D \frac{d \langle T \rangle^f}{dx} \right) = \varepsilon^* k_f \frac{d^2 \langle T \rangle^f}{dx^2} - h_v (\langle T \rangle^f - \langle T \rangle^s) \tag{1}$$

$$\rho_s c_s \frac{\partial \langle T \rangle^s}{\partial t} = (1 - \varepsilon^*) k_s \frac{d^2 \langle T \rangle^s}{dx^2} - h_v (\langle T \rangle^s - \langle T \rangle^f) \tag{2}$$

Where u_D and ϵ^* are the Darcian velocity and effective porosity (Yang and Nakayama [10]) respectively. The interstitial heat transfer coefficient h_v is adjusted to fit the measured temperature developments at the leeward side of the test specimen with the predicted temperature responses.

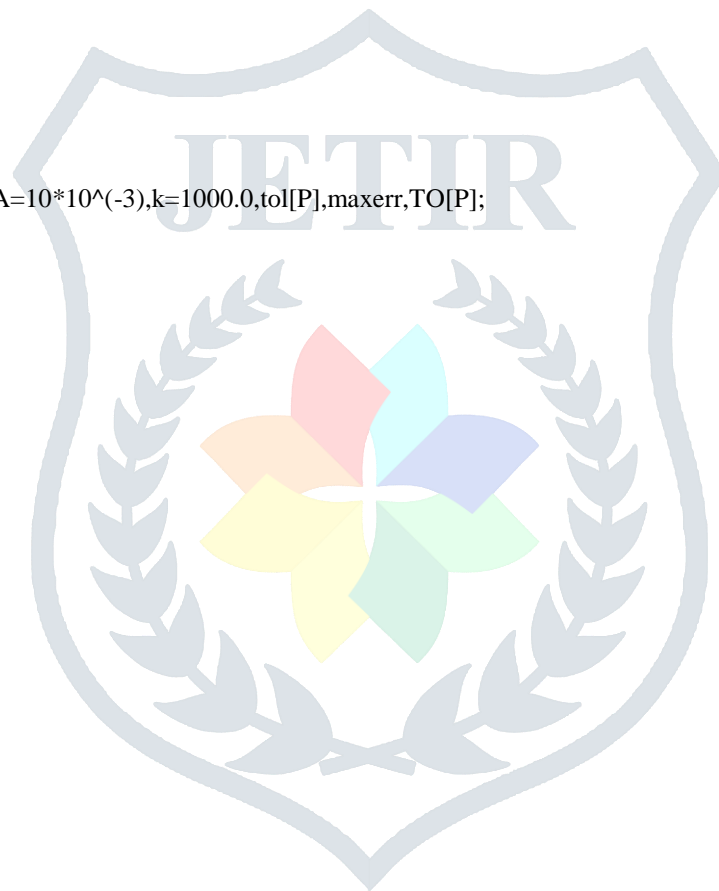
IV. WORK DONE

I have developed so many C program codes like one dimensional steady state heat conduction problem from computational fluid dynamics using finite volume method.

For example: C program code for one dimensional steady state heat conduction problem as follows:-

1. Program for Numerical problem

```
#include<stdio.h>
#include<conio.h>
#include<math.h>
#define P 1000
int main()
//define T[]
{
clrscr();
float i,n=7,aw,ae,T[P],1,deltax,A=10*10^(-3),k=1000.0,tol[P],maxerr,TO[P];
deltax=0.1;
T[1]=100;
T[7]=500;
ae=k*A/deltax;
aw=k*A/deltax;
maxerr=1000;
while (maxerr>=1e-06)
{
for (i=2;i<=6;i++)
{
TO[i]=T[i];
}
for(i=2;i<=6;i++)
{
if(i==2)
{
aw=k*A/(deltax/2);
ae=k*A/deltax;
}
else if(i==n-1)
{
aw=k*A/deltax;
ae=k*A/(deltax/2);
}
else
{
aw=k*A/deltax;
ae=k*A/deltax;
}
T[i]=(aw*T[i-1]+ae*T[i+1])/(aw+ae);
printf("\n%d=%f\t",T[i]);
}
printf("\n the solution is \n");
for(i=2;i<=n-1;i++)
{
printf("\n%f",T[i]);
}
l=1;
//maxerr=0;
```

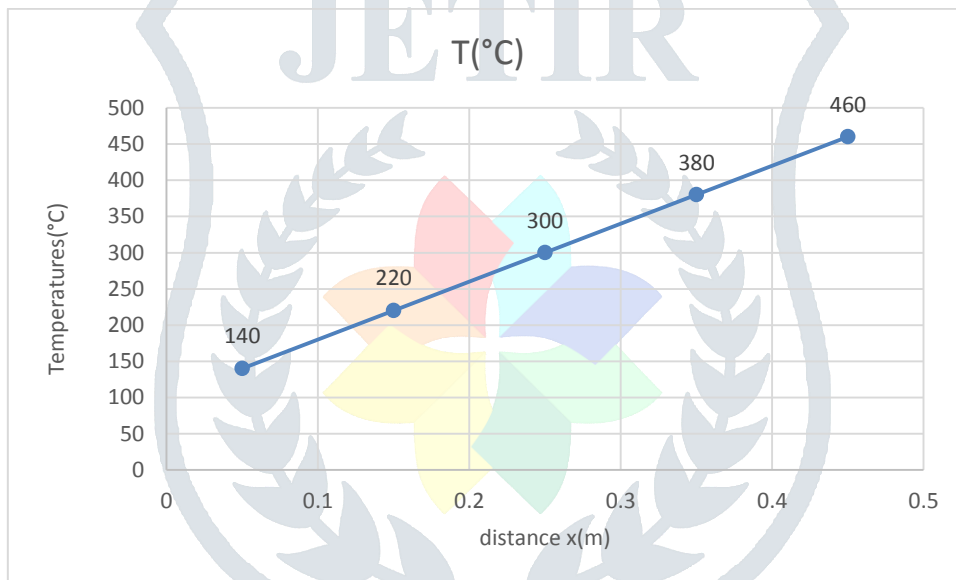


```

for(i=2;i<=n-1;i++)
{
tol[l]=fabs(T[i]-TO[i]);
l=l+1;
maxerr=tol[2];
if (tol[l]>=maxerr)
{
maxerr=tol[l];
}
//err=maxval(tol)
printf("\n%f",maxerr);
//if(maxerr<10*10^(-6))
//{
//exit(0);
//return ();
}
}
getch();
}

```

The graph plotted according to the results availed from the developed C program codes.



Graph 1: this graph plotted between temperatures as (y-coordinate) vs. distance x (m) as (x-coordinate)

2. Program for Numerical problem

```

#include<stdio.h>
#include<conio.h>
#include<math.h>
#define P 1000
int main()
{
float i,n=7,aw,ae,l,T[P],deltax,A=1.0,k=0.5,tol[P],maxerr,TO[P];
deltax=0.004;
T[1]=100.0;
T[7]=200.0;
ae=k*A/deltax;

```

```

aw=k*A/deltax;
maxerr=1000.0;
while(maxerr>=1e-06)
{
for(i=2;i<=6;i++)
{
TO[i]=T[i];
}
for(i=2;i<=6;i++)
{
if(i==2)
{
aw=k*A/(deltax/2);
ae=k*A/deltax;
}
else if(i==n-1)
{
aw=k*A/deltax;
ae=k*A/(deltax/2);
}
else
{
aw=k*A/deltax;
ae=k*A/deltax;
}
T[i]=(aw*T[i-1]+ae*T[i+1]+4000)/(aw+ae);
printf("\n%d=%f\t",T[i]);
}
printf("\n the solution is \n");
for(i=2;i<=n-1;i++)
{
printf("\n%f",T[i]);
}
l=1;
for(i=2;i<=n-1;i++)
{
tol[l]=fabs(T[i]-TO[i]);
l=l+1;
maxerr=tol[2];
if(tol[l]>=maxerr)
{
maxerr=tol[l];
}
}

```

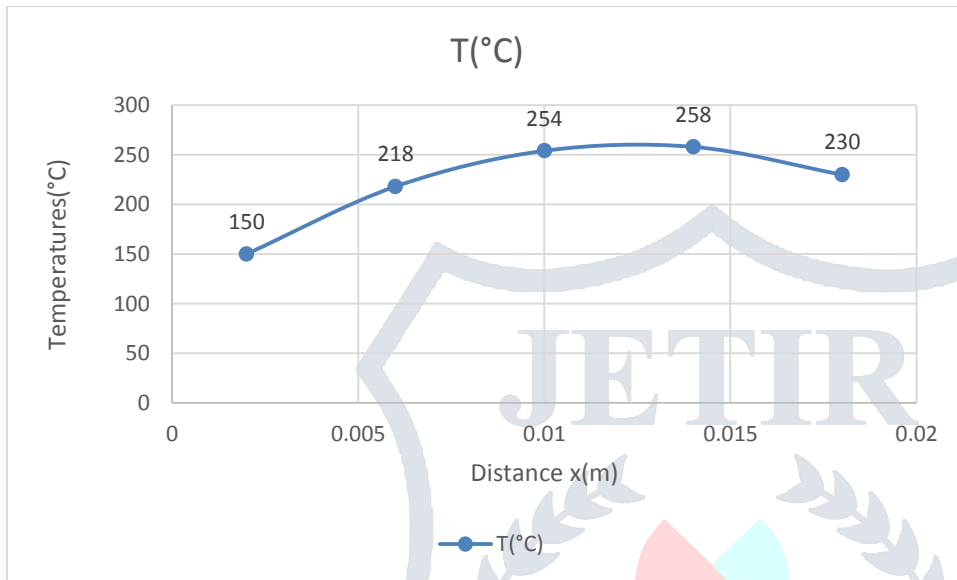


```

}
printf("\n%f",maxerr);
}
}
getch();
}

```

The graph plotted according to the results availed from the developed C program codes.



Graph 2: this graph plotted between temperatures as (y-coordinate) vs. distance x (m) as (x-coordinate)

3. Program for Numerical problem

```

#include<stdio.h>
#include<conio.h>
#include<math.h>
#define P 1000
int main()
{
float i,n=7,aw,ae,l,T[P],deltax,tol[P],maxerr,TO[P];
deltax=0.2;
T[1]=100.0f;
ae=1/deltax;
aw=1/deltax;
maxerr=1000.0;
while(maxerr>=1e-06)
{
for(i=2;i<=6;i++)
{
TO[i]=T[i];
}
}
}

```

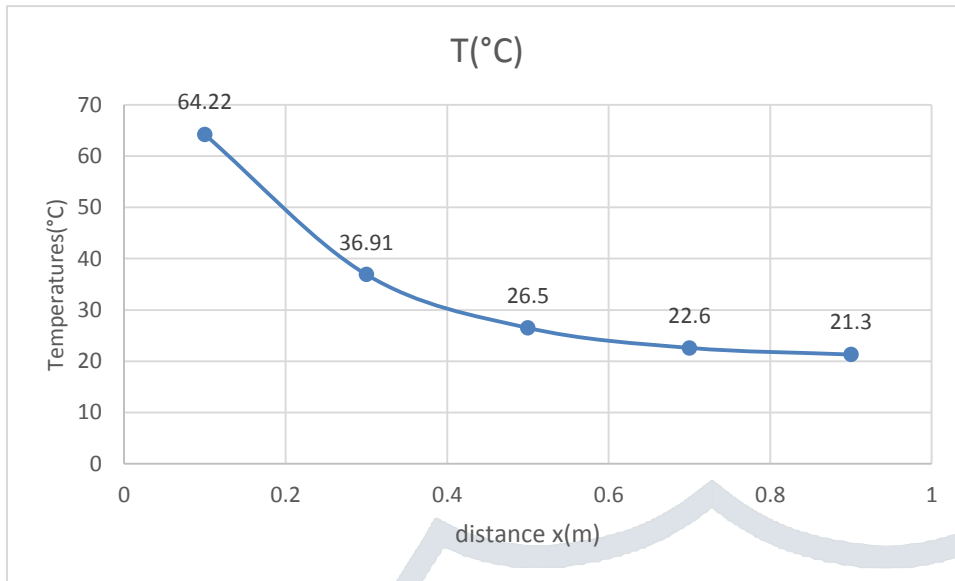
```

for(i=2;i<=6;i++)
{
if(i==2)
{
aw=1/(deltax/2);
ae=1/deltax;
T[i]=(aw*T[i-1]+ae*T[i+1]+100)/(aw+ae+5);
}
else if(i==n-1)
{
aw=1/deltax;
ae=1/(deltax/2);
T[i]=(aw*T[i-1]+ae*T[i+1]+100)/(aw+ae+5);
}
else
{
aw=1/deltax;
ae=1/deltax;
T[i]=(aw*T[i-1]+ae*T[i+1]+100)/(aw+ae+5);
}
printf("\n%d=%f",T[i]);
}
printf("\n the solution is \n");
for(i=2;i<=n-1;i++)
{
printf("\n%f",T[i]);
}
l=1;
for(i=2;i<=n-1;i++)
{
tol[l]=fabs(T[i]-TO[i]);
l=l+1;
maxerr=tol[2];
if(tol[l]>=maxerr)
{
maxerr=tol[l];
}
printf("\n%f",maxerr);
}
}
getch();
}

```



The graph plotted according to the results availed from the developed C program codes.



Graph 3: this graph plotted between temperatures as (y-coordinate) vs. distance x (m) as (x-coordinate)

V. RESULTS AND DISCUSSION

The output generated from the developed C program codes is implemented for the plot of the graph and these data are then compared with the experimental results to obtain the volumetric heat transfer coefficient. The above developed c program codes is for conduction analysis of heat transfer in porous media.

VI. CONCLUSION

Computational study of conductive heat transfer is carried out using c program coding and the output thus generated will be compared with the experimental results. An experimental investigation on the volumetric heat transfer coefficient in porous foams has been carried out using the single blow method. These transient temperature data are compared with the theoretical results to obtain the corresponding volumetric heat transfer coefficients between the foam solid surface and the fluid. The volumetric coefficients thus determined agree well with available sets of experimental data. The method developed in this can be used to explore the interstitial heat transfer within various foams.

VII. ACKNOWLEDGMENT

No great endeavour in any field is possible in solitude. It needs inspiration at every step; I express my deep sense of gratitude to my parents who made this project possible. I would also like to express my gratitude to all who helped me directly or indirectly, I feel a unique pleasure in extending my thanks to various sources for helping me in study in detail. It is quite difficult to mention everyone.

Nomenclature:

- c = specific heat (J/kgK)
- c_p = specific heat at constant pressure (J/kgK)
- d_m = pore diameter (m)
- h_v = interfacial heat transfer coefficient (W/m³K)
- k = thermal conductivity (W/mK)
- T = temperature (K)
- u_D = Darcian velocity (m/s)
- ϵ = porosity (-)
- ϵ^* = effective porosity (-)
- ν = kinematic viscosity (m²/s)
- ρ = density (kg/m³)

SPECIAL SYMBOLS

$\langle \phi \rangle^{f,s}$ = intrinsic average

SUBSCRIPTS AND SUPERSCRIPTS

- f = fluid
- s = solid

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