International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.9, No.01 pp 15-22, 2016

Design and Simulation of Heat Exchanger Fitted with Cu Porous Media and Ridges

Alagu Sundara Pandian[1*], GandikotaSai Koushik[2]

[1]Department of Mechanical Engineering, Vel Tech Multi Tech Dr.RR Dr.Sr Engineering College, Avadi, Chennai, Tamilnadu, India.
[2]RWPC-gskgroups, Avadi, Chennai, Tamilnadu, India.

Abstract: Simulations using the k–epsilon model have been carried out to investigate the fluid flow and heat transfer characteristics in the Heat Exchanger with copper porous media. In designing heat exchanger, copper ridges are made on the surface in order to enhance the heat transfer. The parameters studied include the Reynolds number (Re<2000), pressure drop, temperature, thickness of the porous media used by maintaining the porosity e = 0.8. The comparison analysis is done between the computational work and existing heat exchanger with same boundary condition. Results show that newlydesigned heat exchanger enhance the heat transfer up to 15^0C.
Keywords : Heat Exchanger; Finite volume; Heat Transfer; Pressure Drop; Temperature; Simulation; k-epsilon model; copper ridges.

I. Introduction

Heat exchangers are mostly used in automobiles and other application like space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural gas processing, and sewage treatment[1]. Where fluids are separated by a solid assembly like wall to anticipate bond or they may be in direct contact. Heat exchangers are made out of highly thermally conductive materials for reduction of heat. There are various types of heat exchangers (about 12 types) and details of all the heat exchangers has been collected for study purposes. A critical investigation on every method has been made and the problems found in the above-stated method are size, efficiency & cost.

The development of electronic industry and its trend toward miniaturization and high speed operating processes requires higher performance and small scale cooling systems. The miniaturized Heat exchanger has turned into an essential issue in the connection of cutting edge technologies. Its advancement is displayed as an inspiration to the subject of this paper. In this subject, there are two vital aspects of engineering: a thought radiating to fulfill some need, and the theoretical and computational encapsulation of the thought, keeping in mind the end goal to outline a productive Heat exchanger hardware, one must know the points of interest of both flow and heat transfer attributes in the equipment. So such point by point flow and heat attributes in of an assembly can be investigated theoretical and computational way by solving a set of governing equations based on the principles. Porous media is chosen for developing a new compact heat exchanger. The porous media models had been used in the one to many advanced engineering fields which include flows through filter papers, packed beds, perforated plates, Air Filters, tube banks, and distributors[2].

The majority of the earlier studies dealing with heat and mass transfer in porous media are mostly based on the empirical correlations suggested by earlier researchers[2-15], which mainly concentrates in the applications based on adsorption, stripping and distillation, geothermal operation[3]. Research works which use the porous media concept for design and fabrication of Heat exchanger using Porous Copper were not found in the known literature.

Flow through porous media has been considered as the complex element until the time that Darcy's distribution is proposed[2]. The expansion of Darcy Law was intended by Dupuis[16,17], Forchheimer[18]. Their works characterize the fluid flow over a porous medium. From that point, a progression of upgrades has been made, one of which was representing temperature variations in the fluid[19]. These temperature variations were later connected to the thickness of the porous media[8]. A survey of the historical backdrop of the investigation of fluid flow through porous mediawas done[21-22]. The generally acknowledged mathematical equation in investigating flow through porous media shown in Eq. 1 which superintend the pressure drop(ΔP) of a fluid through a porous medium.

$$\frac{\Delta P}{L} = \frac{\mu V}{K} + \rho C V^2 \qquad 1$$

Further developments in porous media include convective heat transfer[8-20]. Investigation in heat transfer through porous media was done by considered a complete profile as simple uniform cubic unit cell and analyzed fluid velocity profile and rate of cooling[13]. Better explanatory models were presented in convective heat transfer by introducing extended Darcy model[19]. Different theoretical models have been proposed to explain different variables, for example, wall effect[20], variable porosity[23]etc. The larger part of these studies that are secured by considering circular porous media, which have porosities (e) in the range 0:3–0:6. This design is known as a packed bed[24].

The packed bed is basically fabricated either by using spherical particulates or non-spherical particles[25]. Open cell foams are one kind of a non-special porous media. The arrangement of non-spherical particle opens itself to a wide assortment of conceivable applications[26].The open-cell metal porous media structure have attractive characteristics to be a heat exchanger, i.e. a Conducting solid surface, solid–fluid interface and high surface area. Contingent upon the specific open cell metal porous media arrangement, its particular surface area of the packed structure varies from 500- 10,000m^2[25]. The composite can be fabricated from the materials with good thermal conductivity constant, for example, aluminum or copper which, just by its vicinity in a static fluid, significantly increases the thermal conductivity of the fluid too[8]. The conductivity of the solid–fluid framework can be anticipated by Eq. (2) was first explained in the 2-D conduction model[27].

$$K_{eff} = \epsilon K_f + (1 - \epsilon) K_s \qquad 2$$

Taking structure of the porous media into consideration, an enhanced model was explained considering porous media as a 3D unit cell[10], where author analyzed both thermal conductivity and fluid flow. Many scientists had continued exploring the Packed bed and as of now there exist a data bank of theoretical[3 -7]and experimental models[7-15, 25]based on the size, shape, orientation of structure of the porous media. The standard governing equation with boundary conditions for flow and heat transfer in open cell porous media[27]. On account of open-cell metal porous media, the numerical models had constrained achievement[14], and the experimentation to check these models is limited, especially to the coolant, which is common air. In cooling hardware which produce a lot of overabundance heat, a fluid coolant is preferred. In the perspective of these prerequisites, tests utilizing a constrained fluid coolant are required not just to examine the possibility of utilizing open-cell porous media as Heat exchangers, additionally to give a premise against which are theoretically analyzed.

Most of the applications which are based on the porous media are manufactured by anodizing required material wafer into electrolytes[28] (like Hydrofluoric acid/ethanol/water). The thickness of porous media (d) and porosity (p) are the driving parameters helps to determine the concentration electrolyte solution[29].In the recent past, a new methodology was proposed in fabricating the porous media using powder metallurgy[15]. Fabricating the porous media by slip casting process gives an advantage in deciding the porosity.

II. Design and Simulation Premises

The following design and simulation premises are considered based on the literature survey and the requirements of the heat exchanger are;

1. The Flow through heat exchanger is either laminar or turbulent.
2. The Porosity of the porous media is constant over the length.
3. The Orientation or packing arrangement is considered as cubical.
4. The simple unit cell structure shall be considered.
5. The Surface topology of the particle is considered as smooth.
6. The ratio of the diameter of the tube to particle diameter (D/d_p) shall be between15-17[30].
7. The Reynolds number of the fluid flow through the heat exchanger shall be low.
8. The velocity profile has minimal effect on pressure drop except possibly at high Reynolds numbers.
9. Finite Volume Method shall be considered.
10. Heat transfer rate in all porous particles is uniform
11. Particles used in manufacturing the porous media is complete solid
12. Heat transfer in the porous is either by conduction or convection or both
13. Ridges fitted on the surface are uniform and isotropic in nature

III Design and Simulation of Heat Exchanger:

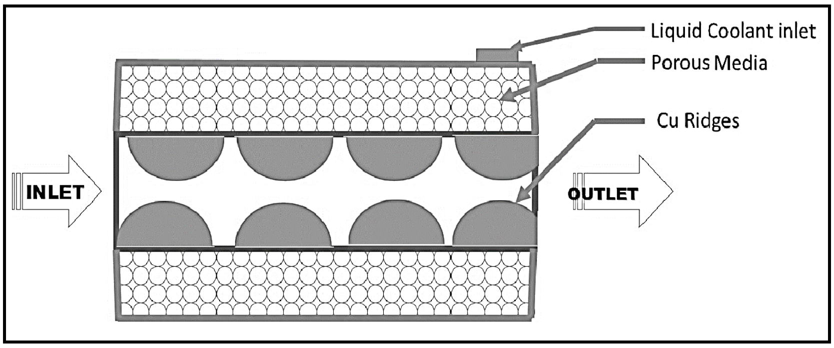

Figure 1. Heat Exchanger fitted with Porous Media and ridges

In the main goal of this work is to design a compact Heat exchanger with Copper porous media fitted at the outer surface and copper ridges are made on the surface as shown in figure 1.The porous on the outer surface is considered as heat pipe[31]. Heat pipe plays significant role in designing the porous media heat exchanger and it is made out of a fixed, emptied vessel in which the internal surfaces are filled with a Cu porous media and loaded with enough working liquid to immerse the porous media[32]. Heat is absorbed from the working fluid will evaporate the fluid in the heat exchanger and set out as a vapor. This vapor will move to the cooler region of the vessel, where the vapor condensates back to fluid travel automatically to the hot region in a cyclic process.

Heat pipes are frequently classified by the structure[33]. Primary classification of structure can incorporate sintered powder or filaments, porous media, hub grooves, separated annuli, and wrapped screens etc. A few prerequisites for heat channel operation are collected from literature survey and decided to use the Open cell metal porous media. This porous media attached to the evaporator wall. The complete porous media is filled with the fluid which is compatible with the material. Working fluid’s critical point and triple point are properly analyzed and selected Glycerin.Heat pipe control heat by evaporating the fluid uniformly, or to assimilate a high heat flux in the evaporator and reject the heat geometrically[31]. It is this last component that for the most part makes heat pipe alluring for high heat flux applications.

The geometry of the heat exchanger was built using CATIA V5 R12 and imported to the FLUENT software for analysis of the heat transfer and flow behavior in the heat exchanger.The tetrahedral mesh creation was done utilizing GAMBIT package, Here the space was fit with tetrahedron cells however it also incorporates couple of different sorts of cells in Fig. 3. The meshing is done with a concentration on nodesthe space was split into cells containing 352955 countenances and115976 nodes. The other mesh details are; max cell volume 4.429944e-13, min cell volume 2.248704e-07, max face area 9.696133e-09, min face area 7.421699e-05 and mesh volume 8.193584e-04. The simulationwork is carried out based on the theoretical design of Yang[14]. The Yang had proposed a following governing equations for fluid and heat flow through the porous media. Energy equation, continuity equation and momentum Equation are given below in Eq-3, Eq-4, Eq-5 respectively.

$$\frac{\partial}{\partial r}\left(rK_e\frac{\partial T}{\partial r}\right)+\frac{\partial}{\partial Z\left(K_e\frac{\partial T}{\partial Z}\right)} \quad (3)$$

Where K_e = Effective conductivity(based on porous media geometry)
F = Inertial Coefficient
K = Permeability
u = Viscosity of the fluid
ß = density
r = radial coordinate
T = Temperature
U = Dimension less velocity

Continuity Equation

$$\frac{1}{r}\frac{\partial}{\partial r}(r\rho_f v)+\frac{\partial}{\partial z}(\rho_f u)=0 \quad (4)$$

Momentum Equation

$$\frac{\partial}{\partial z}(\rho_f uu)+\frac{1}{r}\frac{\partial}{\partial r}(r\rho_f vu)=-\frac{\partial P}{\partial Z}+\frac{\partial}{\partial z}\left[u_e\frac{\partial u}{\partial z}\right]+\frac{1}{r}\frac{\partial}{\partial r}\left[ru_e\frac{\partial u}{\partial r}\right]-\frac{u_e}{k}u-\frac{\rho_f F}{\sqrt{K}}|U|u. \quad (5)$$

The simulation process is initiated at the entrance of the heat exchanger with initial pressure, temperature. In simulation process the k-ε model is used for analyzing the mean flow rate and temperature characteristics because this model is capable of describing the both the laminar and turbulent characteristics. The porous media is considered as substrate. Laminar flow is considered during the simulation process and cell condition of the substrate is considered based on inertial and viscous resistance. The simulation is continued until it reached the convergence.

The heat exchanger is analyzed with three different thickness (50mm,60mm,70mm), three different pressures(108041Pa, 147062Pa, 196082Pa) and three different temperatures (60°C, 70°C, 80°C) are maintained and analyzed . These simulated are results are compared with the existing heat exchanger tested with standard experimental setup.For the simulation and experimental work, Taguchi based Design of Experiment was implemented. The method provides a set of nine well-balanced designs which are presented in Table 1. The experimental pressure drop and Temperature on the nine well balanced designs are presented below in table 2.

Table 1.Nine well balanced designs

S.No	Thickness(mm)	Pressure(Pa)	Temperature(°C)
D1	50	108041	60
D2	50	147062	70
D3	50	196082	80
D4	60	108041	70
D5	60	147062	80
D6	60	196082	60
D7	70	108041	80
D8	70	147062	70
D9	70	196082	60

Table 2. Experimental Results of Nine well balanced designs

S.No	Pressure P_1 (At the inlet)	Pressure P_1 (At the Outlet)	Pressure drop ΔP= P1~P2	Temperature T_1(^{0}C) (At the inlet)	Temperature T_2(^{0}C) (At the outlet)	Temperature difference (^{0}C)
D1	108041	106509	1532	60	32	28
D2	147062	145564	1498	70	43	27
D3	196082	194482	1600	80	48	32
D4	108041	106573	1468	70	39	31
D5	147062	145530	1532	80	50	30
D6	196082	194650	1432	60	27	33
D7	108041	106431	1610	80	51	29
D8	147062	145628	1434	70	43	27
D9	196082	194552	1530	60	36	24

The simulation results with the temperature and pressure drop in the flow of nine well balanced designs are presented intable 3.

Table 3. Simulation Results of Nine well balanced designs

S.No	Thickness(mm)	Pressure drop (Pa)	Temperature(^{0}C)
D1	50	1512	17
D2	50	1475	25
D3	50	1575	33
D4	60	1449	24
D5	60	1512	37
D6	60	1408	20
D7	70	1595	34
D8	70	1412	27
D9	70	1501	19

Results and Discussion:

Thecomparative analysisof temperatureand pressure drop is done between theexisting heat exchanger and computationaldata. From the table 2 and 3, we inferred that design no D9 works with better pressure drop and final temperature of the fluid at the outlet. The static pressure variations of design no: D9 are shown in the figure 2. From the results, we can infer that the pressure drop in the newly designed heat exchanger is slightly higher than the existing design due to the copper ridges made on the surface of the heat exchanger. The velocity profile of the fluid in the heat exchanger is shown in the figure 3.

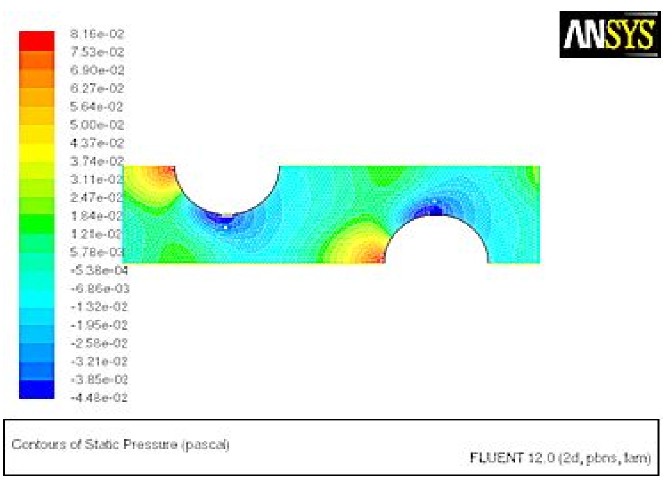

Figure 2. Static pressure vs. curve length

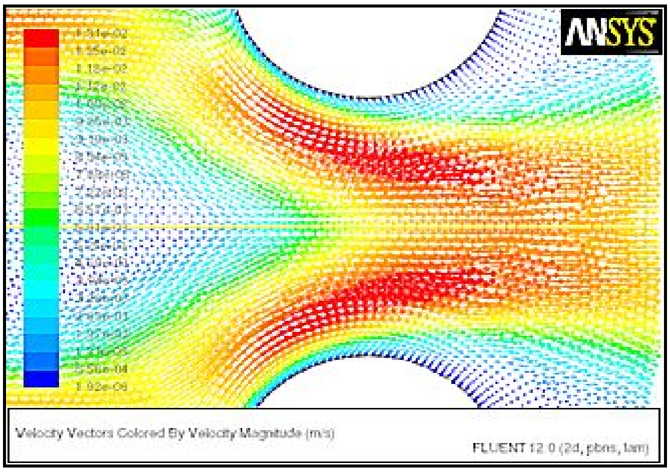

Figure 3. Velocity profile

The existing heat exchangers reduce the temperature on an average of 30^{0}C in one pass with pressure drop of 1515 Pa. It is inferred form the result, we can conclude that new modelis capable of reduce an average temperature of45^{0}C.The temperature variations over the length of the heat exchanger is shown in figure 4. It is also observed that at low pressure a better reduction in temperature is observed and vice-versa.

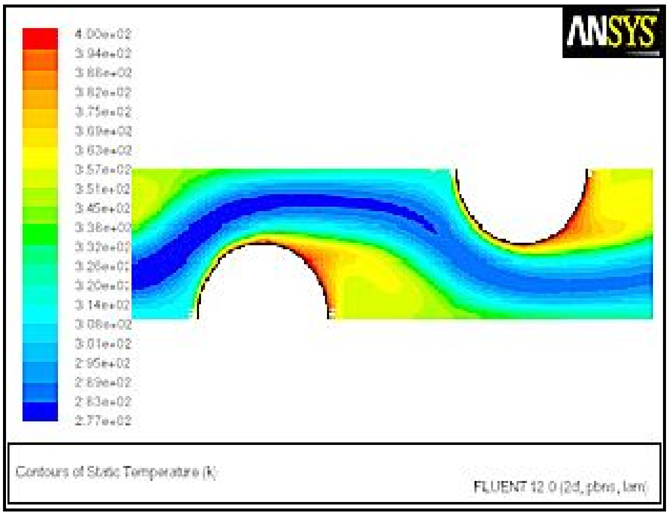

Figure 4. Temperature variation Vs curve Length

Conclusion:

1. Open cell Cu porous media can replace the existing Heat exchanger with better reduction in temperature with the same size.
2. Addition of fins to the outer surface of the heat exchanger can reduce the further temperature.
3. Based on the simulationresults D9are recommended for further experimental work and validation of results.

References

1. Kakac S, Liu H, Pramuanjaroenkij A. Heat exchangers: selection, rating, and thermal design. CRC press; 2012 Mar 1.ISBN 0-8493-0902-6
2. Darcy H. Les fontainespubliques de la ville de Dijon: exposition et application... Victor Dalmont; 1856.
3. Carman PC. Fluid flow through packed beds. Transactions of the Institution of Chemical Engineers. 1937;15:150-66.

4. Du Plessis P, Montillet A, Comiti J, Legrand J. Pressure drop prediction for flow through high porosity metallic foams. Chemical Engineering Science. 1994 Dec 31;49(21):3545-53.
5. Diedericks GP, DuPlessis JP. Modelling of flow through homogeneous foams. Mathematical Engineering in Industry. 1997 Jan 1;6(2):133-54.
6. Smit GJ, Du Plessis JP. Modelling of non-Newtonian purely viscous flow through isotropic high porosity synthetic foams. Chemical Engineering Science. 1999 Mar 31;54(5):645-54.
7. Lage JL, Antohe BV. Darcy's experiments and the deviation to nonlinear flow regime. Journal of fluids engineering. 2000 Sep 1;122(3):619-25.
8. Boomsma K, Poulikakos D, Zwick F. Metal foams as compact high performance heat exchangers. Mechanics of materials. 2003 Dec 31;35(12):1161-76.
9. Calmidi VV, Mahajan RL. Forced convection in high porosity metal foams. Journal of Heat Transfer. 2000 Aug 1;122(3):557-65.
10. Boomsma K, Poulikakos D. On the effective thermal conductivity of a three-dimensionally structured fluid-saturated metal foam. International Journal of Heat and Mass Transfer. 2001 Feb 28;44(4):827-36.
11. Boomsma K, Poulikakos D. The effects of compression and pore size variations on the liquid flow characteristics in metal foams. Journal of fluids engineering. 2002 Mar 1;124(1):263-72.
12. Mohamad AA. Heat transfer enhancements in heat exchangers fitted with porous media Part I: constant wall temperature. International Journal of Thermal Sciences. 2003 Apr 30;42(4):385-95.
13. Tzeng SC. Convective heat transfer in a rectangular channel filled with sintered bronze beads and periodically spaced heated blocks. Journal of heat transfer. 2006 May 1;128(5):453-64.
14. Yang YT, Hwang ML. Numerical simulation of turbulent fluid flow and heat transfer characteristics in heat exchangers fitted with porous media. International Journal of Heat and Mass Transfer. 2009 Jun 30;52(13):2956-65.
15. Koushik GS, Panneer R. Design and Simulation of a Hollow Cylindrical Ceramic Air filter using Finite Volume Technique. Indian Journal of Science and Technology. 2015 Sep 1;8(23).
16. Dupuit J. Etudes theoriquesetpratiquessur le mouvement des eauxdans les canauxdecouverts et a travers les terrains permeables avec des considerations relatives au regime des grandeseaux, au debouche a leurdonner et a la marche des alluvionsdans les rivieres a fond mobile. Dunod; 1863.
17. Barles S. La boue, la voitureetl'amuseur public. Les transformations de la voirieparisienne, fin xviii e-fin xix e siècles. Ethnologiefrançaise. 2015 Jul 28(3):421-30.
18. Mathias SA, Wen Z. Numerical simulation of Forchheimer flow to a partially penetrating well with a mixed-type boundary condition. Journal of Hydrology. 2015 May 31;524:53-61.
19. Mahdi RA, Mohammed HA, Munisamy KM, Saeid NH. Review of convection heat transfer and fluid flow in porous media with nanofluid. Renewable and Sustainable Energy Reviews. 2015 Jan 31;41:715-34.
20. Kaviany M. Principles of heat transfer in porous media. Springer Science & Business Media; 2012 Dec 6.
21. Dullien FA. Porous media: fluid transport and pore structure. Academic press; 2012 Dec 2.
22. Nield DA, Bejan A. Mechanics of Fluid Flow Through a Porous Medium. Springer New York; 2013 Jan 1.
23. Amiri A, Vafai K. Analysis of dispersion effects and non-thermal equilibrium, non-Darcian, variable porosity incompressible flow through porous media. International Journal of Heat and Mass Transfer. 1994 Apr 30;37(6):939-54.
24. Nemec D, Levec J. Flow through packed bed reactors: 1. Single-phase flow. Chemical Engineering Science. 2005 Dec 31;60(24):6947-57.
25. Jayarathna CK. Experimental and computational study of the effect of particle size distributions on the flow behavior in fluidized beds.2009
26. Wang M, Pan N. Modeling and prediction of the effective thermal conductivity of random open-cell porous foams. International Journal of Heat and Mass Transfer. 2008 Mar 31;51(5):1325-31.
27. Patankar S. Numerical heat transfer and fluid flow. CRC Press; 1980.
28. Kordás K, Remes J, Beke S, Hu T, Leppävuori S. Manufacturing of porous silicon; porosity and thickness dependence on electrolyte composition. Applied surface science. 2001 Jul 2;178(1):190-3.
29. Hornung U, editor. Homogenization and porous media. Springer Science & Business Media; 2012 Dec 6.

30. Guardo A, Coussirat M, Larrayoz MA, Recasens F, Egusquiza E. Influence of the turbulence model in CFD modeling of wall-to-fluid heat transfer in packed beds. Chemical Engineering Science. 2005 Mar 31;60(6):1733-42.
31. Udell KS. Heat transfer in porous media considering phase change and capillarity—the heat pipe effect. International Journal of Heat and Mass Transfer. 1985 Feb 28;28(2):485-95.
32. Kim SY, Paek JW, Kang BH. Flow and heat transfer correlations for porous fin in a plate-fin heat exchanger. Journal of heat transfer. 2000 Aug 1;122(3):572-8.
33. Dunn PD, Reay D. Heat pipes. Elsevier; 2012 Dec 2.

*****