

A Novel Design and Simulation of Porous Heat Exchanger Using Finite Volume Technique

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Abstract : Heat exchangers are for the mostly utilized in auto mobiles and other application like space warming, refrigeration, aerating and cooling, power stations, petrochemical plants, petroleum refineries, common gas handling, and sewage treatment. Where liquids are isolated by a solid assembly like divider to envision bond or they might be in direct contact. Heat exchangers are made out of exceedingly thermally conductive materials for reduction of heat. The advancement of electronic industry and its pattern toward scaling down and rapid working procedures requires higher execution and little scale cooling frameworks. The scaled down Heat exchanger has transformed into a vital issue in the association of forefront advances. Permeable media is decided for building up another minimal warmth exchanger. Simulation utilized to examine the liquid stream and heat transfer in the liquid in the Heat Exchanger with porous media. In designing heat exchanger, copper is used as a surface for enhanced heat exchange. The parameters examined incorporate the Reynolds number ($Re < 2000$), pressure drop, temperature, thickness of the permeable media utilized by keeping up the constant porosity. The comparative analysis was done between the computational work and existing heat exchanger under standard boundary conditions. Results demonstrate that newly designed heat exchanger enhances the heat exchange

Keywords : Heat Exchanger; Finite volume; Heat Transfer; Pressure Drop; Temperature; Simulation; k -epsilon model; porous media ;copper ridges; Catia v5;Fluent.

1. INTRODUCTION

A heat exchanger is a device built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petro chemical plants, petroleum refineries, and natural gas processing. Liquids are isolated by a solid assembly like divider to envision bond or they might be in direct contact. Heat exchangers are made out of exceedingly 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.

1.1 NATURE OF PROBLEM AND PURPOSE

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 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.

1.2. PREVIOUS WORK

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, which mainly concentrates in the applications based on adsorption, stripping and distillation, geothermal operation. 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. The expansion of Darcy Law was intended by Dupuis, Forchheimer. 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. These temperature variations were later connected to the thickness of the porous media. A survey of the historical backdrop of the investigation of fluid flow through porous media was done. 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.

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

The packed bed is basically fabricated either by using spherical particulates or non-spherical particles. 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. 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 500-10,000 m²/m³. 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. The conductivity of the solid-fluid framework can be anticipated by Eq. (2) was first explained in the 2-D conduction model.

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

Most of the applications which are based on the porous media are manufactured by anodizing required material wafer into electrolytes (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. In the recent past, a new methodology was proposed in fabricating the porous media using powder metallurgy. Fabricating the porous media by slip casting process gives an advantage in deciding the porosity.

2. EXPERIMENT

The parameters examined incorporate the Reynolds number ($Re < 2000$), pressure drop, temperature, thickness of the permeable media utilized by keeping up the constant porosity. The comparative analysis was done between the computational work and existing heat exchanger under standard boundary conditions.

2.1. DESIGN AND SIMULATION PREMISES

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

- The flow through heat exchanger is either laminar or turbulent.
- The simple unit cell structure shall be considered.
- The surface topology of the particle is considered as smooth.
- The orientation or packing arrangement is considered as cubical.
- The porosity of the porous media is constant over the length.
- The ratio of the diameter of the tube to particle diameter (D/d_p) shall be between 15-1730.
- The Reynolds number of the fluid flow through the heat exchanger shall be low.
- The velocity profile has minimal effect on pressure drop except possibly at high Reynolds numbers.
- Finite volume method shall be considered.
- Heat transfer rate in all porous particles is uniform.
- Particles used in manufacturing the porous media are complete solid.

- Heat transfer in the porous is either by conduction or convection or both.
- Ridges fitted on the surface are uniform and isotropic in nature.

2.2. DESIGN AND SIMULATION OF HEAT EXCHANGER

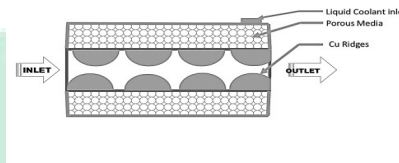


FIGURE 1. MODEL STRUCTURE OF HEAT EXCHANGER WITH POROUS MEDIA AND RIDGES

In the main aim 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. Heat pipe plays major role in designing the porous media heat exchanger and it is made out of a fixed, emptied vessel in which the internal surface are filled with a Cu porous media and loaded with enough working liquid to immerse the porous media. 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. Primary classification of the structure can incorporate sintered powder or filaments, porous media, hub grooves, separated annuli and wrapped screens etc. a few prerequisites for heat control 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 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. It is last component that for the most part makes heat pipe alluring for the 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 nodes the space was split into cells containing 352955 countenances and 115976 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 simulation work is carried out based on the theoretical design of Yang 14. The Yang had proposed a following governing equation for fluid and heat flow through the porous media.

3. EQUATIONS

Energy equation, continuity equation and momentum equation are given below in Eq-3, Eq-4, and Eq-5 respectively.

3.1. ENERGY EQUATION:

$$\frac{\partial}{\partial r} \left(r K_e \frac{\partial T}{\partial r} \right) + \frac{\partial}{\partial z (K_e \frac{\partial T}{\partial z})} \rightarrow 3$$

Where,

K_e = Effective conductivity (based on porous media geometry)

F = Inertial Coefficient

K = Permeability

μ = Viscosity of the fluid

ρ = density r = radial coordinate

T = Temperature

U = Dimension less velocity

3.2. CONTINUITY EQUATION:

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

3.3. MOMENTUM EQUATION:

$$\frac{\partial}{\partial z} (\rho_f u u) + \frac{1}{r} \frac{\partial}{\partial r} (r \rho_f v u) = - \frac{\partial P}{\partial z} + \frac{\partial}{\partial z} \left[\mu_e \frac{\partial u}{\partial z} \right] + \frac{1}{r} \frac{\partial}{\partial r} \left[r \mu_e \frac{\partial u}{\partial r} \right] - \frac{\mu_e}{K} u - \frac{\rho_f F}{\sqrt{K}} |U| u. \rightarrow 5$$

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, 147062 Pa, 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 the Table 2.

3. TABLES

3.1. TABLE 1.NINE WELL BALANCED PARAMETERS FOR DESIGN

| S.No | Thickness (mm) | Pressure (Pa) | Temperature (°C) |
|------|----------------|---------------|------------------|
| D1 | 50 | 107041 | 60 |
| D2 | 50 | 146062 | 70 |
| D3 | 50 | 195082 | 80 |
| D4 | 60 | 107041 | 70 |
| D5 | 60 | 146062 | 80 |
| D6 | 60 | 195082 | 60 |
| D7 | 70 | 107041 | 80 |
| D8 | 70 | 146062 | 70 |
| D9 | 70 | 195082 | 60 |

3.2. TABLE 2.EXPERIMENTAL RESULT OF NINE WELL BALANCED FOR DESIGNS

| S.No | Pressure P1 (At the inlet) | Pressure P1 (At the Outlet) | Pressure drop $\Delta P = P1 - P2$ | Temperature T1(°C) (At the inlet) | Temperature T2(°C) (At the outlet) | Temperature Difference (°C) |
|------|----------------------------|-----------------------------|------------------------------------|------------------------------------|-------------------------------------|-----------------------------|
| D1 | 107040 | 105508 | 1532 | 60 | 32 | 28 |
| D2 | 146062 | 144564 | 1498 | 70 | 43 | 27 |

| | | | | | | |
|----|--------|--------|------|----|----|----|
| D3 | 195082 | 193482 | 1600 | 80 | 48 | 32 |
| D4 | 107041 | 105573 | 1468 | 70 | 39 | 31 |
| D5 | 146062 | 144530 | 1532 | 80 | 50 | 30 |
| D6 | 195082 | 193650 | 1432 | 60 | 27 | 33 |
| D7 | 107041 | 105431 | 1610 | 80 | 51 | 29 |
| D8 | 146062 | 144628 | 1434 | 70 | 43 | 27 |
| D9 | 195082 | 193552 | 1530 | 60 | 36 | 24 |

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

3.3.TABLE 3.SIMULATION RESULTS OF NINE WELL BALANCED FOR DESIGNS

| S.No | Thickness (mm) | Pressure drop (Pa) | Temperature (°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 |

4. ANALYSIS

The comparative analysis of temperature and pressure drop is done between the existing heat exchanger and computational data. 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.

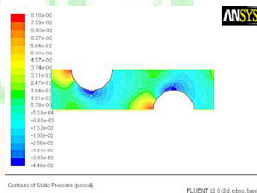


FIGURE 2. STATIC PRESSURE VS. CURVE LENGTH

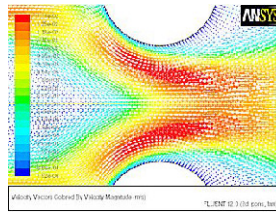


FIGURE 3. VELOCITY PROFILE

The existing heat exchanger reduce the temperature on an average of 30°C in one pass with pressure drop of 1515 Pa. It is inferred from the result, we can conclude that new model is capable of reduce an average temperature of 45°C. The temperature variation over the length of the heat exchanger is shown in figure 4. It is also observed that a low pressure a better reduction in temperature in observed and vice versa.

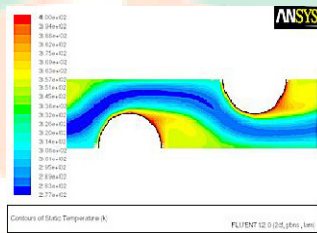


FIGURE 4. TEMPERATURE VARIATION VS CURVE LENGTH

5. CONCLUSION:

Heat exchangers are also very important for energy conservation, conversion, recovery and successful Implementation of new energy sources and wide usage of it involves heat recovery. The potential of porous structures (e.g., metallic foam Cu) in heat exchangers is currently undergoing growing interest due to their large surface area per unit of volume. Recently tremendous works have been conducted on heat transfer enhancement and a large number of techniques for heat transfer enhancement have been developed. This work concerns the investigation on effect of porous media on heat transfer rate in heat exchangers. Here, Open cell Copper (Cu) porous media can replace the existing heat exchanger with better reduction in temperature with the same size on fluid flow areas. Addition of fins to the outer surface of the heat exchanger can reduce the further temperature with effective velocity under some pressure drops. Based on the simulation results D9 are recommended for further experimental work and validation of results.

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