CFD Analysis of Double Pipe Heat Exchanger by Using Perforated Pipe

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Abstract - *Double pipe heat exchanger with corrugation, winglets, inserts, extended surfaces, dimples, nanofluid as well as external energy sources like mechanical vibration, rotation of pipe, etc. are widely used for heat transfer improvement. These methods are grouped in two categories i.e. active and passive methods. In the comparison of active and passive methods, passive methods are easy and simple whereas active methods required special arrangements. Research had been done for various arrangements in heat exchanger and results shown that the active methods produce more heat transfer rate comparing to passive methods, but power consumption & pressure drop also increases significantly. In this paper, The CFD (Computational Fluid Dynamics) analysis is conducted in Ansys Fluent software on Double pipe heat exchanger in which perforated pipe are installed longitudinally in the annulus region for better mixing of fluid, as fluid flows through the holes in the annulus region for heat transfer improvement without significantly increasing pressure drop and comparison was done with various combinations of arrangements of perforated pipe and mass flow rates to identify foremost arrangement. Perforated pipe is taken with 1 mm thickness. The internal fluid was considered as hot fluid whereas in the annulus region fluid was considered as cold fluid. The performance parameters like Heat Transfer rate, Effectiveness, Pressure drop, evaluated for parallel flow condition.*

***Key Words*: Double pipe heat exchanger, Heat transfer rate, Perforated pipe, Computational Fluid Dynamics, Eccentric Perforated Pipe.**

1. INTRODUCTION

Double pipe heat exchangers are widely used in industries because of their simple design and optimal Installation and maintenance cost as well as flexible configuration. The use of accession techniques, such as active and passive, to enhance heat transfer rate and effectiveness in double pipe heat exchanger had been explored in a while. Passive techniques are most commonly used in double pipe heat exchanger are spiral spring insert, Fins, twisted tape, helical wire insert, corrugated tube, baffles, vortex generator, turbulator [1-20]. Whereas in active methods use of mechanical aids, magnetic fields are linked, which commit external power source for heat transfer improvement [10,42,49,51].

Extended surfaces are the most common nomenclature used to improve heat transfer rate by convection phenomenon with an increase in the surface area. Li Zhang et al. [1] experimentally and numerically investigated the fluid flow characteristics of a double pipe heat exchanger with the use of helical and pin fins and measured the three-dimensional velocity components by using a laser doppler anemometer. Mohsen Torabi et al. [2] examined fins of different geometrical shapes with a combination of arrangements. They established the performance characteristics of these fins for different thermal conductivities, emissivity, and convection conduction parameters. Z. Iqbal et al. [3] ascertain optimal fin shape for a finned double pipe in fully developed laminar flow with the aim of maximizing the Nusselt number and they presented and discussed the optimal profiles. However, installing fins in the heat exchanger makes cleaning and maintenance more complex.

H.A. Mohammed et al. [4] investigated the effect of geometric parameters and adding nanoparticles to working fluid on heat transfer. The results indicate wire coil diameter affects heat transfer rate, as wire coil diameter decreases results in an increment in heat transfer rate. Whereas the amount of coil pitch does not have a significant effect on heat transfer rate. Khashayar Sharifi [5] conducted computational fluid dynamics (CFD) analysis to study the effect of coiled wire inserts on the friction coefficient, Nusselt number, and overall efficiency in double pipe heat exchanger. It is observed that the presence of the wires culminates in an increase in pressure drop and friction coefficients in all of the heat transfer processes. J. P. Chiou et al. [6] investigated the effect of coiled wire inserts in chilling horizontal heat exchangers filled with oil. Researcher observed that heat transfer rate is increased due to disturbing laminar sub -ayer near the surface.

Twisted tapes are used in heat exchanger as they direct the flow and increase the effective length of flow, results in an improvement in heat transfer rate by swirl and vortex flow generated by twisted tape design. M. Sheikholeslami et al. [7] presented an experimental and numerical investigation on convective heat transfer and friction loss in a double pipe heat exchanger with perforated turbulators in the annulus region. Observation showed that the thermal performance enhances with increasing open area ratio, while temperature gradient reduces with augmenting of pitch ratio. Ranjith et al. [8] used the twisted tape on both sides i.e. tube and annulus of double pipe heat exchanger. Twisted tape helps to produce swirl motion to fluid and also increases the effective flow length. Observations have shown that flow induced by twisted tape enhanced cross-stream mixing of the fluids are results in improvement in heat exchanger performance. Pongjet Promvonge et al. [9] investigated the effect of the twist ratio on the heat transfer and pressure drop in a helical ribbed tube with twin twisted tape inserts. The observations show that heat transfer increases with twist ratio. Paisarn Naphon et al. [10] performed experimental investigations on the heat transfer and pressure drop behavior in the double pipes with twisted tapes. The results show that pressure drop is high. Saman Pourahmad et al. [11] experimentally investigated a double pipe heat exchanger equipped with wavy strip turbulators, inserted in the inner pipe, their results showed considerable enhancement on heat transfer characteristics. Shaojie Zhang et al. [12] carried out an experimental investigation with perforated self-rotating twisted tape in order to find the optimal design in terms of thermal performance Factor. Peripherical cut twisted tape, v cut twisted tape, square-cut twisted tape, perforated twisted tape, etc. are some of the inserts which are investigated. rotation behavior of twisted tape produces rotational flow that increases the heat transfer rate by enhancing the turbulence intensity along the tangential direction. Suabsakul Gururatana et al. [13] used wavy insert to increase the transfer rate of heat in heat exchanger. With wavy insert, flow becomes turbulent and due to circulation and vortices inside the pipe, enhances the turbulence intensity and mixing of flow. It is observed that wavy insert can disturb both velocity and thermal boundary layer. While boundary layers are unsettled, the heat transfer can be increased with increase in friction factor.

Baffles are mostly used in shell and tube heat exchanger for holding or supporting tubes and directing fluid flow. But in double pipe heat exchanger the use of baffle is limited to directing fluid flow by restricting flow lines results in generating turbulence. Anas El Maakoul et al. [14] numerically investigated the thermal performance of a helically baffled double pipe heat exchanger. The results revealed that heat transfer performance and annulus pressure drop increased compared to the simple heat exchanger, and they are increasing functions of baffle spacing and Reynolds number. M. Vivekanandan et al. [15] performed the experimental as well as CFD analysis on double pipe heat exchanger with helical wire insert and baffle plates are mount in flower pattern around the inner pipe. Heat transfer rate is improved in the heat exchanger due to better mixing of fluid with the combination of helical wire and baffles. M.R. Salem et al. [16] conduct the experiment to investigate the effect of segmental perforated baffles of different spacing, inclination angles, cuts, void and pitch ratios on heat transfer rate in double pipe heat exchanger. They observed that by increasing the number of baffles, heat transfer rate is increasing drastically but pressure drop also increases which is not much favorable condition.

Anil Kumar et al. [17] perform simulations to investigate the effect of various V patterns rib on Nusselt number, Friction factor and thermodynamic performance of heat exchanger. V pattern rib with grooves gives high thermal performance compared with others also cutting down the rib in two parts results in breaking the fluid flow and increases the turbulence bring forth improvement in heat transfer rate. Feng Xin et al. [18] performed the analysis on two start corrugated tube in which fluid flew along with corrugated spiral channel. The spiral channel in the spirally corrugated tube produces a helical guide force and enhances the disturbance of the fluid to the boundary area. In the process, development of boundary layer is restricted by a periodic spiral channel and the heat transfer between tube and fluid is enhanced. Hamed Sadighi Dizaji et al. [19] experimentally investigated heat transfer, pressure drop and effectiveness in a double pipe heat exchanger with both the inner and outer tubes were corrugated with convex and concave arrangement. Corrugated tubes help in improvement in Nusselt number. While the arrangement of corrugated tubes i.e. concave and convex had a significant effect on thermal and frictional characteristics.

L.D. Jathar et al. [20] performed the experiment to investigate the effect of washers on heat transfer rate. 2-slot, 3-slot, 4-slot washer are investigated and observation shows that the washer inserted arrangement yields considerable heat transfer compared with the without washer arrangement. Agung Tri Wijayanta et al. [21] conducted the experiment with double sided delta wing tape inserts which are used to enhance convective heat transfer of a double pipe heat exchanger. Researcher investigated fluid flow characteristics & effect of wing-width ratio on heat transfer rate. It is observed that, tape inserts significantly enhance the average convective heat transfer coefficient and the convective heat transfer increases with an increase in the wing-width ratio.

The mixing of solid particles into fluid is one of the useful techniques for enhancing heat transfer, although considerable concern of nanofluid is, when using micro-sized suspended particles in the heat exchanger is that they prone to cause some issues, such as clogging, abrasion, high pressure drop. Comparing the heat transfer improvement with the use of suspended large particles, the application of nanoparticles in the fluids displayed better properties relating to the heat transfer of fluid mainly because nanoparticles are usually used at very low concentrations and nanometer sizes. L. Syam Sundar et al. [22] conducted experiments with Fe_3O_4 magnetic nanofluid with different flow rates in a circular tube and observed that the ratio of temperature distribution is decreasing with an increase of volume concentration & heat transfer coefficient increases with the increase of volume concentration. M.M. Sarafraz et al. [23] performed an investigation on forced convective heat transfer improvement utilizing a biological nanofluid in a double pipe heat exchanger. The effects of the flow rate, nanofluid concentration and the inlet bulk temperature on heat transfer coefficient are experimentally investigated by researcher. Wael M. El-Maghlany et al. [24] experimentally tested the effect of a compound heat transfer enhancement technique on the thermal performance of a horizontal double tube heat exchanger. Cu/water nanofluid of volume fractions of 0.3% was employed in the annulus side, while the inner tube was rotated with speed from up to 500 rpm. Results show improvement in heat transfer. Moreover, the use of the nanofluid had increase the pressure drop in comparison with the inner tube rotation. Eda Feyza Akyurek et al. [25] Used Al_2O_3 nanofluid to analyze rate of heat transfer by using different volume ratios with and without turbulator combinations. Al_2O_3 with pure water causes an increase in the Nusselt number and the average heat transfer coefficient but marginal pressured drop is also observed. It is observed that the without turbulator rate of heat transfer with nanofluid is better than with turbulator. C. Gnanavel et al. [26] performed the CFD analysis is conducted for analysis of thermal performance of CuO nanofluid, TiO_2 nanofluid, BeO nanofluid and plain water in the double tube heat exchanger with rectangular cut twisted tape insert, results shows that TiO_2 nanofluid is the most efficient.

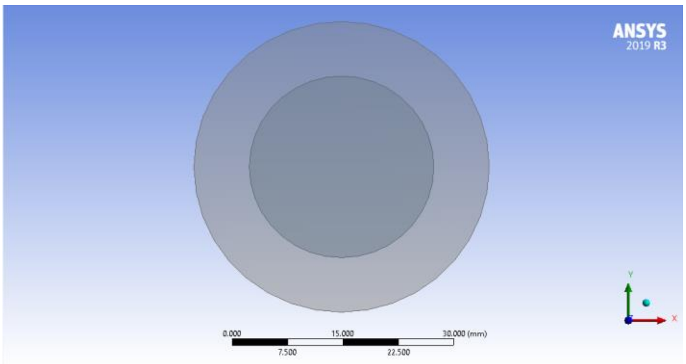
Simple geometric modifications are required to overcome above drawbacks. In recent times some novel techniques are proposed in the field of heat exchanger are, Amin Moosavi et al. [27] used air bubbles in a shell and coiled tube heat exchanger to optimize pressure drop and heat transfer, and determined the best mass flow rate of air and water in accordance with NTU and effectiveness. They observed an increase of 168% in the overall heat transfer coefficient, and concluded that the effects of air bubble injection increase as the air flow rate increases. Mehran Hashemian et al. [28] investigated the innovative geometrical modification of conical tube in heat exchanger. The model was solved numerically, the results indicate enhancement in effectiveness and heat transfer at the optimum condition. Do Huu Quan et al. [29] performed CFD analysis of double pipe heat exchanger with various different inner tube shapes like flat pipe, circular pipe and some other changes in geometrical parameters. Paper signifies the effect of aspect ratio on pressure drop of the fluid, as aspect ratio increases had effect on lower pressure drop.

1.1 Motivation And Objective

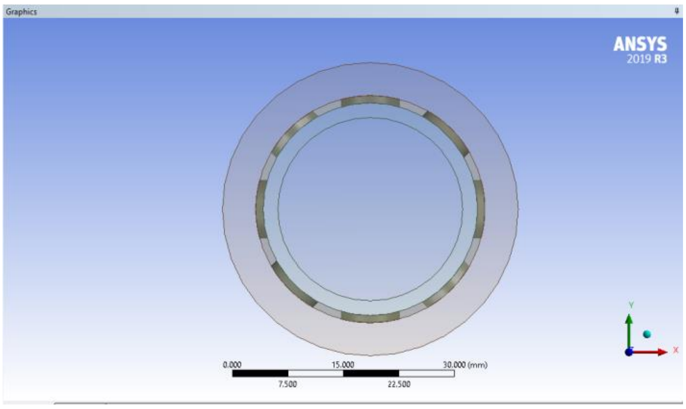
In the field of heat exchanger comprehensive literature is available for improvement of heat transfer and effectiveness. Accordingly, passive methods are widely used which includes fins, wire inserts, twisted tape, baffles etc. These passive methods improve heat transfer by introducing more heat transfer area, rotating, diverting and directing fluid flow etc. but with use of fins and baffles pressure drop also increases significantly. To improve heat transfer and keep pressure drop merest this paper performed CFD simulation on double pipe heat exchanger with perforated pipe in the annulus region.

1.2 Problem statement

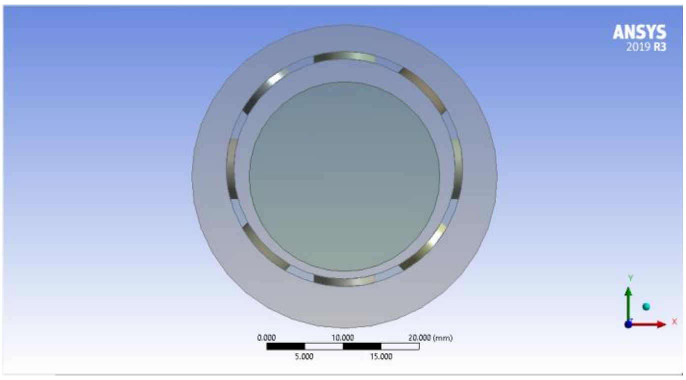
In this paper, Computational Fluid Dynamics (CFD) simulation was carried out to investigate the effect of perforated pipe in the annulus region of double pipe heat exchanger for different geometrical combinations with working fluid mass flow rate for parallel flow configuration. For the simulation, Double Pipe heat exchanger taken in 500mm length with outer diameter of 40mm and 25mm of inner diameter. Copper is used as pipe material. The wall thickness of outer and inner pipe is considered extremely thin and outer pipe wall is considered as adiabatic wall. Whereas perforated pipe of 29mm inner diameter with 1mm thickness having perforation of 10mm in diameter spread in linear and circular pattern. Five different flow rates are simulated in combination with perforated pipe.



Case 01 Simple double pipe heat exchanger

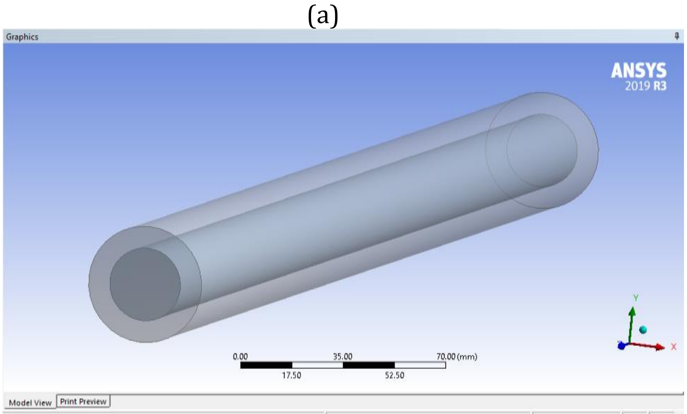


Case 02 Double pipe heat exchanger with concentric perforated pipe

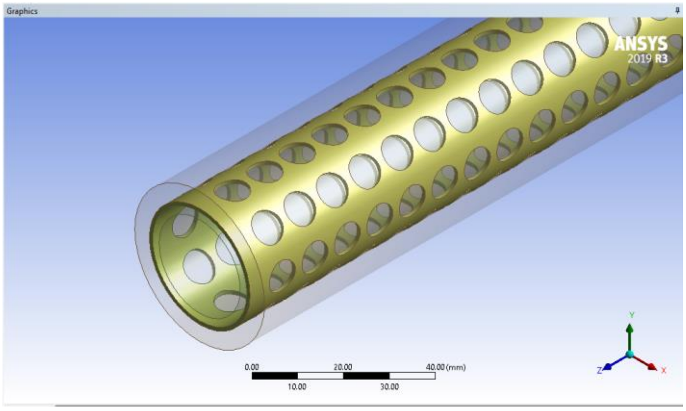


Case 03 Double pipe heat exchanger with eccentric perforated pipe

(a)



3D view of double pipe heat exchanger



3D view of heat exchanger with perforated pipe
(b)

Fig - 1: (a) cross section and (b) 3D overview of double pipe heat exchanger

2. GOVERNING EQUATIONS

In this research, flow is considered as three dimensional, steady and incompressible. Turbulent model was used to investigate the effect of perforation pipe in double pipe heat exchanger. The numerical model was built up by using ANSYS Fluent 2020 rest on continuity, momentum and energy equations.

Continuity equation,

(1)

Where *V* is the fluid velocity

Momentum equation,

(2)

Where ρ is fluid density, *P* is pressure, μ is fluid dynamic viscosity, fluid turbulent viscosity, velocity fluctuation.

Energy equation,

$$\rho C_p V.\nabla T = \nabla.\left(k_{eff}\nabla T\right) \quad (3)$$

The realizable k-e turbulence model is used for the analysis.

3. PERFORMANCE INDICATORS

Several important performance parameters are defined below,

Heat transfer rate of cold fluid,

(4)

(5)

Heat transfer rate of hot fluid,

(6)

(7)

Where, are mass flow rate of hot fluid and cold fluid at inlets. C_{ph} and C_{pc} are specific heat capacity of hot and cold fluid respectively. T_i and T_o are inlet and outlet temperatures of heat exchanger and

, (8)

Are heat capacity rate of hot fluid and cold fluid respectively.

Average heat transfer rate,

$Q = (Q_h + Q_c)/2$ (9)

Effectiveness, where $Q_{max} = C_{min}\left(T_{h,in} - T_{c,in}\right)$

(10)

and C_{min} is minimum heat capacity rate between hot and cold fluids.

Friction coefficient,

, (11)

Where, ΔP_i, ΔP_o shows pressure drop in inner and outer pipe of the heat exchanger. $V_{i,pipe}$, $V_{i,\ annulus}$ shows fluid velocity at inlet of inner pipe and outer pipe of heat exchanger.

Heat exchanger performance index,

(12)

Where, $\Delta P_{tot} = \Delta P_i + \Delta P_o$

Reynolds number,

, (13)

Where, ρ is density of fluid, D_h is hydraulic diameter, μ is dynamic viscosity of fluid.

4. BOUNDARY CONDITIONS

4.1 Boundary condition at inlet

Working fluid is considered to be water enters in the annulus at mass flow rate of 0.1 kg/s and at 20^{0}C. Hot fluid enters in inner pipe at 60^{0}C with varying Reynolds number of fluid flow from 4000 to 13000.

4.2 Boundary conditions at outlet

Both outlets are assumed to be pressure outlets i.e pressure at outlets is considered as atmospheric pressure.

4.3 Boundary conditions at wall

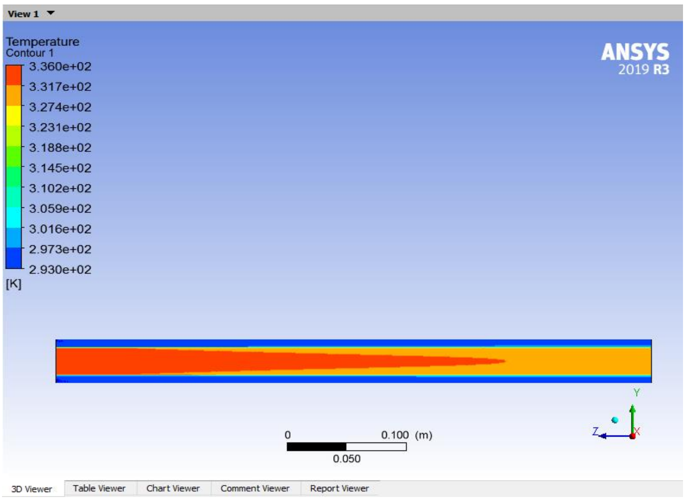
Outer pipe wall is considered as adiabatic wall with non-slip Condition.

4.4 Numerical method and validation

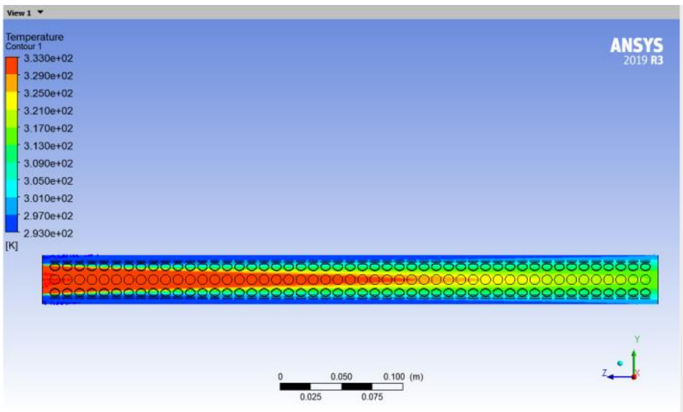
For simulation purpose Ansys fluent software was used with K-epsilon turbulence model. Solution was governed by using finite volume method. Moreover, SIMPLEC algorithm was used with second order method for pressure and second order upwind method for momentum, turbulent kinetic energy, turbulent dissipation rate, energy. For simple double pipe heat exchanger combination of 4199273 nodes, 102400 elements were used. Whereas for double pipe heat exchanger with concentric perforated pipe and eccentric perforated pipe combination of 1274042 nodes, 4257868 elements and 1494368 nodes, 5398616 elements were used.

5. RESULTS AND DISCUSSION

The Performance characteristics of simple double pipe heat exchanger, perforated pipe in the annulus region of double pipe heat exchanger with concentric as well as eccentric position are drawn from the CFD simulation. Graphs are plot for mass flow rate vs. heat transfer and mass flow rate vs. effectiveness for different flow rates.



(a)



(b)

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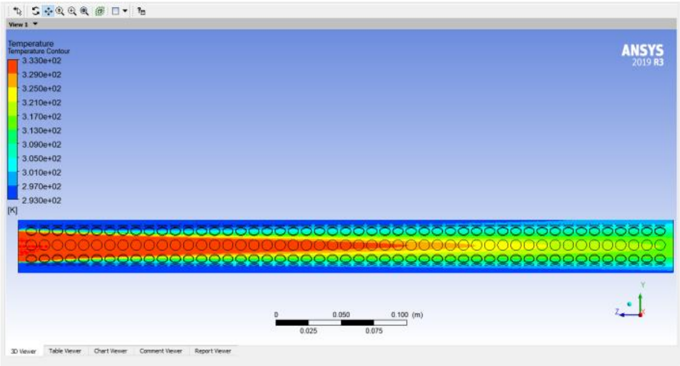

(c)

Fig - 2: (a) case 01 (b) case 02 (c) case 03 Temperature contour

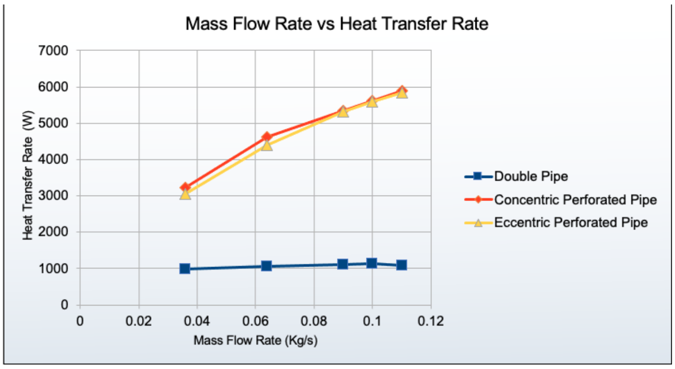

Fig - 3: Mass flow rate vs. Heat transfer rate

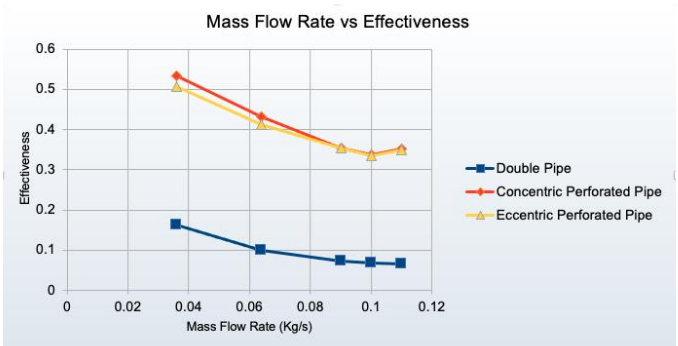

Fig - 4: Mass flow rate vs. Effectiveness

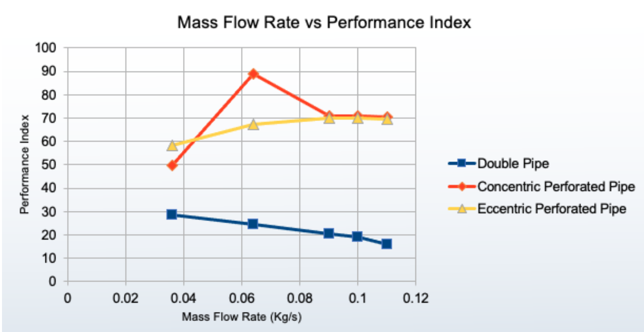

Fig - 5: Mass flow rate vs. Performance Index

1. For case 01 heat transfer rate is increased for Re of 4000 to 10000 by 15.48% as shown in fig. 3, but decrease by 3.25% for Re 13000. In which maximum heat transfer rate was observed at mass flow rate of 0.1kg/s. Whereas Effectiveness is increased by 148% with decreasing the mass flow rate shown in fig. 4.
2. Fig. 3 shows that in case 02 heat transfer rate is maximum at Re = 13000 and minimum for Re = 4000. Heat transfer rate is increased by 83% for mass flow rate varying from 0.036kg/s to 0.11kg/s. Whereas effectiveness is maximum for Re = 4000 and decrease with respect to an increase in mass flow rate by 34% shown in fig. 4.
3. From fig. 3 it can be defined as in case 03 in the heat transfer rate is maximum at Re = 13000 and minimum for Re = 4000. Heat transfer rate is increased by 91.6%. Whereas effectiveness is maximum for Re = 4000 and decrease with respect to increase in mass flow rate by 30%.
4. For same mass flow rates of hot fluid and cold fluid in all three cases the, heat transfer rate and effectiveness observed in simple double pipe heat exchanger is lowest and maximum in double pipe heat exchanger with concentric perforated pipe.
5. For all three cases maximum heat transfer rate is observed at Re = 13000 by 438% in double pipe heat exchanger with concentric perforated pipe.
6. In simple double pipe heat exchanger in inner pipe pressure drop is maximum at mass flow rate of 0.11kg/s and minimum for mass flow rate of 0.036kg/s. whereas in the annulus region pressure drop remains constant.
7. In case 02 and case 03 pressure drop in inner pipe and in the annulus region is maximum at mass flow rate of 0.11kg/s and minimum for mass flow rate of 0.064kg/s and 0.036kg/s respectively.
8. For all three cases maximum heat transfer observed at mass flow rate of 0.11 kg/s, in double pipe heat exchanger with case 02, for same case pressure drop is increased by 96.6%, whereas in case 03 pressure drop is increased by 95.8%.
9. Fig. 5 shows that heat exchanger performance index is decrease in case 1 for an increase in mass flow rate, but in case 2 it is maximum for mass flow rate of 0.064kg/s whereas in case 3 performance index is increased with an increase in mass flow rate.

6. CONCLUSION

In this paper we simulated the double pipe heat exchanger with perforated pipe for concentric and eccentric position with combination of mas flow rates ranging from 0.036kg/s to 0.11kg/s. Among all the combinations maximum heat transfer rate is observed for double pipe heat exchanger with concentric perforated pipe at mass flow rate of 0.11kg/s is 438% more than simple double pipe heat exchanger. Whereas pressure drop increased by 96.6% compared to simple double pipe heat exchanger.

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