HEAT TRANSFER ENHANCEMENT IN HEAT EXCHANGER USING TANGENTIAL INJECTOR TYPE SWIRL GENERATOR

Hanumant Jagdale
Department of Mechanical Engineering, MIT, Aurangabad, India

Subhash Lahane
Department of Mechanical Engineering, MIT, Aurangabad, India

A. T. Autee
Department of Mechanical Engineering, MIT, Aurangabad, India

ABSTRACT

In this work, the effect of heat transfer enhancement of swirl generator with tangential injection of fluid was examined. The five tangential injectors are placed such that they are equidistance along the length of pipe to improve the efficiency of heat transfer in concentric pipe heat exchanger the injectors are designed and placed such that it creates tangential flow in the pipe. The experiment performed for water as working fluid, hot water flowing through inner tube of material mild steel with inner diameter (ID) 16 mm and outer diameter (OD) 21 mm and cold water flowing through annulus space to generate swirling motion. The outer tube of material UPVC (un-plasticized polyvinyl chloride) having ID 35 mm and OD 42 mm. The experiment was performed for different Reynolds number ranging from 2200- 4600 for parallel and counter flow configurations. It is observed from the experimental results that the heat transfer rate increased with increase in Reynolds number. Heat transfer rate was increased about 20 % to 70 % with tangential injector type swirl generator than the heat exchanger without tangential injectors. It was also observed that the maximum heat transfer coefficients (1613 W/ m^2K) could be achieved at Reynolds number of 4600 for all (five) nozzles opening with 70 % increase in heat transfer.

INTRODUCTION

The general function of heat exchanger is to transfer the heat from one fluid to other. Concentric tube heat exchangers are most important device used in industrial and engineering applications like air conditioning, refrigeration systems, process industries, chemical reactors, food preparation etc. As it has wide applications there is need to increase the heat transfer rate of heat exchanger at minimum pumping power, minimizing the energy cost and reduce the equipment size. So, there are different heat transfer enhancement methods available to increase the heat transfer rate and make instrument compact and incorporated into heat exchanger viz: passive, active and compound techniques [1]. Passive technique is used surface or geometrical modifications to the flow by incorporating inserts or additional devices. Higher heat transfer coefficients achieved by disturbing the flow behavior which also leads to increase in the pressure drop. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power [2-3]. This technique includes treated surfaces, rough surfaces, extended fins, swirl flow device, coiled tubes etc. Active techniques require external power to disturb the flow and improvement in heat transfer rate. This technique finds limited application because of the need of external power in many practical applications [2-3]. This technique includes mechanical aids, surface vibration, fluid vibration, injection, jet impingements etc. In compound techniques, there is use of one or more than one of the above mentioned techniques in combination to improve the performance of a heat exchanger [3].

A heat transfer enhancement along with swirl in the flow was proposed by Kreith and Margolis [4]. In this concept, tangential injection was used and the vortex motion maintained by repeated addition of fluid through appropriately spaced injection holes for any desired distance

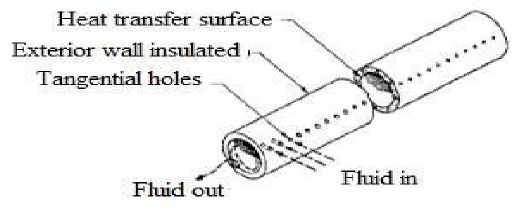

Figure 1: Tangential injection methods for inducing vortex flow [4]

The swirl can be produced in the flow by tangential entry of the fluid by single tangential entry or the combination of axial plus tangential entry [5]. Effective swirl generation is carried out by different methods as follows:

1. Twisted tape insert
2. Fixed & guide vanes
3. Rotating pipe
4. Propeller type swirl generator
5. Tangential injection of fluid

Dhir et al. [6] have experimentally determined enhancement of heat transfer with air as the test fluid and Reynolds numbers varied from 15,000 to 58,000. The air was injected tangential to the inner walls of the heat exchanger tubes through square edged injectors extending perpendicular from the tube surface. The net enhancement of heat transfer, at constant pumping power, was between 3% and 14% depending on the momentum ratio. It was also found that the effectiveness of the system is highly dependent on the ratio of the rates of tangential to total momentum fluxes.

Heat transfer rates was enhanced by imposing swirling motion on the hot air by placing injectors with various diameters and numbers in triangle line rows on the entrance section of the inner pipe of the concentric heat exchanger. The enhancement in the heat transfer is a result of increasing the turbulence of the flow because swirl effect is given to the flow by the located injector type swirl generator. The results showed that up to 93% enhancements could be accomplished in heat transfer rates with this kind of swirl generators compared to heat exchanger without these elements [7].

Kurtbaş [8] studied a novel conical injector type swirl generator (CITSG) and its performances of heat transfer and pressure drop in a pipe. The CITSG examined experimentally for its different angle (α) of 30°, 45° and 60° with Reynolds number (Re) ranging from 10,000 to 35,000. It was found that the improvement in heat transfer rate depends on director angle and diameter of the injectors.

Swirl was generated by placing the different arrangement of holes at the entrance section of the tube. The heat transfer enhancement about 130 % could be accomplished with this type of swirl generator [9]. Swirl decay was studied in laminar pipe flow with inlet swirl flow field for four different inlet swirl numbers, six values of Reynolds number and four different tangential velocity distributions at pipe inlet. It was observed that the swirl number at any location depends on the inlet swirl number, the flow Reynolds number, distance from the pipe inlet, the pipe diameter and the nature of the inlet tangential velocity distribution [10].

EXPERIMENT DETAILS AND PROCEDURES

Concentric tube heat exchanger with tangential injection consists of tube in tube (Concentric tube) type of heat exchanger. Small diameter tube is housed inside another tube. Water flows through both the tubes in same or opposite directions. Hot water is flows through the inner tube and cold water flow through the annular space between outer and inner tube. Water heater is provided to supply hot water at specified temperature continuously. Cold water and hot water is circulated with the help of separate centrifugal pump from the water tank. A pipe lines and valve arrangement is provided to select the direction of flow and control the flow of water. Thermocouples are mounted at the inlet and outlet of the cold and hot water to measure the temperatures. Five equidistance nozzles are used to generate the swirling motion of cold water in annular space and are placed along the length of outer tube tangentially perpendicular to axis of the tube. The more details of experiments are given in Table 1.

Table 1. Experimental conditions of heat exchanger.

Type of heat exchanger	Concentric tube (tube in tube)
Number of tangential entries	5
Parallel flow model:	
Inner tube	Hot water(fixed)
Flow rate	300 LPH
Annulus space	Tangential entry of cold water
Flow rate	300 LPH to 600 LPH (varying, step of 50LPH)
Counter flow model:	
Inner tube	Hot water(fixed)
Flow rate	300 LPH
Annulus space	Tangential entry of cold water
Flow rate	300 LPH to 600 LPH (varying, step of 50LPH)

ISSN No - 2394-3696

Experiment was performed for both parallel flow and counter flow for different values of Reynolds number from 2200 to 4600 and for different nozzles openings. In this experiment hot water was passed through inner tube, while cold water passed through annulus space between inner and outer tube. Hot water was achieved by gas geyser provided to the setup. The mass flow rate of hot water keeping as constant i.e.300 LPH and that of cold water was varied from 300 LPH to 600 LPH in step of 50 LPH and simultaneously temperature of inlet and outlet of hot and cold water were recorded. Temperatures of cold water and hot water inlet and outlet were measured with the help of thermocouples. Five nozzles are fitted tangential to the axis of pipe equidistance along the length of tube. Nozzles are opened one by one and the temperatures at the inlet and outlet of cold and hot water are measured. The experimental setup and tangential injectors are shown in Figures 2-3.

Figure 2: Experimental setup

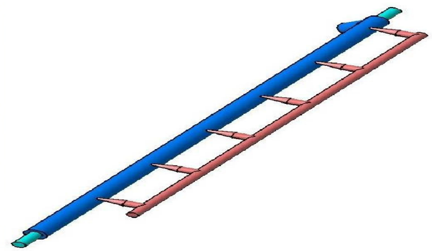

Figure 3: 3D view of tangential injection tube

CALCULATIONS

In concentric heat exchanger the heat given by hot fluid is expressed by Equation 1 and it is the function of mass of hot fluid, specific heat and temperature difference.

$$Qh = m_h C_p (T_{hi} - T_{ho}) \quad (1)$$

The heat received by cold fluid is expressed by Equation 2 and it is the function of mass of cold fluid, specific heat and temperature difference.

$$Qc = m_c C_p (T_{co} - T_{ci}) \quad (2)$$

The average heat transfer rate for hot and cold fluid is calculated using Equation 3 by calculating the average of heat given by hot fluid and heat received by cold fluid.

$$Qavg = \frac{Qc+Qh}{2} \quad (3)$$

The overall heat transfer coefficients is calculated by using Equation 4 and it is the function of average heat transfer, logarithmic mean temperature difference (LMTD) and outer surface area.

$$Uo = \frac{Qavg}{Ao\ LMTD} \quad (4)$$

Reynolds number can be calculated by using Equation 5 and which is the function of inertial force to the viscous force.

$$Re = \frac{\rho VDh}{\mu} \quad (5)$$

The thermo physical properties of water which is used to calculate Reynolds number is determined at mean temperature calculated using Equation 6.

$$Tavg = \frac{Ti+To}{2} \quad (6)$$

The experimental value of heat transfer coefficient is determined by plotting Wilson chart [11-12]. The Wilson chart is plotted for variation of 1/ $Re^{0.8}$ with 1/ Uo as shown in Figure 4. The y intercept as "k" (fouling resistance) taken from the Wilson chart and heat transfer enhancement is calculated by using Equation 7.

$$\frac{1}{h_{expt}} = \frac{1}{U_O} - k \tag{7}$$

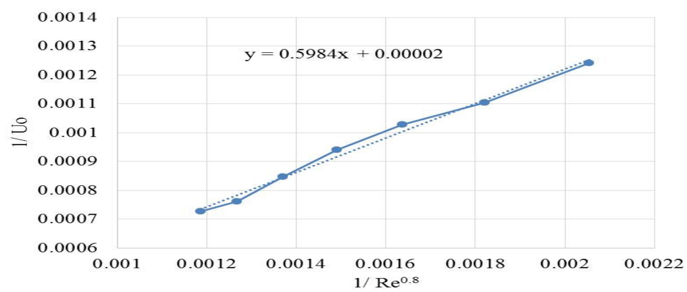

Figure 4: Wilson plot

RESULTS AND DISCUSSION

The experiment was performed for different Reynolds number for different nozzle openings and the results obtained for parallel and counter flow models for heat transfer coefficient are discussed in this section. Heat transfer coefficient results for plain tube and tube with tangential entry for parallel flow and counter flow model are obtained for range of Reynolds number from 2200-4700. The variation of heat transfer coefficient for all nozzles opening with Reynolds number for parallel and counter flow model is shown in Figure 5. It is observed that heat transfer coefficient increases with increase in Reynolds number. The smallest value of heat transfer coefficient is 818 W/ m^2K for Reynolds number of 2286 and it reaches maximum up to 1613 W/ m^2K for Reynolds value of 4600 for all nozzles openings.

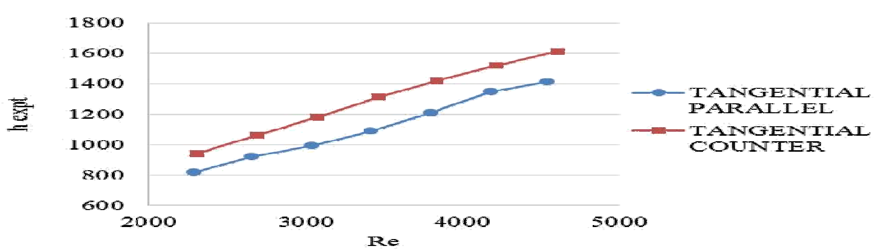

Figure 5: Variation of heat transfer enhancement with Reynolds number for tangential injection with all (5) nozzles open (Parallel and counter flow model)

The variation of heat transfer coefficient with Reynolds number for counter flow model of tangential injection with all nozzle openings and plain tube as shown in Figure 6. It is observed that the appreciable enhancement in heat transfer coefficient in tangential injection with all nozzles openings over a plain tube. It may be due to increase in swirl in the fluid flow which creates the turbulence. Similar results also reported by Reference [13-17]. The heat transfer enhancement of 70 % could be accomplished with tangential injection with all nozzles opening over plain tube. As the Reynolds number increases, enhancement in heat transfer also increases with increase in number of tangential entries.

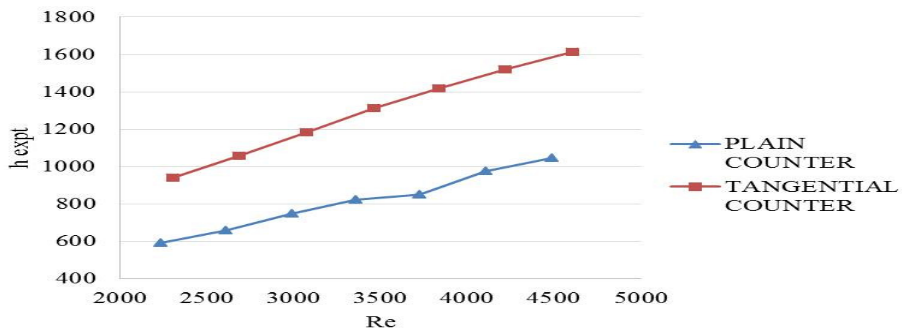

Figure 6: Variation of heat transfer enhancement with Reynolds number for plain tube and tangential injection with all (5) nozzles open (Counter flow model)

Figure 7 shows the relation between heat transfer coefficient and Reynolds number (Re) for counter flow configuration for different nozzles openings. It is found from the results that heat transfer coefficient increases with Reynolds number (Re) for all cases of nozzle openings. As number of injection increases, heat transfer reaches to its maximum value for higher Reynolds number of 4600. However, the lowest value of heat transfer coefficient i.e. 397 W/ m^2K was observed for 1- nozzle opening at lowest Reynolds number of 2180.

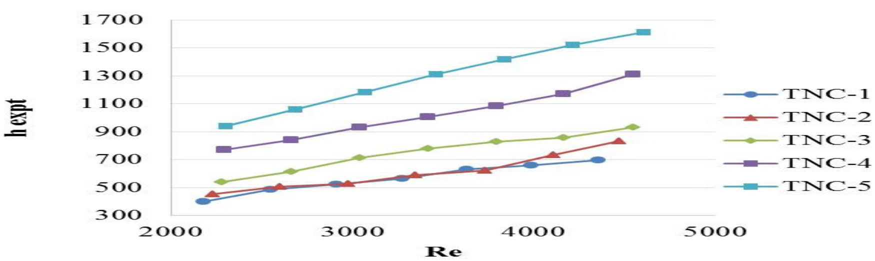

Figure 7: Variation of heat transfer enhancement with Reynolds number for tangential injection with different nozzles openings (Counter flow model)

As the number of tangential entries increases from 1- nozzle opening to five nozzle openings, enhancement in heat transfer was observed about 32% over earlier nozzle opening. The increase in heat transfer for 2-nozzle opening was observed about 20% over 1-nozzle opening. The increase in heat transfer for 3-nozzle opening was observed about 35% over 2-nozzle opening. The increase in heat transfer for 4-nozzle opening was observed about 51% over 3-nozzle opening. The increase in heat transfer for 5-nozzle opening was observed about 24% over 4-nozzle opening.

CONCLUSIONS

The experiment is performed for both the plain tube and tube with tangential injector entries and the conclusion is summarized as follows:

- The heat transfer enhancement is increased with increase in Reynolds number for both plain tube and tangential injection configurations.
- The turbulence in the flow is created with increase in number tangential injection nozzles along the length of tube and heat transfer enhancement is carried out.
- The increase in heat transfer enhancement was observed about 65% to 70 % with
- Tangential swirl generator over plain tube for counter flow configuration. The highest heat transfer enhancement was found 1613 W/ m^2K at Reynolds number of 4600.

- The best operating range of Reynolds number for this experimentation is 4000- 4600.

REFERENCES

[1] J.P.Holman, Souvik Bhattacharyya (2011). Heat Transfer, Tenth ed. New Delhi: McGraw Hill Education.

[2] Kumar, N. C., Murugesan, P., (2012). Review of twisted tapes heat transfer enhancement. International Journal of Scientific and Engineering Research, 3 (4), 1-9.

[3] Gupta, A., Uniyal, M., (2012). Review of heat transfer augmentation through different passive intensifier methods. IOSR Journal of Mechanical and Civil Engineering, 1 (4), 14-21.

[4] Kreith, F., Margolis, D., (1959). Heat transfer and friction in turbulent vortex flow. Appl. Sci. Res. Section, Lehigh university, Bethlehem, Pa, U.S.A.

[5] Yilmaz, M., Comakli, O., Yapici, S., (1999). Enhancement of heat transfer by turbulent decaying swirl flow. Energy Conversion and Management, 40, 1365-1376.

[6] Dhir, VK., Monica, S., (1994). Heat transfer enhancement using tangential injection. United State Patent, US5291943A.

[7] Cengiz, Y.G.C., (2007). The influence of the injectors with swirling flow generating on the heat transfer in the concentric heat exchanger. International Communications in Heat and Mass Transfer, 34, 728-739.

[8] Kurtbaş, I., Gülçimen, F., Akbulut, A., Buran, D., (2009). Heat transfer augmentation by swirl generators inserted into a tube with constant heat flux. International Communications in Heat and Mass Transfer, 36, 865–871.

[9] Akpinar, E. K., Cengiz, Y. B., Pehlivan, Y. D., (2004). Heat transfer enhancement in a concentric double pipe exchanger equipped with swirl elements. International Communications in Heat and Mass Transfer, 31 (6), 857-868.

[10] Ayinde, T. F., (2010). A generalized relationship for swirl decay in laminar pipe flow. Indian Academy of Sciences, 35, 129–137.

[11] Rathore, M. M., Engineering Heat and Mass Transfer (2006). 3rd ed. New Delhi: University science press.

[12] Rose, J. W., (2004). Heat-transfer coefficients, Wilson plots and accuracy of thermal measurements. Experimental Thermal and Fluid Science, 28, (2-3), 77-86.

[13] Hay, N., West, P. D., (1975). Heat transfer in free-swirling flow in a pipe, Trans. ASME J. Heat Transfer, 7, 411–416.

[14] Gupta AK, Lilley DG, Syred N (1984). Swirl Flows. Abacus Press, Cambridge.

[15] Martemianov, S., Okulov, V. L., (2004). Heat transfer enhancement in swirl pipe flows. International Journal of Heat and Mass Transfer, 47, 2379–2393

[16] Guo, Z., Dhir, V. K. (1989). Single- and two-phase heat transfer in tangential injection-induced swirl flow. Mechanical, Aerospace and Nuclear Engineering Department, School of Engineering and Applied Science, University of California, Los Angeles, Los Angeles, CA, USA

[17] Chang, F., Dhir, V. K., (1995). Mechanisms of heat transfer enhancement and slow decay of swirl in tubes using tangential injection. Int. J. Heat Fluid Flow, 16, (2),78-87.