# Heat Transfer Enhancement Studies in a Concentric Tube Heat Exchanger

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## ABSTRACT

Heat exchangers have been commonly used in most of the industries to recover waste heat. In the present work, a simple modification has been made in the existing heat exchanger design and studies have been carried out in the modified heat exchanger. A standard concentric tube heat exchanger has been modified such that the flow area of inner tube is continuously increased and reduced alternately; along the flow axis i.e. inner tube is a convergent-divergent tube. The outer tube is a constant area tube with same diameter along flow axis. Inner tube carries cooling water and outer tube carries hot water, which transfers heat to the cooling water. A convergent-divergent tube-in-tube heat exchanger has been fabricated and an experimental setup has been built with hot and cooing water tanks and pumps, electrical heater, flow meters, pressure gauges, thermocouples, flow control valves and piping. Numerical simulations have been carried out for the system, taking into account, mass flow rate, fluid temperatures, heat transfer rate, etc., which are governed by fundamental heat transfer equations. Results of the simulation are used to analyze the effect of this modification (convergent-divergent tube) on the performance of the heat exchanger. Experimental investigations have also been carried out to validate the numerical results.

**KEY WORDS:** Heat exchanger, Concentric tube, Heat transfer enhancement, Numerical simulation, Experimentation**.**

## 1. INTRODUCTION

Large quantity of heat is generated from the hot flue gases which are exhausted from boiler furnaces and ovens of thermal industries. This heat is generally wasted into the environment without reuse. If some of this waste heat could be recovered, it will reduce the energy loss in thermal systems. Heat exchanger plays a major role in recovering heat from hot flue gases. In some cases, heat can be recovered from hot waste water from different cooling processes, especially in steel industries. To meet this requirement, concentric tube heat exchangers can be used to extract heat from hot waste water and transfer it to the boiler feed water. This arrangement will result in fuel savings as well as energy efficient thermal systems. Enhancing the heat transfer capacity of concentric heat exchanger may further increase its effectiveness. Various enhancement techniques are being tried out to improve the heat duty of these heat exchangers.

A simple heat transfer enhancement is to increase the flow area of the heat exchanger. Triple tube heat exchangers, with an additional flow passage have been developed to increase the heat transfer area per unit length, thereby increasing the heat transfer rate. Gomaa (2016), carried out experimental and numerical investigations on the triple concentric-tube heat exchanger. Three heat transfer fluids were used; chilled water in inner tube, hot water in inner annulus, and normal tap water in outer annulus. The investigation covered the effect of hot fluid temperature velocity, flow patterns and inner annulus spacing on heat transfer rate and heat exchanger effectiveness. It was found that triple tube heat exchanger contributes higher heat exchanger effectiveness and more energy saving compared with double tube heat exchanger per unit length. Another enhancement method is filling the double pipe heat exchanger with porous materials like sintered bronze beads and study the heat transfer performance. Shirvan (2016), carried out numerical simulation and sensitivity analysis in a double pipe heat exchanger filled with porous media using finite volume method and response surface methodology model. Optimum values of three effective parameters like Reynolds number, Darcy number and porous substrate thickness were obtained to enhance the heat transfer rate and heat exchanger effectiveness.

Another heat transfer augmentation technique is replacing traditional coolants with nanofluids, which have exhibited enhanced thermal conductivity and convective heat transfer coefficient. El-Maghlany (2016), conducted an experimental study on the performance of horizontal double tube counter flow heat exchanger. Cold water with copper nanoparticles is used as coolant in the annulus whereas hot water is circulated in the inner tube which is rotated using 1 HP motor, with belt and pulley arrangement. It was observed that both of the addition of nanoparticles and the inner pipe rotation enhanced the heat transfer rate, however, the pressure drop increased significantly with the increase in the inner pipe rotational speed. Shirvan (2017), carried out numerical investigation and sensitivity analysis of Reynolds number, nanoparticles volume fraction and entrance status of nanofluid on heat transfer rate between two pipes of a double pipe heat exchanger filled with nanofluid. It was found that heat exchanger performance was very effective when nanofluid is used as hot fluid in the inner pipe. However, the heat exchanger effectiveness for the case with nanofluid flow in both pipes is more than the cases with nanofluid flow in only one of the pipes.

Turbulators shall also be used to increase the heat transfer and effectiveness of heat exchangers. Spiral and helical twisted tapes or strips, twisted wire brushes are some of the turbulators used nowadays in concentric tube heat exchangers. Pourahmad and Pesteei (2016), investigated the effect of changing wavy strip angles on effectiveness of double tube heat exchanger. Their work also focused on the experimental study on the e-NTU analysis of the double tube heat exchanger with wavy strip considering various angles. A thermal performance enhancement factor was introduced to evaluate the quality of enhancement. The results showed that by installing wavy strip turbulators, heat exchanger effectiveness improved by 26–71%. Also it was a function of wavy strips angles. Maakoul (2017), conducted a numerical study, by developing three dimensional Computational Fluid Dynamics model using the software FLUENT, for a water-to-water double pipe heat exchanger with continuous helical baffles at the annulus side. The influence of baffle spacing on heat transfer augmentation was examined. The results obtained for a helically baffled annulus side provided enhanced heat transfer performance and high-pressure drop compared to the simple double-pipe exchangers. Thermal performance and high-pressure drop are increasing functions of baffle spacing and Reynolds number.

In the present work, a simple heat transfer enhancement technique has been introduced by modifying a standard concentric tube heat exchanger such that the flow area of inner tube is continuously increased and reduced alternately, along the flow axis i.e. inner tube is a convergent-divergent tube. Numerical and experimental investigations have been carried out to analyze the effect of this modification on the performance of the heat exchanger.

**Numerical Simulation:** Numerical simulation of the heat exchanger has been carried out using local or element-by-element method. In this method, at the beginning of simulation, an initial value of pressure and temperature and mass flow for hot water and cooling water circuit are assigned at heat exchanger inlet. The calculations proceed from inlet to outlet of both water tubes, in the flow direction. The heat exchanger is divided into numerous small sections, with section length of 1 mm. In each small section, heat transfer rate is calculated by ε-NTU method, using temperature difference between hot and cooling water tubes. Pressure drop in every section is calculated and temperature at inlet of each section is corrected with changed pressure. After heat transfer rate is calculated, downstream temperature of both water tubes passing through each section is determined. Temperature, pressure, heat transfer coefficient and heat transfer rate of each section are also calculated. Once the first section is analyzed, calculated downstream parameters are assigned to the inlet of next section. Simulation results have been obtained by means of a computer code written in MATLAB.

In heat exchanger analysis, flow area of inner tube is continuously increased and reduced alternately, along the flow axis. The diameter of inner pipe at any position '*x*' is calculated by the formula:

$$D_x = D_i \pm 2(x/L)\tan\alpha \quad \text{(Eq. 1)}$$

For the annular tube, effective diameter is given by: $D_e = [(D_x - d_o) - (D_i - d_o)]/2$ (Eq. 2)

Water properties are calculated based on the International Association for Properties of Water and Steam Industrial Formulation 1997 (IAPWS IF-97).

## 2. EXPERIMENTATION

The schematic diagram of experimental setup has been shown in Fig.1. The setup consists of heat exchanger, hot and cooling water tanks and pumps, electrical heater, flow meters, pressure gauges, thermocouples, flow control valves and piping. Figure.2, shows the modified inner tube of the heat exchanger.

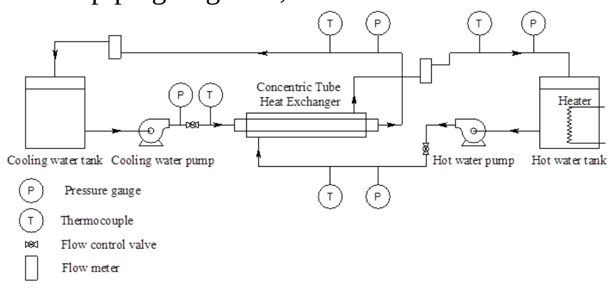


**Figure.1. Schematic of experimental setup**


**Figure.2. Modified inner tube of HX**

## 3. RESULTS AND DISCUSSION

**Numerical simulation:** The following range of input data is used for the numerical simulation.

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|---|---|---|
| Hot water flow rate | : | 150 – 600 lph |
| Hot water inlet temperature | : | 60° – 80°C |
| Hot water inlet pressure | : | 150 kPa |
| Cooling water flow rate | : | 300 lph |
| Cooling water inlet temperature | : | 35°C |
| Cooling water inlet pressure | : | 150 kPa |

Simulation has been carried out for following three configurations of heat exchanger (HX): i) Small inner tube (HX surface area = 0.0421 $m^2$), ii) Convergent-Divergent inner tube (HX surface area: 0.0521 $m^2$), iii) Big inner tube (HX surface area = 0.0619 $m^2$). Cooling water flows through the inner tube whereas hot water flows through the annulus. Figure 3 a) and b) depict the effect of hot water flow rate and inlet temperature on overall heat transfer coefficient (U) at various HX configurations. At high hot water flow rates, flow velocity is more, resulting in increase in Reynolds number and hot waterside heat transfer coefficient. This leads to increase in 'U', since it is a function of hot and cooling water heat transfer coefficients. In Fig. 3 b), at high inlet temperatures of hot water, for a given flow rate, density of hot water decreases, resulting in increase in flow velocity, thereby increasing 'U'. In both cases, ‘U’ is more for small inner tube, since cooling water flow area is small and flow velocity is more, resulting in increase in cooling waterside heat transfer coefficient.

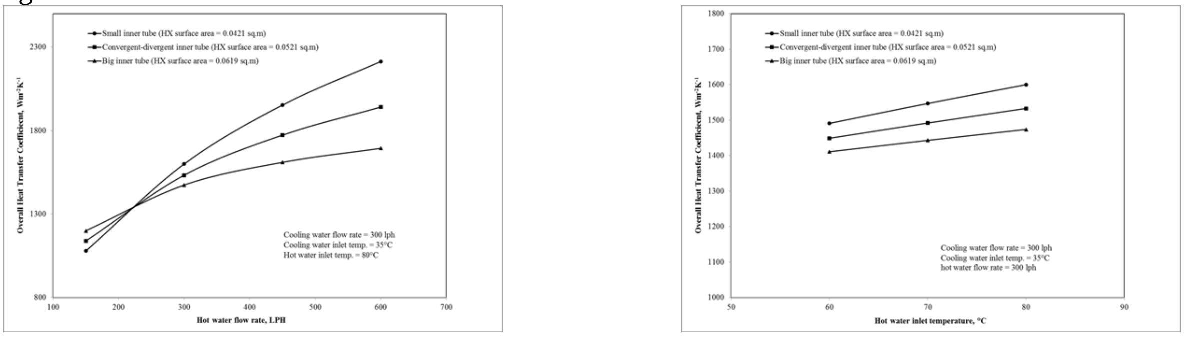


**Figure.3. Variation of overall heat transfer coefficient with respect to hot water a) flow rate b) inlet temperature**

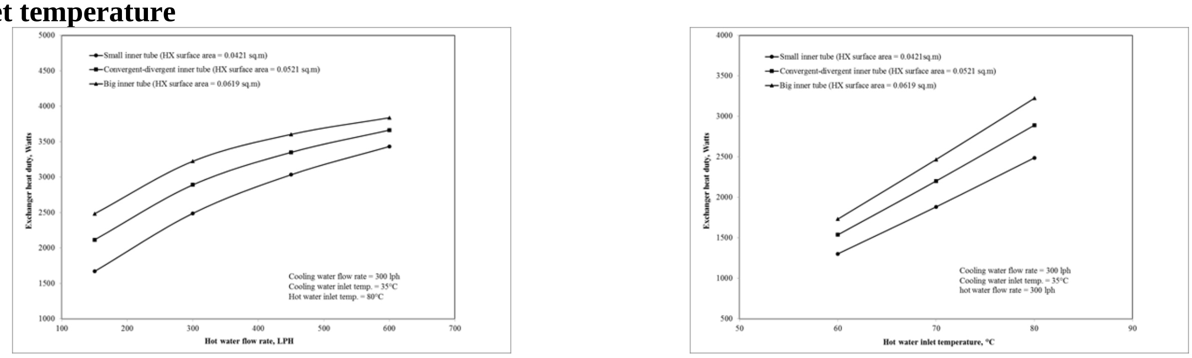


**Figure.4. Variation of heat exchanger duty with respect to hot water a) flow rate b) inlet temperature**

Figure.4 a) and b) show the effect of hot water flow rate and inlet temperature on heat duty of the heat exchanger at various HX configurations. Heat duty increases as hot water flow rate and inlet temperature increase. This is due to the reason that heat duty is a function of 'U', which increases at higher hot water flow rates and inlet temperatures (as discussed in Fig.3 a) and b)). In both cases, heat duty is more for big inner tube, since its heat transfer surface area is more. HX surface area contributes significantly to heat transfer enhancement than overall heat transfer coefficient.

Figure.5 a) and b) show the effect hot water flow rate on total pressure drop in hot water and cooling water circuits at various HX configurations. Pressure drop increases in both circuits since it is a function of flow velocity, which increases at higher hot water flow rates. Pressure drop is more for big inner tube configuration in hot water circuit and is more for small inner tube configuration in cooling water circuit. In both cases, flow area is less and velocity is more, resulting in increase in pressure drop.

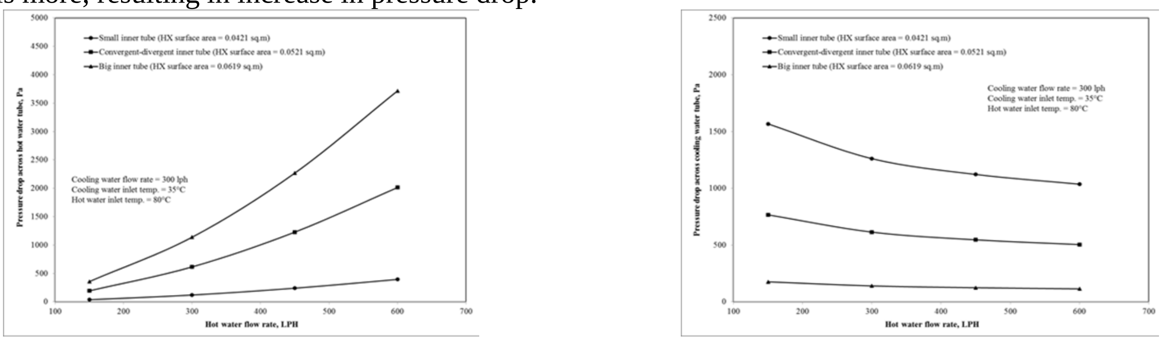


**Figure.5. Variation of pressure drop with respect to hot water flow rate in a) hot water circuit, b) Cooling water circuit**

**Experimentation:** Experimentation was conducted on the modified convergent-divergent concentric tube heat exchanger by maintaining constant flow rates at 130 lph for hot water and 170 lph for cooling water respectively.

Cooling water inlet temperature was maintained at 35°C. The parametric studies were carried out by varying the hot water inlet temperature from 62°C to 80°C.

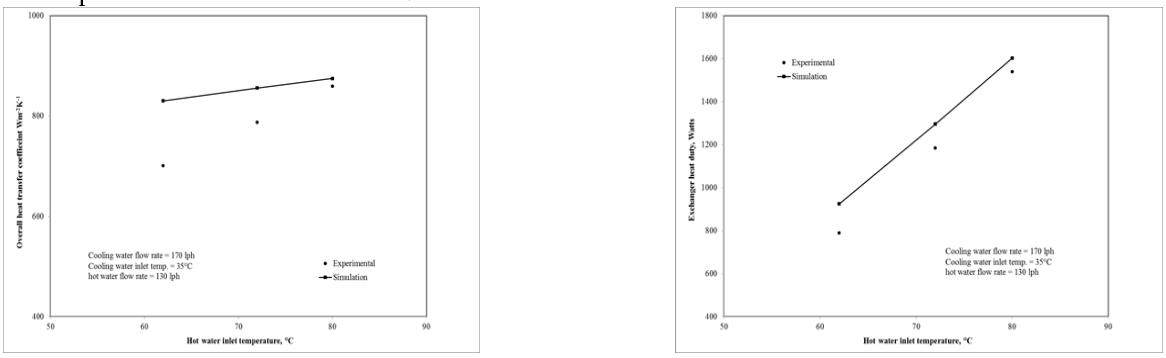


**Figure.6. Variation of a) overall heat transfer coefficient b) Heat duty with respect to hot water inlet temperature**

Figure 6 a) and b) show the effect of hot water inlet temperature on overall heat transfer coefficient and heat exchanger duty at constant hot water and cooling water flow rates. As discussed earlier, both 'U' and heat transfer rate increase as hot water inlet temperature increases. Figure 7 shows the effect of hot water inlet temperature on heat exchanger effectiveness. HX effectiveness increases due to better heat duty at high hot water inlet temperatures. When experimental values of 'U', heat transfer rate and HX effectiveness are compared with those of numerical simulation, the agreement is generally good.

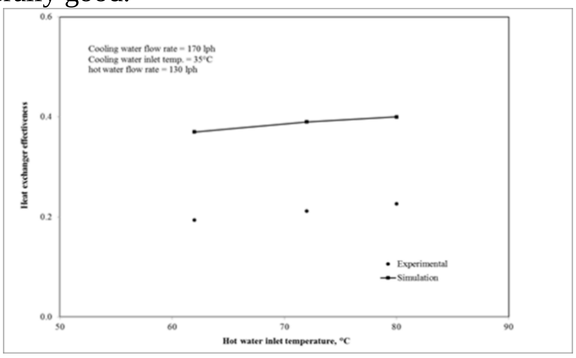


**Figure.7. Variation of heat exchanger effectiveness with respect to hot water inlet temperature**

## 4. CONCLUSIONS

A numerical simulation has been developed to investigate heat transfer enhancement in a modified convergent-divergent concentric tube heat exchanger. An experimental setup has been built to test the modified heat exchanger and to validate the numerical results. Experimental values of overall heat transfer coefficient, heat transfer rate and heat exchanger effectiveness are compared with those of numerical simulation and the agreement is generally good. Following conclusions have been drawn from the investigations

- Increase in heat exchanger surface area contributes significantly to heat transfer enhancement than increase in overall heat transfer coefficient. Modified heat exchanger increases the heat transfer rate due to increase in surface area. Effect of increase in flow velocity due to surface modification, on the heat transfer rate is not significant.
- Heat transfer enhancement without increasing the surface area shall be effectively done by incorporating well-designed turbulators at the expense of high pressure drops.
- Modified convergent-divergent concentric tube heat exchanger could give better heat transfer enhancement when gases are used as heat transfer fluids.

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