



Experimental Investigation of Heat Transfer Characteristics in an Internal Flow by Inserting Vortex Generators with Different Attack Angles

Dr. S. B. Prakash¹, Sheshagiri A.T²

¹ Professor, Department of Thermal Power Engg, VTU, Centre for PG Studies, Mysuru, Karnatak, India

² PG Scholar, Department of Thermal Power Engg, VTU, Centre for PG Studies, Mysuru, Karnataka, India

Abstract: The effect of different arrangement of the delta winglet on the heat transfer and pressure drop characteristics in a pipe equipped with vortex generator inserts, experimentally conducted. The experiment carried out in the turbulence region with constant temperature. According to the results validated after calculations, for the similar working condition, the average heat transfer rate is enhanced by 15% by the implementation of the VGs inside over a plain tube. At the same time the overall heat transfer coefficient also increased by 15% over a plain tube for the same surface area of contact. Even though the insertion of the VGs inside the tube enhances the heat transfer rate and coefficient, on the negative side it also increases the pressure drop across the flow. The number and size of the winglet in the VGs plays an important role in the creation of turbulence. The positive side of this increases the heat transfer rate; on the other hand it has negative effect on pressure drop. The present study revealed that by changing the fluid properties also enhances the heat transfer rate. Compared with other previous work the current experimental design of vortex generator inserts provides an optimum heat transfer with low resistance to the flow rate, thus achieves a high overall thermal performance.

Keywords: VGs, Vortex Generator, Winglet, Thermal Performance.

I. Introduction

Energy crosses the boundary in the form of either work or heat. Hence heat is defined as the energy in transit. It cannot be measured or observed directly but its effects are measured and observable. Whenever a temperature difference exists within a system or between the systems, energy is transferred as heat. The temperature differences in a system or between the systems are reduced in the course of time by heat flowing from the regions of higher temperature to the regions of lower temperature. The process by which the transfer of heat takes place is known as heat transfer. Since differences in temperature exist all over the universe, the phenomenon of heat flow is as universal as that associated with gravitational attractions. The calculation of the rate of heat transfer for a particular temperature difference is very important in engineering applications. A detailed analysis of heat transfer phenomenon is necessary to affect transfer of heat in a specified time and to calculate the cost, feasibility and size of the equipment. The dimensions of boilers, heaters, refrigerators and heat exchangers depend on the rate of heat transfer required under the given conditions. Heat exchangers are used to transfer heat between two sources. The exchange can take place between a process stream and a utility stream (cold water, pressurized steam, etc), a process stream and a power source (electric heat), or between two process streams resulting in energy integration and reduction of external heat sources. Typically [2], a heat exchanger is used with two process streams. However, multistream heat exchangers are sometimes used with energy extensive processes, such as LNG processing, to reduce capital cost. The term heat exchanger applies to all equipment used to transfer heat between two streams. However, the term is commonly used to equipment in which two process streams exchange heat with each other. In the other hand, the term heater or cooler is used when the exchange occurs between a process stream and a plant service stream. Other terms used to describe heating equipment include: vaporizer and reboiler (for vaporization) and evaporator (for stream concentration).

A heat transfer enhancement is a technique used to improve the effectiveness of heat exchangers. By increasing the heat transfer power or decreasing the pressure losses it can be achieved for a device. There are many optimized techniques to achieve this. It includes allowing a secondary flow with the main flow of liquid or making surface as rough or increasing the turbulence level in the flow to breakdown the thermal boundary layer formation. Improved surface geometry able to give a higher heat transfer coefficient value per unit surface area in comparison with a plain surface. The ratio of heat transfer in treated surface to the plain surface is called enhancement ratio E_h . Thus $E_h = \frac{hA}{(hA)_p}$

Generally Fins were used to increase the heat transfer rate. These fins are made up of material with higher thermal conductivity. In working these fins were exposed to the flowing fluid, which heats or cools it. The higher thermal conductivity factor helps to increase the heat being transferred from the wall to the fin.

Other than fins passive and active techniques are employed to optimize the thermal performance of heat exchange devices working with liquids. In passive technique the surface is modified to enhance the heat transfer rate. In active technique the thermal properties of the flowing fluid is changed to achieve the rate of heat transfer. The improvised passive and active techniques are application of Vortex-Generators (VGs) and inclusion of Nanoparticles in the flowing fluid. The VGs intensify the liquid mixing by creating longitudinal, transverse, or normal swirl in the flow. These swirl flows breaks the thermal boundary layers and increases the heat transfer coefficient. On the other case, mixing nanoparticles into conventional liquids, i.e. nano-fluids (NFs), provides a better thermal property.

Some of the main types of vortex generators are fins, baffles, ribs, twisted tapes, wire coils, winglets, etc. to thin or interrupt the boundary layer formation inside the tube. Introducing Vortex generators increase the heat transfer rate but on the other hand it also increases the pressure drop in the flow. Therefore, to achieve optimal thermal performance the dimensional parameters of the vortex generators plays an important role, such as the blockage height, pitch spacing and angle of attack

II. Research and Methodology

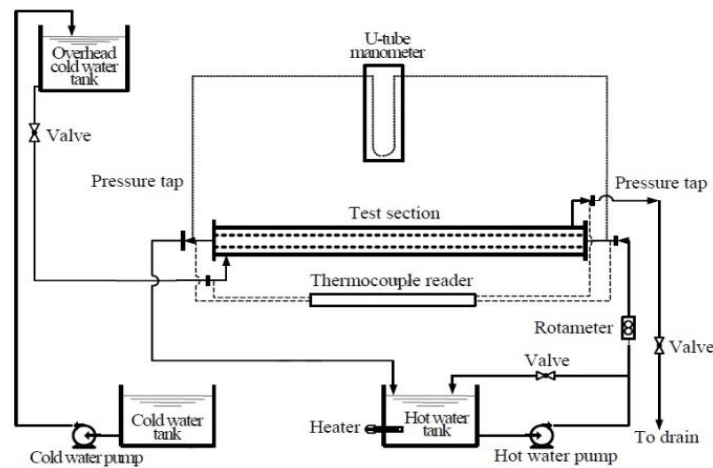


Fig. 2.1: Circuit Diagram of the Experimental work

The circuit diagram shows a practical set up of the experiment. It consists of mainly three loops, one temperature measurement, hot water circulating loop and cold water circulating loop. A horizontal double pipe heat exchanger was taken as test specimen. It was fabricated from two materials. The outer tube made from mild steel with $D_2=54\text{mm}$ outer diameter, $D_1=48\text{mm}$ inner diameter and a length of $L=1000\text{mm}$. The inner tube is fabricated from aluminum with $d_2=38\text{mm}$ outer diameter, $d_1=35\text{mm}$ inner diameter and a length of $L=1500\text{mm}$. The effective heat transfer length is about 1000mm . The arrangement and looping systems were made such that it can be easily replaceable. The looping system also includes two Rotameter for measuring hot and cold water flow rate in the circuit, an electric coil for heating purpose, a centrifugal pump for pumping hot water and calibrated K-type thermocouple with data logger. The arrangements were made such that the hot water flows inside the inner tube and the cold water flows in the outer tube. A U-tube manometer is connected to the circuit to measure the pressure drop across the hot water flow inside the inner tube. In the experiment the turbulence is created using a strip of thickness 0.5mm . The strip is made from JSW steel with included angle of 160° degree. This strip has Winglets on either side in zig zag manner with dimensions $20\text{mm} \times 20\text{mm}$ in T section.

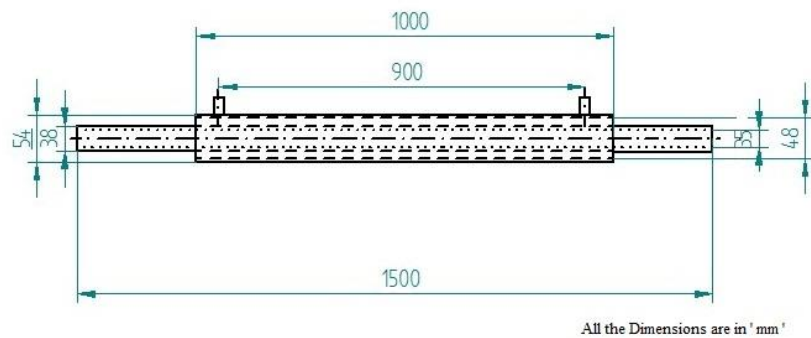




Fig. 2.2: Fabricated Strip and its Insertion inside the Tube

III. Experimental Setup

The water is taken as working fluid because its availability. The experimental set up is shown in the figure 3.5. The connections were made such that the hot fluid flows inside the inner tube with the help of centrifugal pump. The cold water flows inside the outer tube, supplied from the overhead tank. The Rotameters were connected one each on inlet of the cold water and hot water. Rubber hose connections to supply the both hot and cold water with regulating valve. A U-tube manometer to measure pressure drop across the hot fluid is connected at the inlet and outlet. 4 K-type thermocouples connected, one each at the inlet and outlet of the hot and cold water. The temperature of the water is displayed by the data logger connected to the thermocouple. The hot water temperature is maintained at 60°C by using immersion coil. The plain tube is connected; the cold water flow is set to 180 LPH. The hot fluid flow is varied from 210 to 570 LPH with the increment of 60 LPH. At each flow rate of the hot fluid, the temperature readings were taken. For the each hot fluid flow rate, the hot water temperature maintained to 60°C. The experiment was repeated by inserting the punched delta winglet insert inside the inner tube. The water flow rate and initial temperatures were maintained same as that of plain tube. The temperature readings are tabulated for each flow rate of the hot water. The heat transfer rate and thermal performance factor are calculated using standard correlations.

IV. Results and Discussion

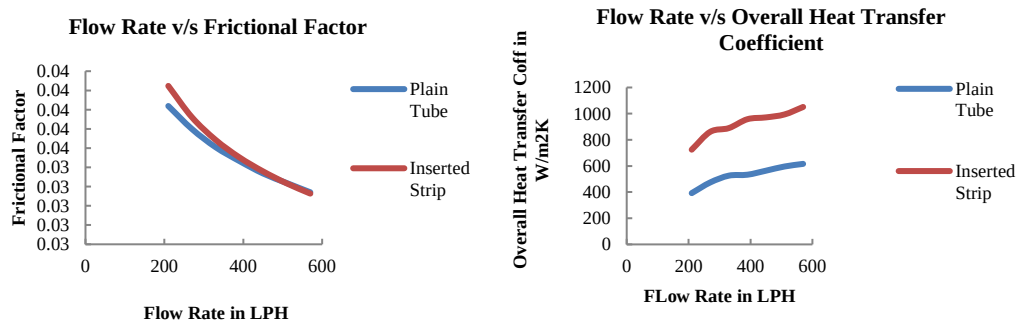


Fig. 4.1: Effect of Flow Rate over Frictional Factor and Heat Transfer Coefficient

The friction factor mainly depends on the Reynolds number, intern flow rate of the fluid. It also widely affected by the roughness of the inner wall of the tube. In the experimental work due to implementation of the VGs in the tube, blockage area for the flow increases. Due to obstacle to the fluid flow the pressure drop also goes high. The figure 4.1 validates the decrease in the friction factor by increasing in the flow rate. The overall heat transfer coefficient is the combined effect of convective heat transfer and conductance in the tube material. The major parameter which influences the overall all heat transfer is the conductivity of the tube material. Since the area exposed to the hot and cold fluid is same, the conductivity of the material plays a vital role in the transfer of heat. The figure 4.1 is the graphical representation of flow rate verses overall heat transfer coefficient. Due to increment in the flow rate the overall heat transfer coefficient increased by nearly 20%.

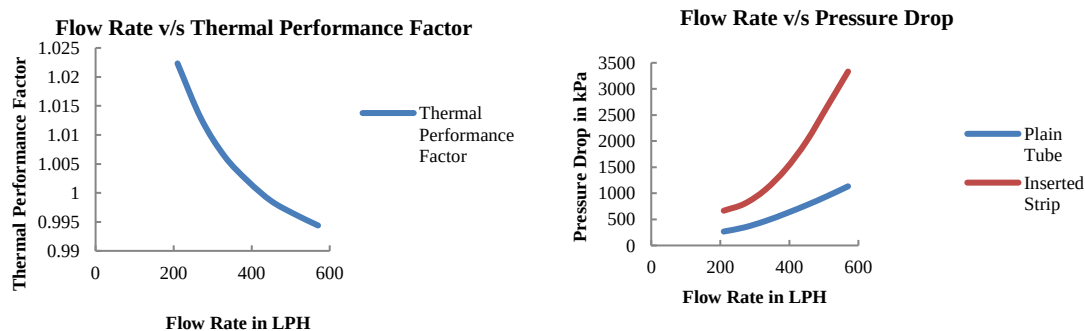


Fig. 4.2: Effect of Flow Rate over Performance Factor and Pressure Drop

The thermal performance factor indicates the practical benefits of the vortex generator. In designing the heat exchanger, thermal performance factor is a key parameter. This thermal performance factor internally depends on the flow surface area, inlet temperature of the fluid, flow type (parallel or counter) and convective conductance of the fluid. In the present experimental work this factor is calculated by taking ratio of heat transfer coefficient of plain tube with inserted tube. The figure 4.2 shows the influence of flow rate on the thermal performance factor. Due to increase in the Reynolds number the thermal performance factor decreases, for all the cases. It is examined as a measure of amount between flow resistances to the heat transfer enhancement. It could be observed that all the methods of insertion inside the tube not advantageous. Because at higher Reynolds number it negative effects on the pumping energy to the fluid. The thermal performance factor is higher at the lower Reynolds number due to thickness of the boundary. Hence it is relevant disturb the formation of boundary layer rather than increasing in the Reynolds number. The effect of increasing the frictional force inside the tube by inserting the obstacles makes a large pressure drop over a plain tube is shown in the figure 4.2. The breakage of thermal boundary layer inside the tube wall makes an increase in the heat transfer rate but on the hand it also increases the pressure drop across the flow. There should be optimum resistance to the flow so that the heat transfer rate in the upward direction with balanced pressure drop.

V. Conclusion

The effect of different arrangement of the delta winglet on the heat transfer and pressure drop characteristics in a pipe equipped with vortex generator inserts, experimentally conducted. While conducting the experiment the turbulent region maintained by varying the fluid flow rate at a constant temperature condition. According to the results validated after calculations for the similar working condition, the average heat transfer rate is enhanced by 15% by the implementation of the VGs inside over a plain tube. At the same time the overall heat transfer coefficient also increased by 20% over a plain tube for the same surface area of contact. Even though the insertion of the VGs inside the tube enhances the heat transfer rate and coefficient, on the negative side it also increases the pressure drop across the flow. The number and size of the winglet in the VGs plays an important role in the creation of turbulence. The positive side of this increases the heat transfer rate; on the other hand it has negative effect on pressure drop. The present study revealed that by changing the fluid properties also enhances the heat transfer rate. Compared with other previous work the current experimental design of vortex generator inserts provides an optimum heat transfer with low resistance to the flow rate, thus achieves a high overall thermal performance.

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