Session 2526

Experimental Comparison Between Heat Transfer Enhancement Methods in Heat Exchangers

Hosni I. Abu-Mulaweh
Department of Engineering
Indiana University-Purdue University at Fort Wayne
Fort Wayne, IN 46805, USA

Abstract

This paper presents an experimental comparison between four different types of heat transfer enhancement techniques or methods in heat exchangers: Two insert devices (displacement device and swirl flow device), extended surfaces, and obstruction devices. The objective of these experiments is to assist the undergraduate mechanical engineering students in the understanding of the basic heat transfer processes and the methods and devices that can be implemented to enhance the heat transfer.

The experimental setup and apparatus required to carry out these experiments is relatively simple. It includes five tube-within-a-tube heat exchangers that are instrumented with three thermocouples at each end, two rotameters, heating element, water pump, and Data Acquisition. Four of the five heat exchangers are modified by one type of the above-mentioned heat transfer enhancement techniques. These equipments are relatively inexpensive and available in almost all undergraduate heat transfer laboratories.

I. Introduction

Heat transfer enhancement in heat exchangers is gaining industrial importance because it gives one the opportunity to reduce the heat transfer surface area required for a given application and thus reduce the heat exchanger size and cost, increase the heat duty of the exchanger for fixed surface area, reduce logarithmic mean temperature difference (LMTD) for fixed heat duty and surface area, and reduce pumping power for fixed heat duty and surface area. The automotive and refrigeration industries routinely use enhanced surfaces in their heat exchangers. Also, the process industry is aggressively working to incorporate enhanced heat transfer surfaces in their heat exchangers.

Bergles et al. [1] has identified thirteen enhancement techniques. These techniques can be divided into two groups: “active” and “passive” techniques. The active techniques require external power, such as surface vibration, fluid vibration, injection, suction, and electric or acoustic fields. Passive techniques employ special surface geometries for enhancement, such as extended surfaces, rough surfaces, displacement enhancement devices, swirl flow devices, obstruction devices, and treated surfaces.

In the present paper only passive enhancement techniques were considered. Four different passive enhancement techniques were employed. Two of these techniques were simply inserts into the inner copper tube, while the other two were modification to the annulus. The two inserts were a displacement device and a swirl flow device. The displacement device was basically a spiraled rod. This type of device is inserted into the flow channel to indirectly improve heat transfer by promoting turbulence and flow mixing. The swirl flow device was a twisted-tape insert. This device creates rotating and/or secondary flow that enhances the heat transfer. One of the modifications to the annulus was the use of extended surfaces. This type of modification is routinely employed in many heat exchangers. Fins were placed on the outer surface of the copper tube. A special shape was of the fins was employed to increase the heat transfer coefficient. Also, extended surfaces may take the form of interrupted fins, which forces the redevelopment of boundary layers. The other modification technique to the annulus was obstruction device. This was accomplished by periodically restricting the flow with annulus rings or disks. The opening in the disk is located in the center and forces the liquid to pass through a narrow opening near the surface of the copper tube. Because this opening is much smaller than the rest of the annulus, the liquid velocity is high through the opening. In addition, the rapid expansion on the opposite side of the opening triggers transition from laminar to turbulent flow. Thus, enhancing the rate of heat transfer.

II. Basic Heat Exchanger

The heat exchanger is a simple, double-pipe heat exchanger. The inner tube is copper of an inside diameter of 14.35 mm and an outside diameter of 15.875 mm. The outer tube is PVC pipe with an inside diameter of 40.13 mm. The outer surface of the PVC pipe was insulated to minimize the heat loss to the outside air. Hot water flows through the copper tube and the cold water flows through the PVC pipe. Three thermocouples are installed in each end: they measure the temperatures of the hot water, the cold water, and the copper tube. These measurements are necessary to determine the log mean temperature difference (LMTD). A schematic diagram of the basic heat exchanger is shown in Figure 1. The flow rates of both the cold and hot flows are controlled and measured by two separate flow rotameters. Depending on the connections of inlet and the outlet of the cold flow, the heat exchanger can be operated either as a counter-flow heat exchanger or as a parallel-flow heat exchanger.

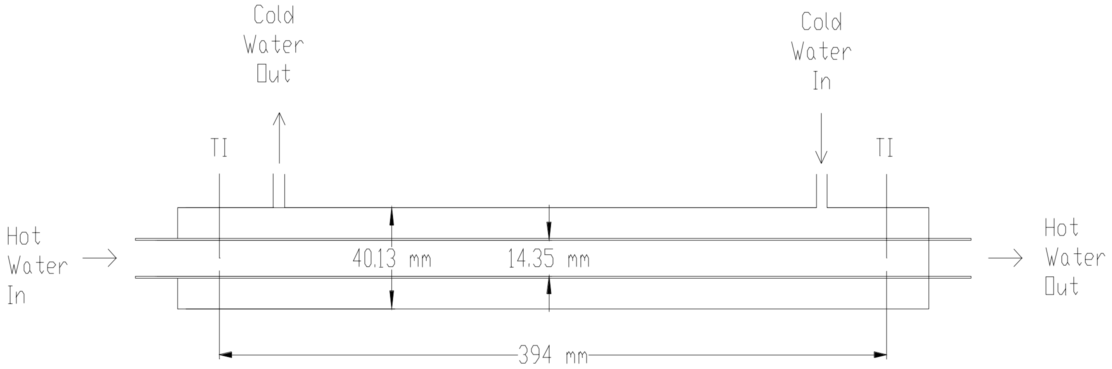


Figure 1: Basic heat exchanger

III. Modified Heat Exchangers

It should be noted that the four different modifications presented here are a result of a design project that was assigned to the students in ME 425 (Intermediate Heat Transfer – Theory and Applications) during the Fall Semester of 2000.

1. Extended Surfaces: Addition of Fins to the Outer Surface of the Copper Tube

A total of 42 fins were placed on the inner tube. These fins were placed in 7 banks of 6 fins each. The distance between consecutive banks is 1/16 inch, with the fins at the closest allowable distance to the entrance and exit of the flow. The length of each bank of fins was chosen to be 2 inches. The six fins in each bank are radially spaced, in increments of 60 degrees, on the outside surface of the inner tube. The fins are made of copper due to its high thermal conductivity. The maximum allowable fin height based on the outer diameter of the tube and the inner diameter of the shell was calculated to be 0.477 inch. Given this constraint, a fin height of 7/16 inch was chosen for ease of manufacturability, assembly, and material availability. The fin thickness was chosen to be 0.025 of an inch, since material of this gage is readily available and inexpensive. The base of each fin is soldered to the inner copper tube. Plumbing solder is used because of its relatively high thermal conductivity, low cost, high strength, and lack of lead content (for toxicity reasons). The fin dimensions are illustrated in Figure 2. The inner copper tube with the attached fins and a portion of the shell removed are shown in Figure 3.

These fins not only increase the surface area, but they also increase turbulence, and induce a mixing effect inside the water jacket. This was accomplished by bending the top-rear corner of the fin towards the center of the tube. The increase in turbulence and the induced mixing tend to increase the heat transfer coefficient.

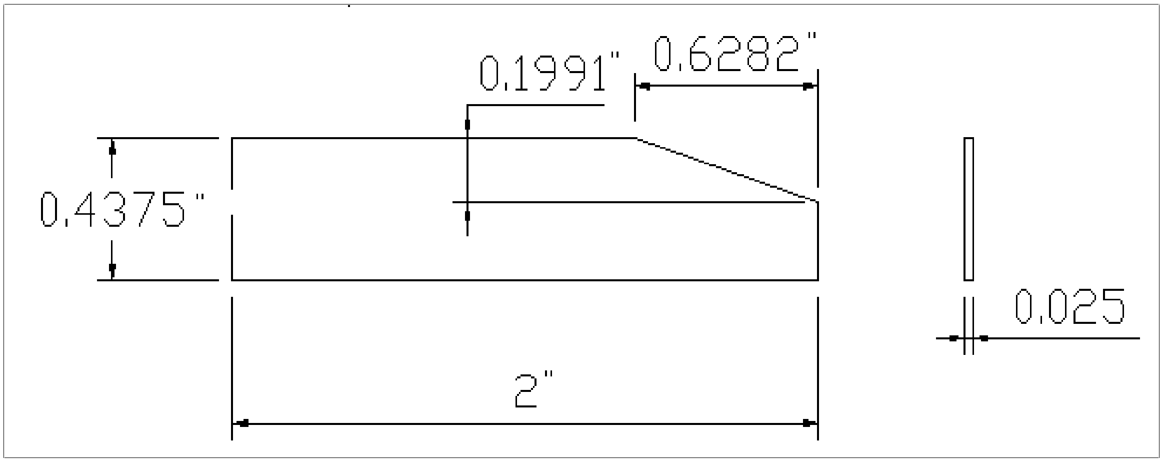


Figure 2: Fin dimensions

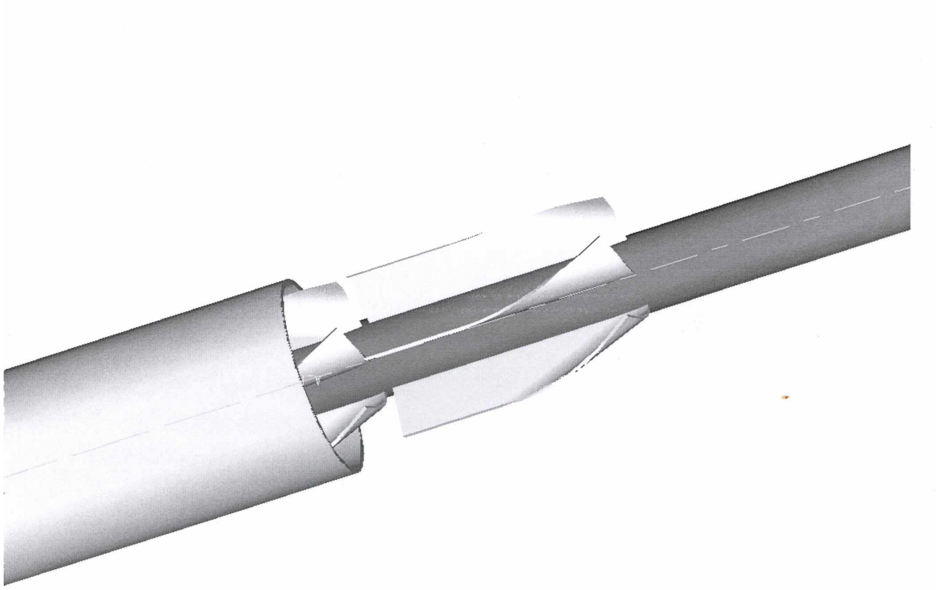
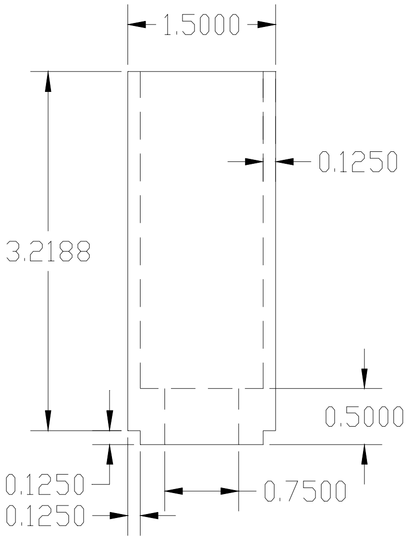


Figure 3: The copper tube with the attached fins and a portion of the shell removed

2. Obstruction Devices: Annular Rings or Disks:

Orifices or other *temporary* restrictions to flow often induce turbulence. Our approach, therefore, is to periodically restrict the flow with annular rings or disks. A schematic of the disk/ring is shown in Figure 4. The opening in the disk is in the center. This forces all the fluid to pass through a narrow opening near the surface of the copper tube. Because this opening is much smaller than the rest of the annulus, liquid velocity is high through the opening. Also, the rapid expansion on the opposite side of the opening triggers the transition form laminar flow to turbulent. The outside edges of the disks are sealed to the PVC pipe to force the fluid through the narrow opening near the copper tube. The resulted high liquid velocity and flow turbulence tend to increase the heat transfer coefficient.

The problem is then how to install and support the annular disks inside the PVC pipe. The method that was chosen is to make the disk an integral part of a thin walled tube that slips inside the PVC pipe. To do this, five annular disks were made and installed. The end result was a tube 12 7/8 inches long, with an inside diameter of 1 1/4 inch, with disks having a 3/4 inch openings spaced on 3 3/32 inch centers along the tube. To keep this assembly centered about the copper tube, three small screws were inserted in the disk portion of the sections, 120 degrees apart. The head of the screws projected into the opening just enough to touch the copper tube, keeping the disks centered about it. This assembly was cemented inside the PVC pipe resulting in the flow channel shown in the cross-section in Figure 5.



All dimensions
are in inches

Figure 4: Tube and disk sections

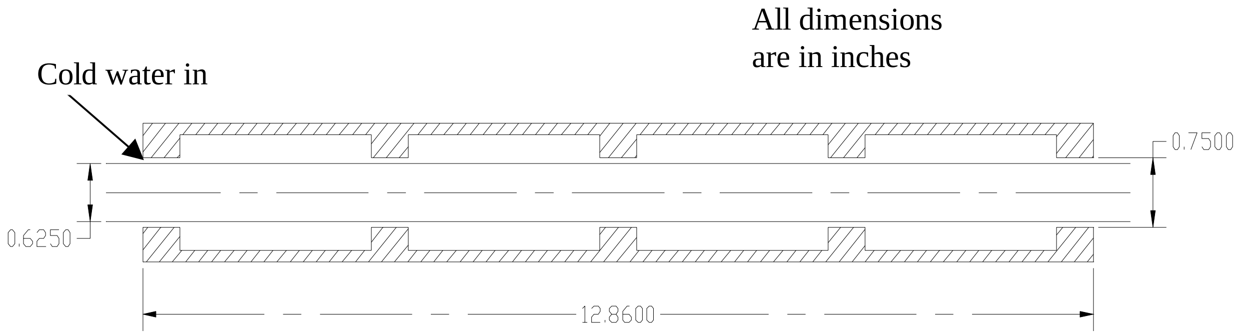


Figure 5: Heat exchanger cross sectional area

3. Displacement Device: A Spiraled Rod Inside the Copper Tube

The spiraled rod, shown in Figure 6, is basically a 0.125 inches diameter stainless steel S316 rod with pins inserted into it. The diameter of the pins is 0.0938 inches and the angle of rotation of the pins is 45 degrees. They are arranged at 0.5 inch intervals along the axial length.

The spiraled rod should enhance the heat exchanger for three reasons. First, the pins act as triggers and promoters of turbulence. Secondly, secondary flow develops as the flow field is spiraled inside the annulus. And thirdly, the spiraled rod reduces the hydraulic diameter of the heat exchanger. All of these three effects: turbulence, secondary flow, and reduction in the hydraulic diameter tend to increase the heat transfer coefficient (i.e., enhance the heat exchanger).

Figure 6: Spiraled Rod

4. Swirl Flow Device: A Twisted-Tape Insert

The thin twisted helical tape, shown in figure 7, was made of an aluminum sheet (1.6 mm thick and 12.7 mm wide). The twisted tape consisted of 8 twists. There was a small clearance between the twisted tape and the walls of the copper tube to allow easy insertion of the tape. Recently, the work by Manglik and Bergles [2,3] on twisted tapes presented an updated understanding of the heat transfer for both laminar and turbulent flow.

The blockage caused by the finite tape thickness increases the average velocity. Heat transfer enhancement may occur for two reasons: (1) The tape reduces the hydraulic diameter of the inner copper tube; this tends to increase the heat transfer coefficient, even for zero tape twist. (2) The twist of the tape causes a tangential velocity component. This causes the speed of the flow to increase, particularly near the wall. The enhancement in the heat transfer is a result of the mixing by the secondary flow and the increased shear stress at the wall.

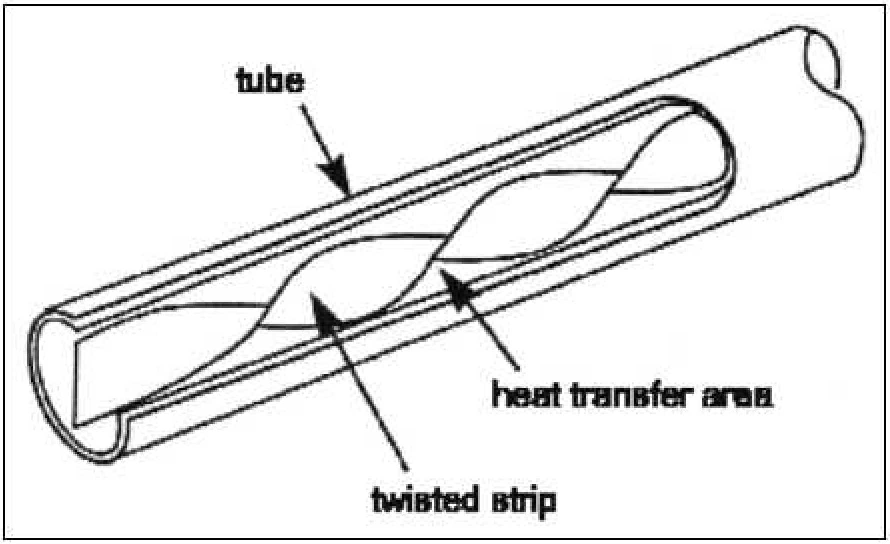


Figure 7: Twisted Tape inside the copper tube

IV. Testing and Evaluation

The students who designed and incorporated the modifications tested and compared the four modified heat exchangers to the basic heat exchanger. First, the basic heat exchanger was hooked up to both hot and cold-water flows in a counter-flow mode. The cold-water flow was an open circuit while the hot water flow was a closed circuit. The water was heated to the desired temperature by a heating element. Adjusting the electrical energy input to the heating element controlled the water temperature. The flow rates of both flows were controlled two rotameters. The temperatures at the inlet and exit were measured by the use of six thermocouples that were connected to a data acquisition system. After the system had reached steady-state conditions the following data was measured and recorded: hot water flow rate, cooling water flow rate, inlet and exit hot water temperatures T_1 and T_2, respectively, the inside metal wall temperatures at the inlet and the exit, T_3 and T_4, respectively, and inlet and exit cooling water temperatures T_5 and T_6, respectively. This was carried out for several flow rates. In order to evaluate the enhancement techniques, the same experimental procedure was repeated for the modified heat exchangers and data was recorded for the same experimental conditions.

There are several parameters that can be determined from these measurements, such as the heat duty Q, the overall heat transfer coefficient U, and the logarithmic mean temperature difference LMTD, that can be employed in the evaluation of the degree of enhancement of the modified heat exchangers. Figure 8 presents the performance, based on heat duty Q, of the four modified heat exchangers. This figure presents the results for following experimental conditions: Counter-flow mode, cooling water flow rate of 10 grams/s, cooling water inlet temperature of 20^{o}C, and hot water inlet temperature of 70^{o}C. The figure clearly shows that the four different enhancement techniques faired well with the annular disks and the spiraled rod enhancement techniques, respectively, being the highest and the lowest.

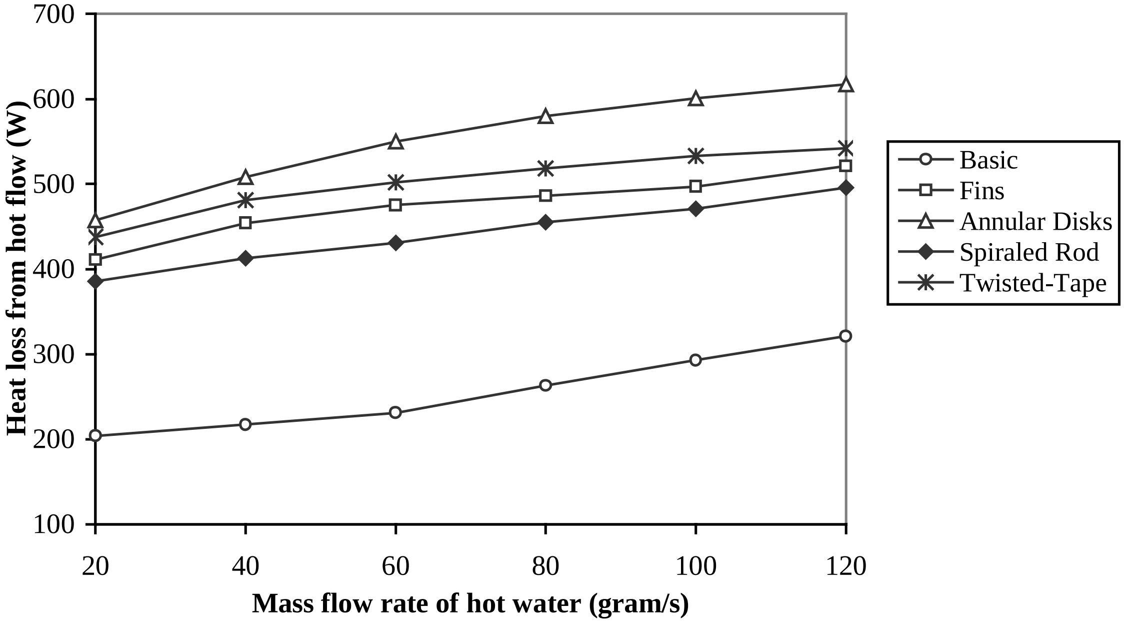


Figure 8: Performance of the modified heat exchangers

It should noted that the performance of these heat exchangers can be tested under other experimental conditions, such as parallel-flow mode, different cooling water flow rates, and different inlet temperatures.

V. Conclusion

This paper has discussed and outlined an experimental setup for the evaluation of different heat exchangers enhancement techniques. The apparatus/experimental setup is simple and relatively inexpensive and can be incorporated in undergraduate heat transfer laboratory. These types of experiments assist the undergraduate mechanical engineering students in the understanding of the basic heat transfer processes and the methods and devices that can be implemented to enhance the heat transfer.

Bibliography

1. Bergles, A. E. (1985), "Techniques to Augment Heat Transfer ," *Handbook of Heat Transfer Applications, 2nd edition*, Chapter 1 McGraw-Hill, New York.
2. Manglik, R. M. and Bergles, A. E. (1992), "Heat Transfer and Pressure Drop Correlations for Twisted-Tape Inserts in Isothermal Tubes: Part I – Laminar Flows," *Enhanced Heat Transfer, ASME Symposium*, Vol. HTD-Vol 202, pp. 89-98.
3. Manglik, R. M. and Bergles, A. E. (1992), "Heat Transfer and Pressure Drop Correlations for Twisted-Tape Inserts in Isothermal Tubes: Part II – Transition and Turbulent Flows," *Enhanced Heat Transfer, ASME Symposium*, Vol. HTD-Vol 202, pp. 99-106.

HOSNI I. ABU-MULAWEH
Hosni I. Abu-Mulaweh is an Assistant Professor of Mechanical Engineering at Indiana University-Purdue University, Fort Wayne, Indiana. He earned his B.S., M.S., and Ph.D. in Mechanical Engineering from the University of Missouri-Rolla, Rolla, Missouri. His areas of interest are Heat Transfer, Thermodynamics, and Fluid Mechanics.