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Comparative Study between Heat Transfer through Laminar Flow and Turbulent Flow

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ABSTRACT: A common situation encountered by an engineer is heat transfer to fluid flowing through a tube. This can occur in heat exchangers, boilers, condensers, evaporators, and a host of other process equipment. The study of heat transfer can be done either in laminar flow or in turbulent flow. Both conditions show different performance characteristics of the heat transfer. In this paper, comparative study of heat transfer in both conditions is done. Under turbulent flow conditions, the increase in heat transfer rate is more significant than that under laminar flow conditions. This is due to the increase in the Reynolds number of the flowing fluid in turbulent flow. The turbulent effects become a dominant factor over secondary flow at higher Reynolds number.

KEYWORDS: Turbulent flow, Laminar flow, Reynolds number, heat transfer performance.

I. INTRODUCTION

Many efforts have been made on heat transfer enhancement according to the progress of thermal systems. The recent researches in heat transfer enhancement lead to the development of currently used heat transfer techniques. We can classify the flow of a fluid in a straight circular tube into either laminar or turbulent flow. It is assumed from here on that we assume fully developed incompressible, Newtonian, steady flow conditions. Fully developed flow implies that the tube is long compared with the entrance length in which the velocity distribution at the inlet adjusts itself to the geometry and no longer changes with distance along the tube. It is generally accepted that the heat transfer from the fluid tube of a fin absorber to the fluid itself, depends to a great extent on the flow condition. Laminar flow, as compared to turbulent flow, can result in a considerable loss in efficiency which could often be avoided by the appropriate design of the absorber and the absorber arrangement in co-ordination with the actual use.

II. RAYNOLDS NUMBER

The value of the Reynolds number permits us to determine whether the flow is laminar or turbulent. We define the Reynolds number as follows.

$$\text{Reynolds number } Re = \frac{DV\rho}{\mu} = \frac{DV}{\nu}$$

Here, D is the inside diameter of the tube (or pipe), V is the average velocity of the fluid, ρ is the density of the fluid and μ is its dynamic viscosity. It is common to use the kinematic viscosity $\nu = \mu/\rho$ in defining the Reynolds number. Another common form involves using the mass flow rate m instead of the average velocity. The mass flow rate is related to the volumetric flow rate Q via $m = Q \cdot \rho$, and we can write

$$Q = \frac{\pi}{4} D^2 V$$

. Therefore, the Reynolds number also can be defined as

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$$Re = \frac{4m}{\pi\mu D}$$

The flow in a commercial circular tube or pipe is usually laminar when the Reynolds number is below 2,300. In the range, $2300 < Re < 4000$, the status of the flow is in transition and for $Re > 4000$, flow can be regarded as turbulent. Results for heat transfer in the transition regime are difficult to predict, and it is best to avoid this regime in designing heat exchange equipment. By the way, turbulent flow is inherently unsteady, being characterized by time-dependent fluctuations in the velocity and pressure, but we usually average over these fluctuations and define time-smoothed or time-average velocity and pressure; these time-smoothed entities can be steady or time-dependent (on a time scale much larger than that of the fluctuations), and here we only focus on steady conditions when we discuss either laminar or turbulent flow.

Principal differences between heat transfer in laminar flow and that in turbulent flow

In discussing heat transfer to or from a fluid flowing through a straight circular tube, it is useful to distinguish between the axial or main flow direction, and the directions that lie in a plane perpendicular to the tube axis. In that plane, transverse heat flow can be broken into radial and azimuthal components.

The principal difference between laminar and turbulent flow, as far as heat transfer is concerned, is that an additional mechanism of heat transfer in the radial and azimuthal directions becomes available in turbulent flow. This is commonly termed “eddy transport” and is intense, providing much better transfer of energy across the flow at a given axial position than in laminar flow, wherein conduction is typically the only mechanism that operates in the transverse directions (an exception occurs when there are secondary flows in the transverse direction, such as in coiled tubes). Another difference worthwhile noting is the extent of the “thermal entrance region” in which the transverse temperature distribution becomes “fully developed.” This region is relatively short in turbulent flow (precisely because of the intense turbulent transverse transport of energy), whereas it tends to be long in laminar flow. Heat transfer correlations, based on experimental results, are typically divided into those applicable in the thermal entrance region, and those that apply in the “fully developed” region. In the case of laminar flow, it is important to be aware of this distinction, and normally a laminar flow heat exchanger is designed to be short, to take advantage of relatively high heat transfer rates that are achievable in the thermal entrance region. In the case of turbulent flow, the thermal entrance region is short, as noted earlier, and typically heat transfer occurs mostly in the “fully developed” region. Therefore, turbulent heat transfer correlations are commonly provided for the latter region.

III. PERFORMANCE EVALUATION OF PLATE HEAT EXCHANGER IN LAMINAR AND TURBULENT FLOW CONDITIONS^[1]

Manoj B. Kumbhare et.al [1] performed the experiment on a plate heat exchanger for water/water system, at different flow rate and different hot water inlet temperature, at steady state conditions. Overall heat transfer coefficient (U) is determined for the performance evaluation of plate heat exchanger as shown in figure 1

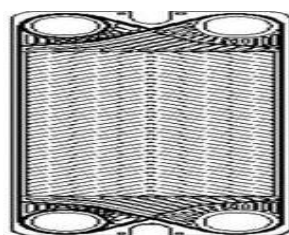


Figure 1. heat exchanger consist of a number of corrugated metal sheets

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The experiments were performed in a plate type heat exchanger having following geometrical Line diagram of experimental set up is shown in configuration. The Convective heat transfer coefficient of hot and cold water is a function of the Reynolds number. From the experimental data the graphs were plotted for Reynolds number Re against $(Nu/Pr^{0.333})$ as shown in figure 2.

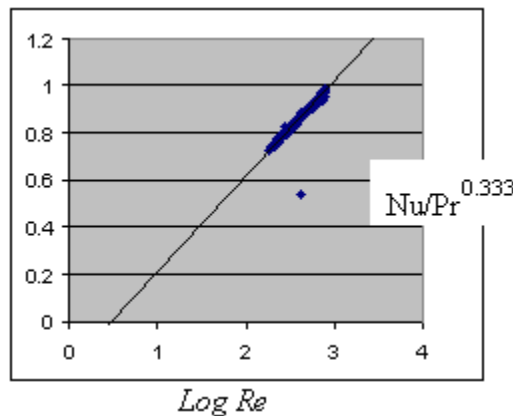


Figure 2. Reynolds number Re against $(Nu_h/Pr_h^{0.333})$ For Laminar flow

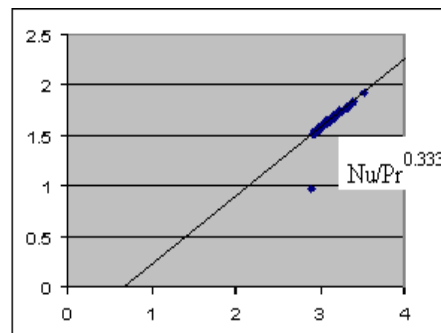


Figure 3. Reynolds number Re against $(Nu_h/Pr_h^{0.333})$ For Turbulent flow

For the Reynolds number less than 800 the experimental data generates a straight line of slope approximately 0.333 which indicates the laminar flow conditions and the heat transfer correlation proposed as;

$$Nu = C.(Re)^a .(Pr)^{0.33}$$

$$Nu = 0.977(Re.Pr)^{0.33}$$

For the Reynolds number greater than 800 the experimental data generates a straight line having a slope 0.68 and intercept equal to 0.338 .The correlation developed from these values is;

$$Nu = 0.338Re^{0.68} Pr^{0.33}$$

IV. LAMINAR FLOW & TURBULENT FLOW

By experimentation it has been found that Reynolds numbers of less than 1200 describe the condition at which there is no breaking away from the tube wall which is termed laminar flow. The physical properties of the fluid are the determining factors for the heat transfer in this area which is inefficient in heat transfer terms. The blue line in the graph is for a smooth tube while the red one is for a corrugated tube. As can be seen, whether or not the tubes are corrugated, when operating in a laminar flow regime corrugated tubes have no positive effect until the Reynolds number is above 1000.

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Vol. 4, Issue 4, April 2015

At Reynolds numbers above 2000 there is substantial breaking away from the tube wall and the condition is described as turbulent flow with significant mixing of the boundary layer and the bulk fluid. This is the most efficient area for heat exchangers to work in.

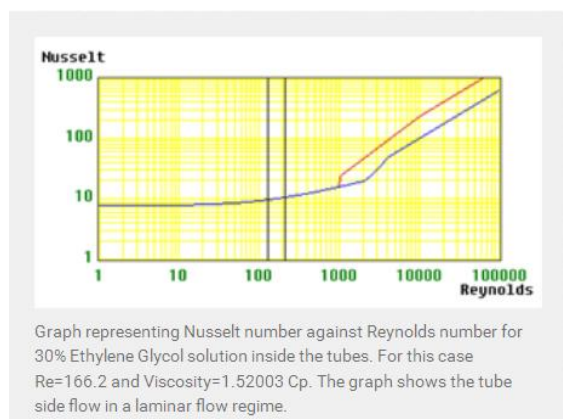


Figure 4. Laminar Flow

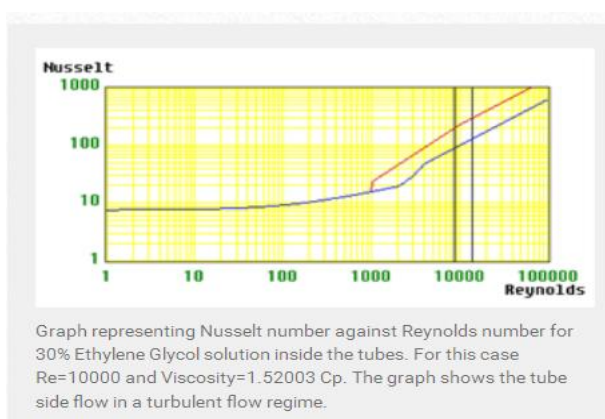


Figure 5. Turbulent Flow

This graphs shows that corrugation in turbulent flow regimes has a significant enhancing effect for Reynolds numbers above 2000 when compared to the equivalent smooth tubes. Many techniques have been tried in order to reduce the Reynolds number value at which turbulent flow is produced but most have the disadvantage of increasing the resistance to fluid flow, the pressure loss, at a rate which increases more rapidly than the decrease in boundary layer resistance. Some are not useable if there are solids present, others if the fluid is very viscous. One technique which is universally useful and does not have the disadvantages of the others is that of deforming the tube with a continuous shallow spiral indentation or an intermittent spot indentation. Research has shown that by choosing the depth, angle and width of the indentation carefully, the Reynolds number at which turbulent flow is produced can be reduced significantly below 2000.

IV. CONCLUSIONS

Under turbulent flow conditions, the increase in heat transfer rate is more significant than that under laminar flow conditions. The turbulent effects become a dominant factor over secondary flow at higher Reynolds number. The turbulent flow can be produced by inserting different geometries in the circular pipe. This study focuses on the various methods or geometries used to produce turbulent geometries and its effect on the heat transfer. The turbulent generators with different geometrical configurations have been used as one of the passive heat transfer enhancement techniques and are the most widely used in tubes in several heat transfer applications

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