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The Experimental Study on Enhanged heat Transfer Performance in Plate Type Heat Exchanger

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Abstract

In this experimental study investigated the effects of various operating and design parameters to enhanced heat transfer performance in plate type heat exchanger. Compact heat exchangers (CHE) are very well known for their special design which includes high heat transfer coefficient and maximum temperature driving force between the hot and cold fluids. The test section consists of a plate pack length 31 mm with 100^0C work temperature, surface area and design pressure 6 kg/cm^2 and varying of different operating parameters (flow rates, temperature, pressure and properties of test fluid) of hot and cold fluids. The effects of relevant parameters on plate type heat exchanger are investigated. The plate type heat exchangers have the advantages over the shell and tube heat exchanger for the heat recovery as large area can be provided in smaller space. If the experimental work enhances the overall heat transfer coefficient and its supports the system to improve the energy efficient and cost reduction.

Keywords: Heat transfer, plate type heat exchanger, flow rates, Reynolds number, Nusselt number, overall heat transfer coefficient.

Introduction

Compact heat exchangers can be defined as heat exchangers characterized by a high wetted surface area (heat transfer area) per unit volume. This ratio should be typically higher than $100m^2/m^3$ for the heat exchanger to be treated as compact, whereas for typical industrial shell and tube heat exchangers this ratio goes down to less than 60-70 m^2/m^3. Making the heat exchanger compact has the advantage of reducing space, weight, cost, energy required, in addition to the high heat transfer per unit footprint area it affords. Examples for CHE are a bundle of very small-diameter tubes for both high and low-density fluids, circular tubes with extended surfaces or circular fins attached to the outside, stack of flat plates placed very close together and compact matrix constructed using stacks of plates and fins or packed bundle of tubes frequently used in liquid to gas exchangers. Compact heat exchangers have a major role in the development of light cheap and efficient heat exchangers used for aerospace, marine transportation system, air conditioning and refrigeration applications.

One of the most common designs in these applications use a cross flow heat exchangers like spiral / plate type heat exchangers. Nowadays, plate heat exchangers (PHEs) are extensively Used for heating, cooling and heat-regeneration applications in the chemical, food and pharmaceutical industries. This type of exchanger was originally developed for use in hygienic applications such as the pasteurization of liquid food products. For improving the performance and to make these exchangers more compact and light weight, experiments can be conducted at different Reynolds numbers and turbulence levels for selecting an optimum heat exchanger design. However, the range of applications of this type of exchanger largely expanded in the last decades due to the continual design and construction improvements.

Plate heat exchangers are less widely used than tubular exchangers but have characteristics that make them the system of choice in some applications. Plate heat exchangers can be classified in four principal groups: i. Plate- and- frame heat exchangers, used as an alternative to tube and shell exchanger for low and medium pressure liquid/liquid heat transfer applications. ii. Spiral heat exchangers, used as an alternative to tube and shell exchangers for low and medium pressure applications of all kinds. These are of particular value where low maintenance is required, and with fluids tending to sludge or containing solids in suspension. iii. Plate coil heat exchangers, made from previously embossed plates to form a conduit or coils for liquids coupled by fins. iv. Plate fin heat exchangers in which a stack of die formed corrugated plates is welded or brazed to provide compact heat exchanger surfaces for various gas/gas exchange process. These are commonly used in cryogenic applications and in exhaust or inlet air preheating, waste heat recovery systems for building, gas turbines, etc.

Compact Plate Type Heat Exchangers have a number of applications in the pharmaceutical, petrochemical, chemical, power, sugar and dairy, food and beverage industry. In the recent past plate type heat exchangers are commonly used when compared to other types of heat exchangers such as shell and tube type in the process of heat transfer and heat recovery. This is with respect to their compactness, ease of production, sensitivity and efficiency. Plate types Heat Exchangers (PHEs) are very common in dairy and sugar industries. This is due to their ease of maintenance and cleaning, their compact design and their excellent heat transfer coefficient compare to another types of heat exchangers. However Kanev et al.[1] conducted numerical investigations to study the impact of heat loss from the geothermal wellbore on produced fluid temperatures and pressures. Their study identifies flow rate as a key parameter in determining the wellhead conditions, with elapsed time and geothermal gradient playing secondary roles.

Ramey et al[2] derived an approximate solution to the wellbore heat transmission problem that could be used to predict the bottom hole temperature of the fluid when it is injected at the surface. The assumptions used in deriving the analytical solution were that i. heat flows in the radial direction in the formation; ii. heat transmission in the wellbore is rapid compared to heat flow in the formation, hence, could be represented by steady-state solutions; and iii. physical and thermal properties of the earth and wellbore fluids do not vary with temperature.

T.A. Cowell et al[3] obtained heat transfer and pressure drop characteristics of flat tube and louvered plate fin surfaces. From his work, friction factor and Stanton number were evaluated at certain range of Reynolds number.

Joshi and Webb et al[4] explained the goodness factor comparison for different fin surfaces particularly for plate fin surfaces. They show goodness factor of offset strip fin is higher than that of triangular and rectangular plain surface operation in same conditions. Later, they presented analytical models to predict the heat transfer coefficients and friction factors of an offset strip-fin heat exchanger by idealizing a unit cell model. The model neglected the possible burrs on the fin ends and also the roughness on the top and bottom of the channel.

Bhowmik and Lee et al[5] studied the heat transfer and pressure drop characteristics of an offset strip fin heat exchanger using a steady-state three-dimensional numerical model. They observed the variations in the Fanning friction factor f and the Colburn heat transfer factor j relative to *Redh*. General correlations for the f and j factors were derived, which was used to analyze fluid flow and heat transfer characteristics of offset strip fins in the laminar, transition, and turbulent regions.

Martin et al[6] numerically studied the heat transfer and pressure drop characteristics of plate heat exchanger. The apparatus used in the investigations had a cross section of 5×30 mm^2, number of turns n = 8.5, core diameter of 250mm, outer diameter of 495mm and 5×5 cylindrical bolds in a rectangular in line arrangement of 61×50 mm. for data in the range of $4x10^2 < Re < 3x10^4$ Nusselt number correlation for their particular set up with water as a medium is given in equation as follows $Nu = 0.04Re^{0.74}Pr^{0.4}$.

Yasar Islamoglu and Cem Parmaksizoglu et al[7] investigated the correlations for fully developed Nusselt number and friction coefficients for air flowing inside the corrugated channels of plate heat exchangers. Experimental data were obtained for the channel height of 5 and 10 mm for the Reynolds range of 1200 to 4000. As a result, they suggested that both the Nu and f coefficients increase with the rising height of the channel.

If the following literature[8-9] analysis for the flow field and heat transfer characteristics within fully developed region of corrugated channels were analyzed numerically and the predicted pressure drop within the corrugated channel was in good agreement with experimental observations.

Murugesan M.P. and Balasubramani et al[10] deals with the effect of mass flow rate and heat transfer characteristics of a corrugated plate heat exchanger were studied for increase of mass flow rate with subsequent increase in the flow velocity has led to an increase in the overall heat exchanger coefficient as well as the individual heat transfer coefficient. Its providing corrugated (or) embossed patterns is to import high turbulence to the fluids which result in high heat transfer co efficient as high as 2-5 times of those obtainable in shell and tube heat exchanger for similar duties.

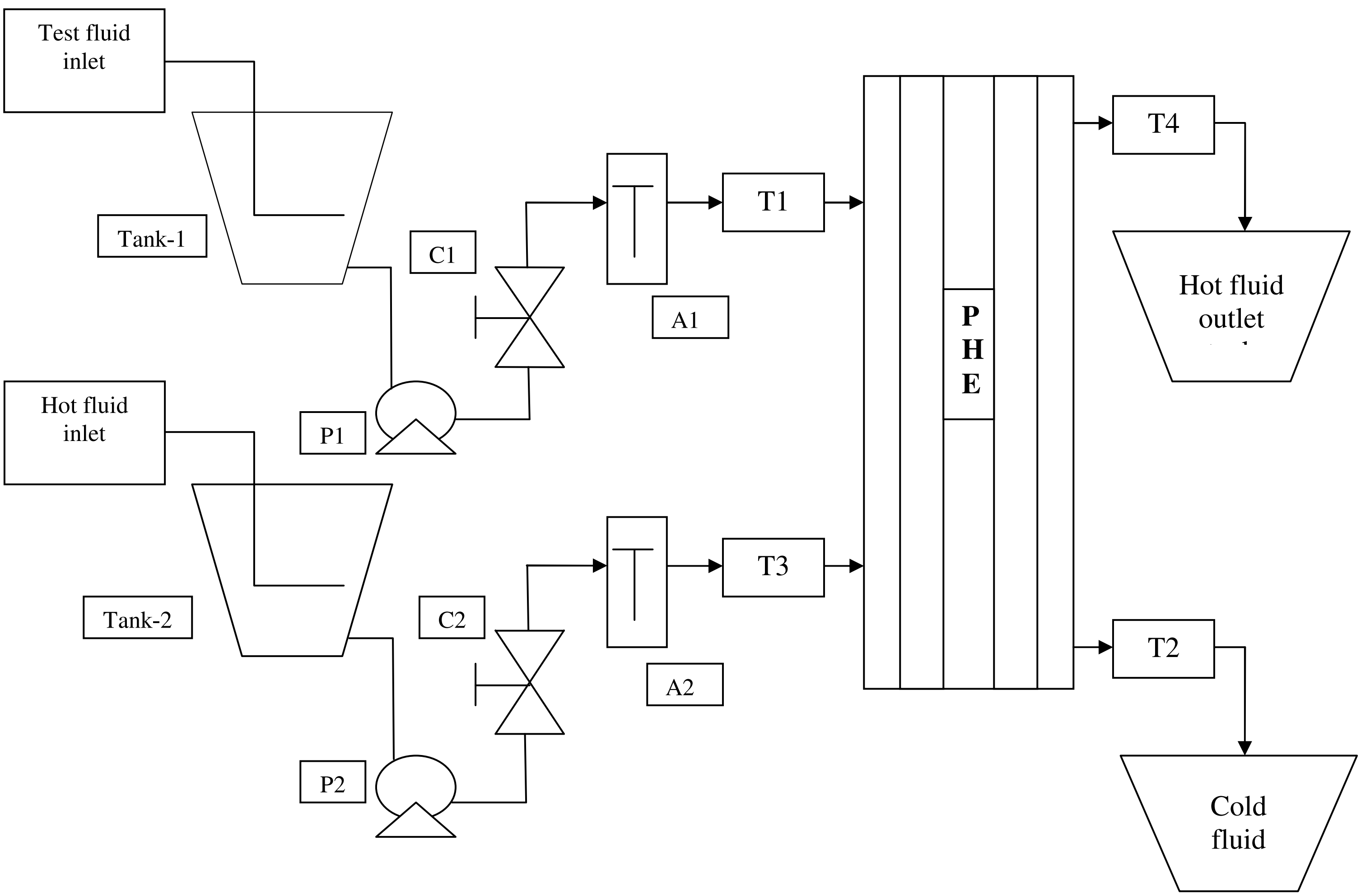
Murugesan M.P. and Balasubramani et al[11] established link between protein denaturation and fouling, the relative impact of the denatured and aggregated proteins on the deposit formation is not clear. In general, it is believed that fouling is controlled by the aggregation reaction of proteins and the formation of protein aggregates reduces fouling. The mass transfer of proteins between the fluid and heat transfer surface also plays an important role. It may not be possible to completely eliminate fouling in heat exchangers simply due to the fact that denaturation and aggregation reactions initiate as soon as milk is subjected to heating. Fouling, however, can be controlled and mitigated by selecting appropriate thermal and hydraulic conditions. Both increasing the flow rate, decreasing the temperature and proper cleaning process in done for reduce the fouling. In this experimental work used for three mechanism used for reducing of fouling as well as surface coating, preheating, cleaning of corrugated plate surfaces. It's provides higher heat treatment efficiency and controlling of fouling.

In this present study investigate the effect of various operating and design parameters of plate heat exchanger, parametric analysis is also carried out. The key operating parameters like inlet temperature of fluids, mass flow rate of fluids, and inlet pressure of fluids are varied for the same. The results for different operating parameters of plate type heat exchanger provides for high heat transfer rates.

Material and Methods

Experimental apparatus: The experimental setup consists of plate type heat exchanger, rotameter, and thermocouples, pumps and tanks figure 1. The channel configuration is characterized by the corrugated channel height, the respective values of 10 mm. In the plate type heat exchanger designed for 31 mm plate pack length with $100^{O}C$ work temperature and design pressure 6 kg/cm^2. The heat exchanger was constructed using 316 stainless steel plates. It should be giving of higher heat transfer efficiency of pasteurization and sterilization process. The plate heat exchanger had a height of 304 mm and a plate thickness of 1mm. The total heat transfer area of $2.24m^2$. Plate had a gap between the plate is 10mm. A pump was used to provide flow to the cold fluid side. The flow rate was controlled by a calibrated area flow meter, allowing flows to be controlled and measured between 0.42 and 0.46 kg/s. The hot fluid inlet pipe is connected at the bottom of the heat exchanger and the outlet pipe is from the periphery of the exchanger, the hot fluid used is about 60-$70^{0}C$ can be heated up by purging steam form the boiler in to an 1000 liters tank-2 and this was pumped to heat exchanger using a 1/2hp pump. The cold fluid inlet pipe is connected at the top of the heat exchanger and the outlet is from the bottom of the heat exchanger. The cold fluid supplied is at room temperature from the tank-1 and was this also pumped to heat exchanger using a 1/2hp pump. The flow of cold and hot fluids was varied using control valves (c1 and c2) respectively for cold and hot fluids. Rota meters are installed at the inlet sections of cold and hot fluids for measuring the flow rates. Thermometers (T^1, T^2, T^3, T^4) are fixed at the inlet and outlet section of the cold and hot fluids. T^1 and T^3, are used to measure the inlet of cold and hot fluids; $T^2$and T^4 are used to measure the outlet of cold and hot fluids respectively.

Experimental setup:



P1-Test fluid inlet pump, P2-Hotfluid inlet pump, C1 and C2-Control valve for hot and cold fluid, A1 and A2-Area flow meter, T1 T2-Test fluid inlet and out let temperature, T3 and T4 -Hot fluid inlet and outlet temperature.

Figure 1
Schematic of Experiment set up

Experimental Procedure: The proposed parameter estimation procedure for generalized configurations is to be tested using an Alfa Laval, model P5-VRB, plate heat exchanger is used for conducting experiments as shown in figure 1, using hot water about 60-70^{0}C as hot service fluids and the cold service fluid used were varying compositions of two-phase liquids (water – ethylene glycol) at room temperature. The flow configurations used were countercurrent flow pattern. The inlet hot fluid flow rate was kept constant and the inlet cold fluid flow rate was varied using control valve, for different cold fluid flow rate the temperatures at the Inlet and outlet of hot and cold fluids were recorded after steady state was reached. The same procedure was repeated for different hot fluid flow rate and the corresponding temperatures are measured for different cold fluid flow rates. This procedure was repeated for the varying compositions of cold fluid and the results were tabulated.

Parameters Considered: The performance of the plate type heat exchanger mainly depends on mass flow rates of the fluids, flow area and logarithmic temperature difference between the fluids. The volumetric flow rate is measured using flow meter (rotameter). The inlet and outlet temperatures of hot and cold service fluid are measured using resistance temperature devices at corresponding inlet and outlet section respectively.

Flow Measurements: Flow, defined as volume per unit of time at specified temperature and pressure conditions, and is generally measured by positive-displacement or rate meters. The term “positive-displacement meter” applies to a device in which the flow is divided into isolated measured volumes when the number of fillings of these volumes is counted in some manner. The term “rate meter” applies to all types of flow meters through which the material passes without being divided into isolated quantities. Movement of the material is usually sensed by a primary measuring element that activates a secondary device. The flow rate is then inferred from the response of the secondary device by means of known physical laws or from empirical relationships. The principal classes of flow-measuring instruments used in the process industries are variable-head, variable-area, positive-displacement, and turbine instruments.

Rotameter: A rotameter consists of a vertical tube with a tapered bore in which a float changes position with the flow rate through the tube. For a given flow rate the float remains stationary since the vertical forces of differential pressure, gravity, viscosity, and buoyancy are balanced. The float position is the output of the meter and can be made essentially linear with flow rate by making the tube area vary linearly with the vertical distance.

Heat duty (Q): Heat duty is defined as the product of mass flow rate specific heat capacity and the temperature difference between inlet and outlet fluid temperatures $Q = m_h * c_p * \Delta T$

Hydraulic radius: The hydraulic radius is defined as the ratio of the cross sectional area of the channel to the wetted perimeter of the channel.

$$R_h = \frac{\text{Cross sectional area of the channel}}{\text{Perimeter of the channel in contact with the fluid}} = 2b$$

Reynolds number: After defining the hydraulic radius and the average flow velocity Reynolds number will be defined as

$$NRe = \frac{\rho V De}{\mu}$$

Log mean difference temperature: The log mean difference temperature was defined as the "average" driving temperature difference between the hot and cold streams for heat transfer calculations. For heat exchangers, the use of the log mean difference temperature makes the calculation of the heat transfer coefficient more accurate. For counter current flow, It is defined as

$$\Delta T = \frac{(T_{ho} - T_{ci}) - (T_{hi} - T_{co})}{\text{Ln}\ \{(T_{ho} - T_{ci}) / (T_{hi} - T_{co})\}}$$

Heat transfer coefficient: The heat transfer coefficient was calculated based on the wetted surface area and the log mean temperature difference. It is defined as $U = Q / A * \Delta T$.

Nusselt number: The Nusselt number is calculated as below

$$Nu = \frac{hDe}{k}$$

Thermal Design: The following equations have been described for conventional heat exchanger design a corrected log mean temperature equation was used $Q = U * A * \Delta T$.

To apply heat duty equation to the plate type heat exchanger, empirical correlation of the film heat coefficients are needed. In order to validate the use of the design equation, the following conditions are imposed: i. The temperature and flow transients in the plate type heat exchanger are negligible. ii. The heat losses to the surroundings are negligible. iii. The fluids exist only in the liquid phase within the exchanger. iv. The overall heat transfer coefficient is constant throughout the exchanger.

The overall heat transfer coefficient for a clean surface is

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_i} + \frac{t}{k_m}$$

Results and Discussion

Water – Water System: The heat transfer characteristics of Water-Water system in a plate type heat exchanger is shown in figure 2. From this figure it is found that the heat transfer coefficient increases with increase in Reynolds number.

This is due to the reason that localized secondary flow is formed in the spiral plate heat exchanger. Due to this secondary flow more turbulence is created (evident from the increases in Reynolds number) causing increased heat transfer between surfaces.

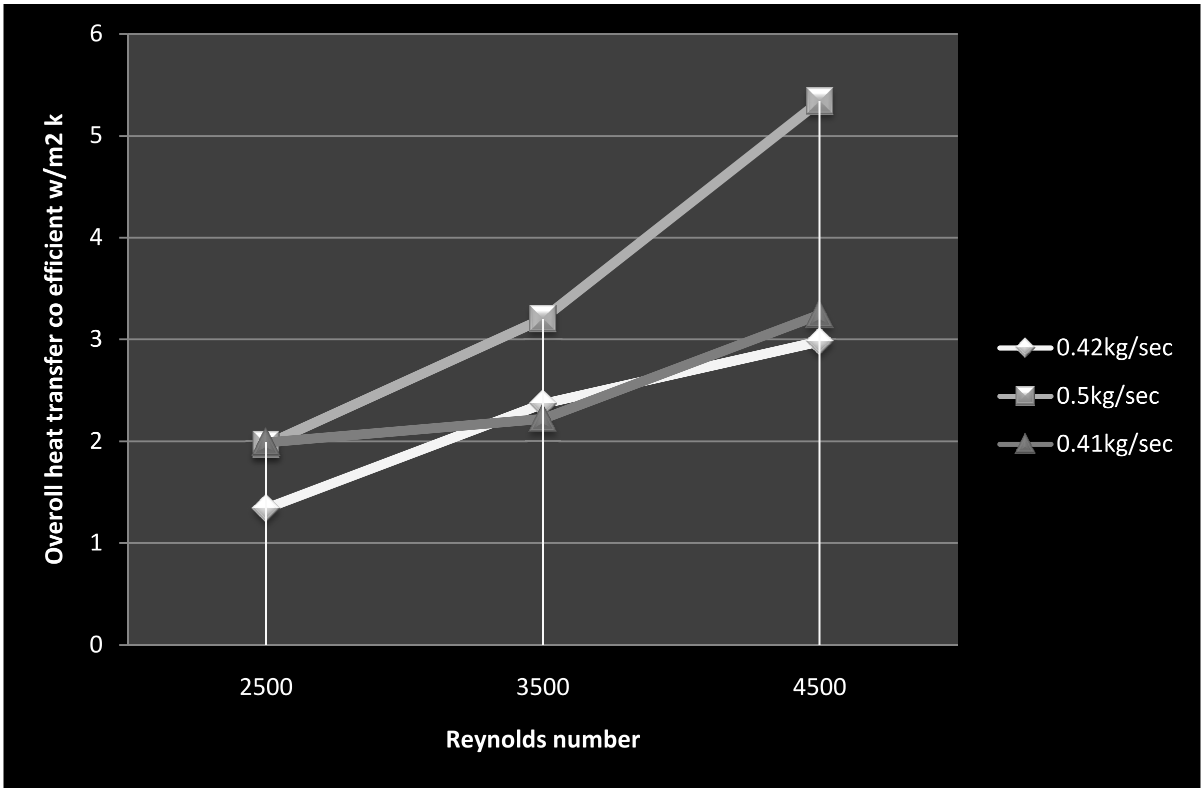


Figure-2
Effect of Reynolds number on heat transfer coefficient for Water-Water system

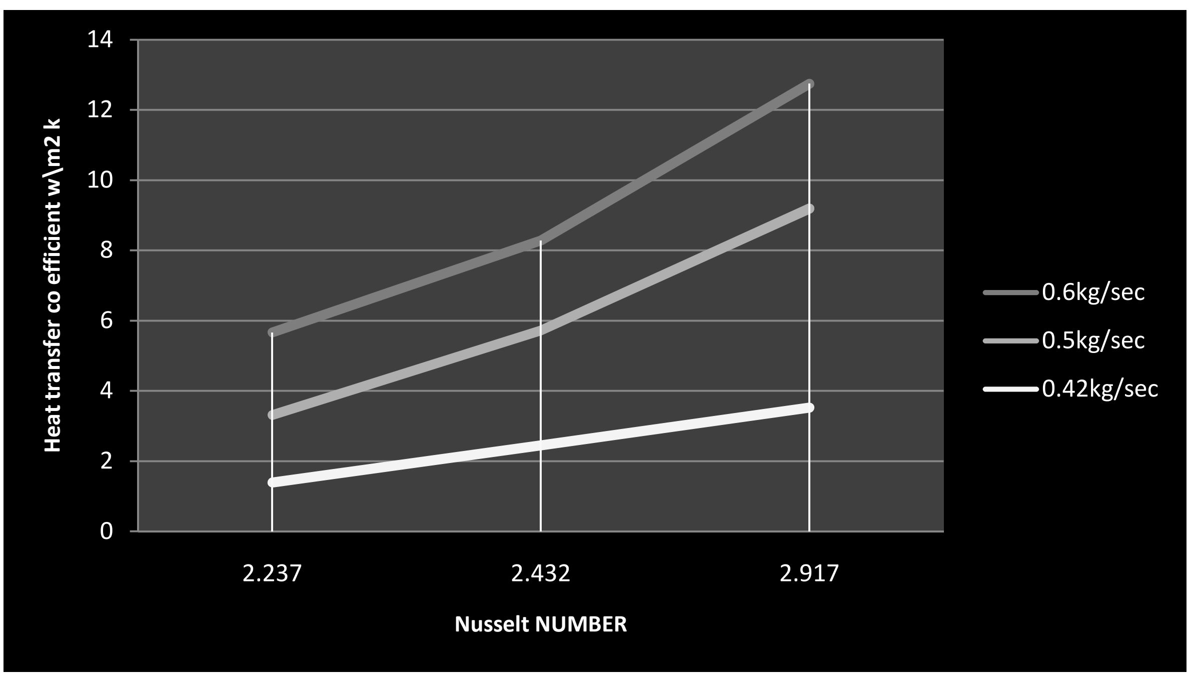


Figure-3
Effect of Nusselt number on heat transfer coefficient For Water – Water system

Ethylene Glycol – Water System: The heat transfer characteristics of ethylene glycol -Water system in a plate type heat exchanger is shown in figure 4. From this figure it is found that the heat transfer coefficient increases with increase in Reynolds number.

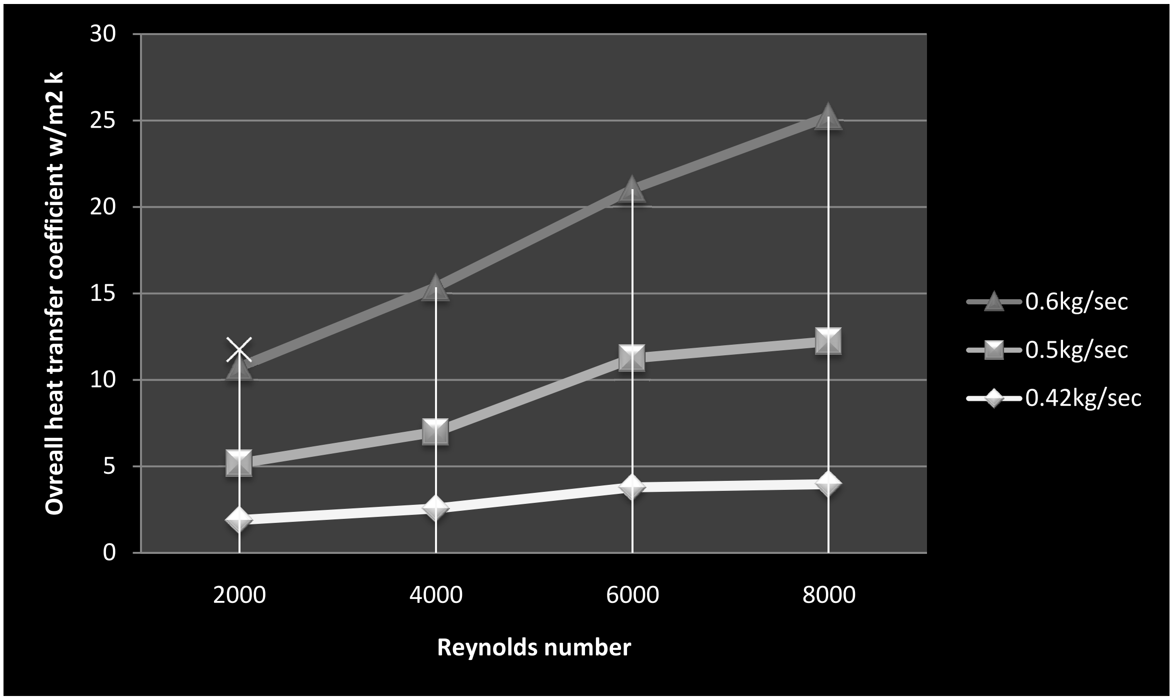


Figure-4
Effect of Reynolds number on heat transfer Coefficient for Ethylene glycol – Water system

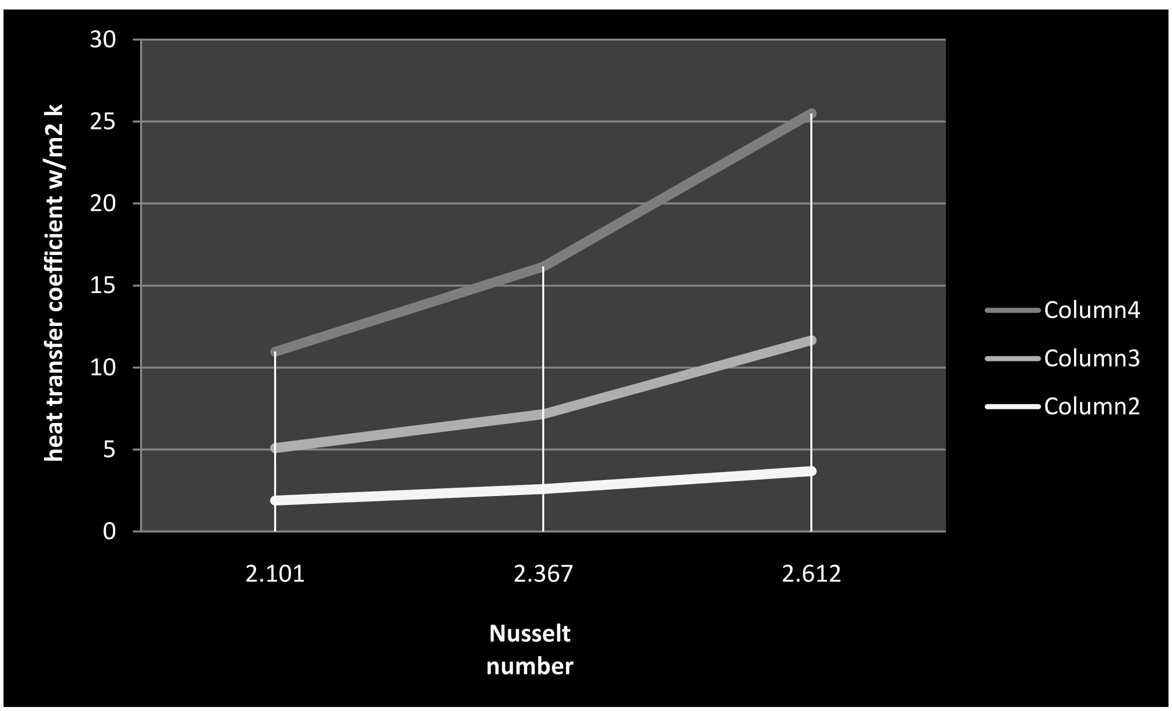


Figure-5
Effect of Nusselt number on heat transfer Coefficient for Ethylene glycol – Water system.

Conclusion

Compact heat exchangers are advantages over conventional heat exchangers. Unfortunately, unlike the conventional shell- and –tube heat exchanger for plate heat exchangers there is a lack of a generalized thermal and hydraulic design method. In this experimental work investigated for heat transfer performance of plate type heat exchanger by varying of operating parameters and design parameters. Heat transfer coefficient was studied for various fluids like water and ethylene glycol. The increase mass flow rate with subsequently increase in the flow velocity has led to an increased overall heat transfer coefficient as well as individual heat transfer coefficient.

Nomenclature: Abbreviations: PHEs plate heat exchangers, LMTD log mean temperature difference.

Symbols: T1 = Temperature inlet – hot side, T2 = Temperature outlet – hot side, T3 = Temperature inlet – cold side, T4 = Temperature outlet – cold side, Hhs =the heat transfer coefficient between the medium and the heat transfer surface (W/m^2 °C), Hcs =the heat transfer coefficient between the heat transfer surface and the cold medium (W/m^2 °C), Δx = the thickness of the heat transfer surface (m), k = the thermal conductivity of the material Separating the Medias (W/m °C)

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