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The Effect of Mass Flow Rate on the Enhanced Heat Transfer Charactristics in A Corrugated Plate Type Heat Exchanger

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Abstract

Heat exchanger is a device in which heat is transferred from one medium to another medium across a corrugation angle plate surface. In many leather, textile, dying, and chemical process industries are making a salt separation (or) solid separation process by using of heat exchanging device in shell and tube heat exchanger. It was provided a lower heat transfer rate compare to plate type heat exchanger. This present work can be designed for corrugated plate type heat exchanger with different mass flow rates and corrugation angle. In the plate type heat exchanger having a advantages over the shell and tube heat exchanger as large area can be provided in smaller space. The basic objective of 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.

Keywords: Heat transfer, corrugated plate type heat exchanger with mixing type, Heat transfer co efficient, mass flow rate.

Introduction

Plate heat exchangers (PHEs) are widely applied throughout different kinds of heat transfer operations used for process industries and are commonly designed with a corrugated channel surface resulting in the enhanced heat transfer performance by increasing the area over which heat transfer takes place and generating a vigorous mixing effect within the working fluid. In order to achieve enhanced heat transfer, corrugated channels are often employed in the design of plate heat exchangers. Because of corrugated channel can be designed 25^0 of corrugation angle with baffles arrangement of channel surface and counter current flow. It should be increased for mixing ability of two fluids (Hot and Cold fluid) and fluids are exposed to a much larger surface area because the fluids spread out over the plates. So that heat transfer characteristics are quite different than flat plates. This type corrugated channels interrupt the thermal boundary layer and thereby increase the convection heat transfer coefficient.

In the literature[1-2] it is shown that the use of a corrugated channel results in a more complex flow structure and improves the heat transfer by as much as two or three times compared to a conventional straight channel.

In the literature[3-6] the authors demonstrated that sinusoidal wavy plate arrangements and channel geometries improved the heat transfer performance by increasing the surface area and prompting the formation of vortexes in the flow. The symmetric arrangement yields a superior heat transfer performance to an asymmetric arrangement. Unfortunately, the geometric parameters are not expressed clearly.

In literature[7-8] 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.

In the literature[9] 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.

In the literature[10] 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

$$Nu = 0.04Re^{0.74}Pr^{0.4}$$

In this literature[11-12] deal with the repair and improvement of the Buonopane bridge in Ischia Island. It is an historical bridge that showed degradation defects due to material aging and to incorrect repair works performed in the past. This specific case bears out that it is necessary to seek all information on construction technique, mechanical, physical and chemical properties of materials, analysis methods used in design of structure. Investigations and tests must be performed during both design phase and construction phase.

In this present study, the heat transfer and flow characteristics of different fluids for corrugated plate heat exchanger have been experimental work enhanced heat transfer efficiency of corrugated or embossed patterns is to impart high turbulence and mixing of fluids which result in high heat transfer coefficients as high as 4 – 5 times of those obtainable in shell and tube exchanger for similar duties.

Material and Methods

Experimental apparatus: A schematic diagram of the experimental apparatus and the sharp edge version of the corrugated duct used in the heat transfer experiments are presented in Figs 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 25^{O} corrugation angle and 31 mm plate pack length with $100^{O}C$ work temperature and design pressure 6 kg/cm^2. The advanced technology of corrugated plate type heat exchanger enhances the overall heat transfer coefficient and its supports the system to improve the energy efficient and cost reduction.

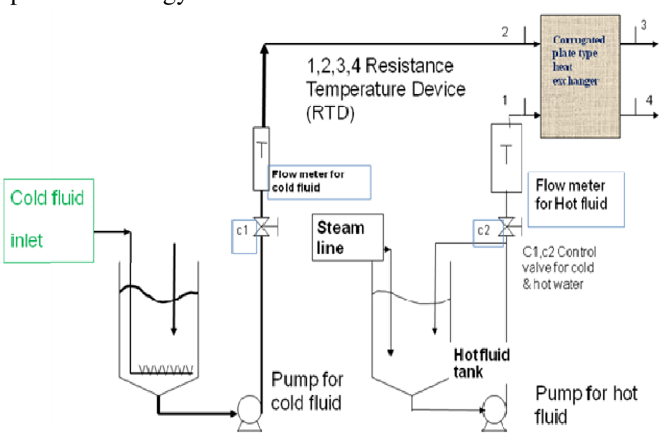

Figure 1
Schematic of Experiment set up

The experimental heat exchanger set up is shown in figure 1. The heat exchanger was constructed using 316 stainless steel plates. 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 5mm.

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 0.2 to 1.0 kg/s. The cold fluid inlet pipe is connected to the bottom of the corrugated plate type heat exchanger and the outlet is taken from another end top of the heat exchanger.

The hot fluid is heated by pumping the steam from the boiler to the temperature of about 75-93^{o} C and connected to hot fluid reservoir, and then the hot solution is pumped to heat exchanger using a pump. The hot fluid inlet pipe is connected at the top of the corrugated plate type heat exchanger and the outlet pipe is taken from bottom of the heat exchanger.

The flow rate for the hot fluid was controlled by an identical flow meter as it was done for the cold fluid flow. Thermocouples were inserted into the pipe to measure the inlet and the outlet temperatures for both fluids. Temperature data was recorded using a data acquisition unit connected to a personal computer.

Experimental Procedure: The heat transfer and flow characteristics of water, and sodium chloride (NaCl) were tested in corrugated plate type heat exchanger as shown in figure 1. Water was used as the hot fluid. The inlet hot fluid flow rate was kept constant and the inlet cold fluid flow rate was varied using a control valve.

The flow of cold and hot fluid was varied using control valves, C1 and C2 respectively. Hot and cold fluid paths of heat exchanger are shown in figure 1. Thermocouples T1 and T2 were used to measure outlet temperature of hot and cold fluids respectively; T3 and T4 were used to measure the inlet temperature of hot and cold fluids respectively. For different cold fluid flow rate the temperature at the inlet and outlet of hot and cold fluids were recorded. The same procedure was repeated for different hot fluid flow rates and the data related to cold fluid temperature and mass flow rates were recorded.

Log Mean Temperature Difference: 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

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

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

$$Q = m_h * c_p * \Delta T$$

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

$$Re = \frac{\rho V D_e}{\mu}$$

Nusselt number: The Nusselt number is calculated as below

$$Nu = h D_e / K$$

Heat transfer co efficient: The heat transfer coefficient was calculated based on the wetted surface area and the log mean temperature difference. It is defined as

$$U = Q / (A * \Delta T)$$

Thermal design: The following equations have been described in the literature[10,12] for conventional heat exchanger design. A corrected log mean temperature equation was used

$$Q = U / (A * \Delta T)$$

To apply ΔT to the corrugated 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 heat losses to the surroundings are negligible. ii. The fluids exist only in the liquid phase within the exchanger. iii. The overall heat transfer coefficient is constant throughout the exchanger.

The overall heat transfer coefficient for a clean surface is

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

Where, U- Overall heat transfer coefficient, W/m^2 K, h_0- heat transfer coefficient at hot fluid side, W/ m^2 K, hi- heat transfer coefficient at cold fluid side, W/ m^2 K, t- Thickness (m), K_m- Thermal conductive of the material, W/m K.

From the actual overall heat transfer coefficient determined and from water heat transfer film coefficient is calculated to get the water heat transfer film coefficient data were obtained from runs with water in both sides and by the use of an iterative calculation.

Result and Discussion

Water – Water System: The heat transfer characteristics of Water-Water system in a corrugated 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 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.

Sodium Chloride–Water System: The heat transfer characteristics of Sodium chloride -Water system in a plate heat exchanger is shown in figure 3. From this figure it is found that the heat transfer coefficient increases with increase in Reynolds number. Here it was found that the heat transfer was lesser than water – water system. It is because Sodium Chloride contains molecules that cause increased turbulence comparative to water system.

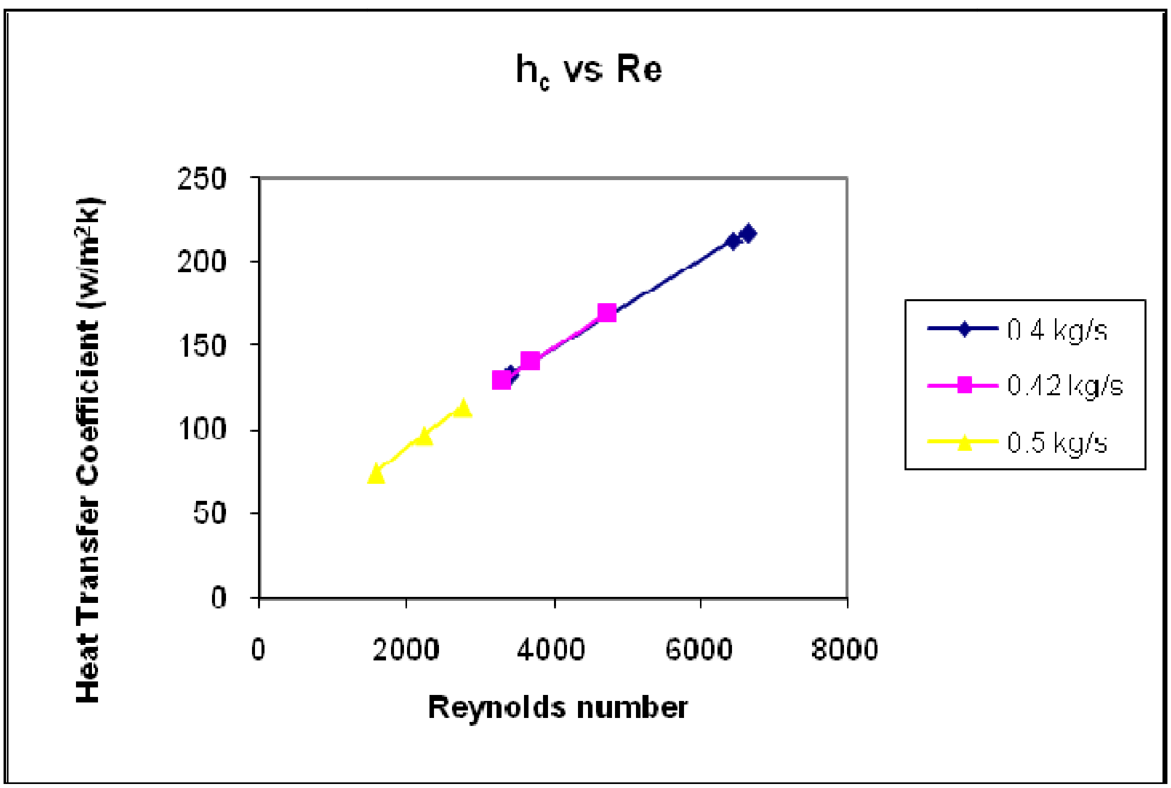

Figure-2
Effect of Reynolds number on heat transfer coefficient For Water – Water system

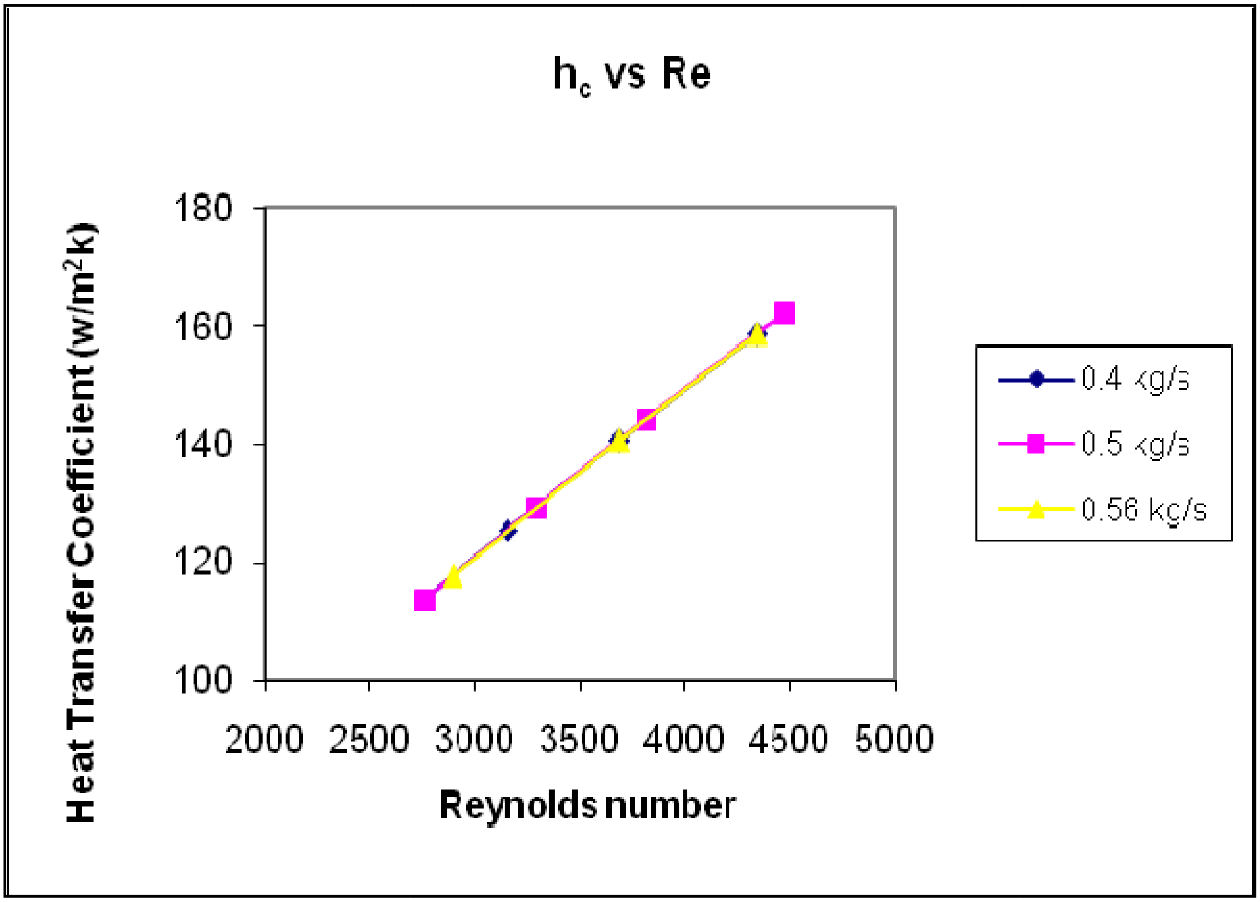

Figure-3
Effect of Reynolds number on heat transfer Co efficient for Sodium Chloride – Water system

Comparison of different systems: From the experimental data obtained a comparison has been done which is shown in figure 4. The figure clearly shows that apart from the water - water system the NaCl – Water system has the best heat transfer.

Comparison of Heat Transfer Coefficient of NaCl-water and Water –water system at different flow rates:

Table-1

Mc (Kg/S)	Heat transfer co efficient, (W/m^2K)	
	Water	Nacl
0.4	129.22	117.7
0.45	134.5	123.0
0.5	142.2	129.7
0.6	161.5	149.1
0.7	178.9	162.1

Conclusion

Experiments were conducted in the corrugated plate type Heat Exchanger with different process fluids. The experimental data provide the following conclusions. Heat transfer and flow characteristics of a corrugated plate type heat exchanger were studied. Heat transfer coefficient for process fluids was studied for different mass flow rate. Heat transfer coefficient was studied for various fluids like water and the process fluid like Nacl. The following observation was made

Water > NaCl

The increase of mass flow rate with subsequent increase in the flow velocity has led to an increase in the overall heat transfer coefficient as well as the individual heat transfer coefficient

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

Symbols: A- Area of heat transfer, m2, Q -heat transfer rate, Kw, Qc -heat transfer rate of cold streams, kW, Tci - temperature of cold streams at inlet port, K, Tco -temperature of cold streams at outlet port, K, Thi -temperature of hot streams at inlet port, K, Tho -temperature of hot streams at outlet port, _K, U- over all heat transfer coefficient, W/m^2 k.

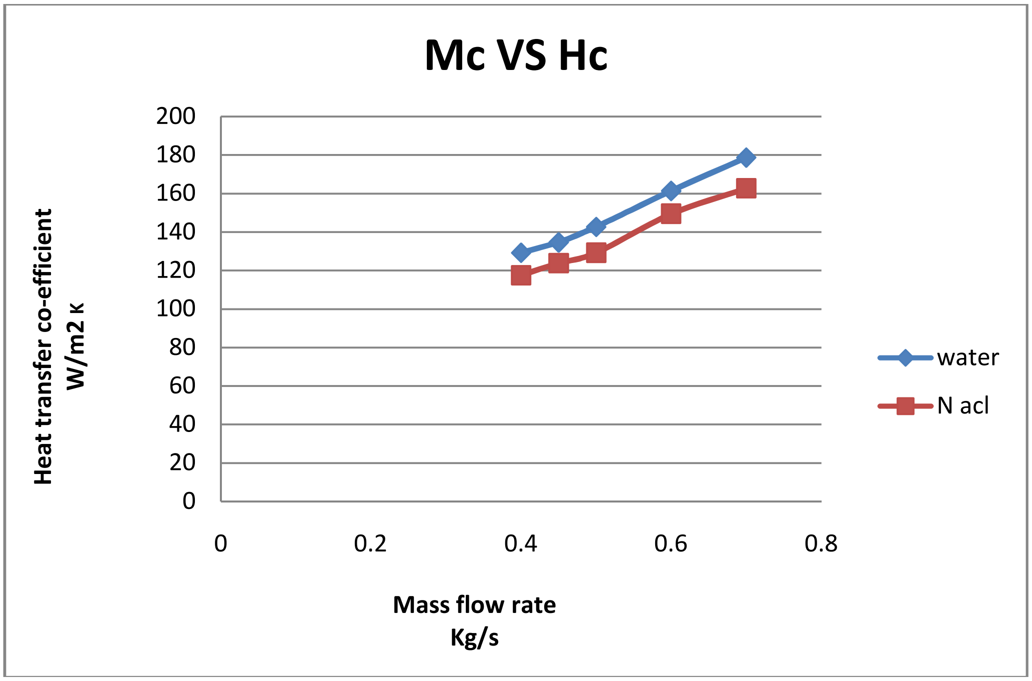

Figure-4
Comparison of Heat Transfer Coefficient of Nacl & Water at different flow rates

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