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RESEARCH ARTICLE

THE HEAT TRANSFER CHARACTERISTICS OF PLATE HEAT EXCHANGER WITH DIFFERENT CORRUGATION ANGLES

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ABSTRACT

Experiments to measure the heat transfer coefficient and the pressure drop in plate heat exchangers (PHEs) were performed pasteurization unit dairy industry. The test fluids we can use for hot fluid milk and cold fluid ammonia liquid. Plate heat exchangers with different chevron angles of 35^0, 30^0, 25^0, were used. Varying the flow rate, temperature, pressure, we measured the heat transfer coefficients and the pressure drops. Both the heat transfer coefficients and the pressure drop increased proportionally with the flow rate, temperature and the plate corrugation angle. 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. Correlations of the Nusselt number and the friction factor with the geometric parameters are suggested for the tested Plate Heat Exchanger.

INTRODUCTION

Plate heat exchangers (PHEs) were introduced in the 1930s and were almost exclusively used as liquid/liquid heat exchangers in the food industries because of their ease of cleaning. Over the years, the development of the PHE has generally continued towards larger capacity, as well as higher working temperature and pressure. Recently, a gasket sealing was replaced by a brazed material, and each thermal plate was formed with a series of corrugations (herringbone or chevron). These greatly increased the pressure and the temperature capabilities. The corrugated pattern on the thermal plate induces a highly turbulent fluid flow. The high turbulence in the PHE leads to an enhanced heat transfer, to a low fouling rate, and to a reduced heat transfer area. Therefore, PHEs can be used as alternatives to shell-and-tube heat exchangers. 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.

The heat transfer and the pressure drop characteristics in PHEs are related to the hydraulic diameter, the increased heat transfer area, the number of the flow channels, and the profile of the corrugation waviness, such as the inclination angle, the corrugation amplitude, and the corrugation wavelength. These geometric factors influence the separation, the boundary layer, and the vortex or swirl flow generation. However, earlier experimental and numerical works were restricted to a single-phase flow. Since the advent of a Brazed plate heat exchanger (BPHE) in the 1990s, studies of the condensation and/or evaporation heat transfer have focused on their applications in refrigerating and air conditioning systems, but only a few studies have been done. Much work is needed to understand the features of the two-phase flow in the Brazed plate heat exchanger (BPHEs) with alternative refrigerants. However (Xiaoyang *et al.* 1995) experimented with the two-phase flow distribution in stacked PHEs at both vertical upward and downward flow orientations. They indicated that non-uniform distributions were found and that the flow distribution was strongly affected by the total inlet flow rate, the vapor quality, the flow channel orientation, and the geometry of the inlet (Port Holger *et al.*1996) Theoretically predicted the performance of chevron-type PHEs under singlephase conditions and recommended the correlations for the friction factors and heat transfer coefficients as functions of the corrugation chevron angles.

Lee *et al.*, [1999][3] investigated the characteristics of the evaporation heat transfer and pressure drop in BPHEs with R404A and R407C.

(Kedzierski *et al.*1997) reported the effect of inclination on the performance of a BPHE using R22 in both the condenser and the evaporator. Several single-phase correlations for heat transfer coefficients and friction factors have been proposed, but few correlations for the two-phase flow have been proposed.

(Yan *et al.*1992) reported that the mass flux, the vapor quality, and the condensation pressure affected the heat transfer coefficients and the pressure drops.

(Bhowmik and Lee *et al* 2009) 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

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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* 1992) 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

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

(Murugesan M.P. and Balasubramani *et al* 2012) 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* 2013)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.

(Murugesan M.P. and Balasubramani *et al* 2013) 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.

(Kück and Hartmann*et al.* 2007) observed the application of nano-coatings with anti-adhesion effect which reduces the buildup of deposits on the surface of heat exchanger plates. Due to the reduction of adhesive forces, the operation efficiency of the plant can be significantly improved and the general hygienic situation of the product can be increased. Additionally, intensity and frequency of cleaning can be substantially reduced to achieve the desired degree of product quality.

(Sandu *et al.*1989) presents a considerable amount of work on milk fouling, in plate heat exchangers. He developed a detailed physic mathematical model where fouling kinetics and dynamics were de"ned based on experimental results.

(Bansal *et al.*2007) shows that the investigated the formation of CaSO4 deposit generated by a combination of crystallization and particulate fouling.

The main objective of this work was to experimentally investigate the heat transfer coefficients and the pressure drops inside plate heat exchanger (PHEs. Three plate heat exchanger (PHEs) with different chevron angles of 35^o, 30^o, and 25^0 were used. The geometric effects of the plate on the heat transfer and the pressure drop were investigated by varying the flow rate, and different temperature. From the results, the geometric effects, especially the chevron angle, must be considered to develop the correlations for the Nusselt number and the friction factor. Correlations for the Nusselt number and the friction factor with the geometric parameters are suggested in this study.

METHODS AND MATERIAL

Plate Heat Exchangers

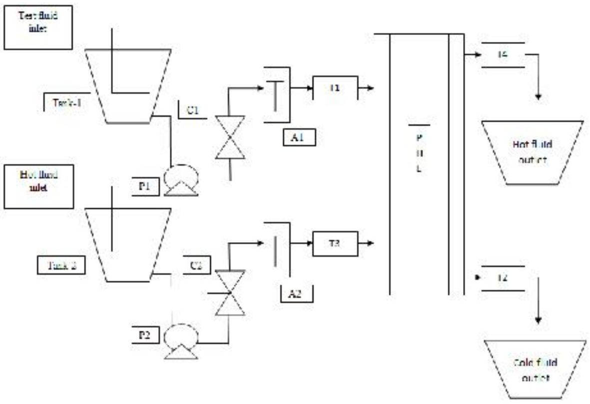
Three Plate Heat Exchangers PHEs with chevron angles of 35^o, 30^o, and 25^o were used as the test sections. The angles of corrugation were measured from the horizontal axis. The hot milk and cooling ammonia liquor were directed into the alternate passages between the plates through corner ports, creating counter flow conditions. The cooling ammonia liquor flowed from the bottom to the top of every other channel on the basis of a central channel. On the other hand, the milk flowed from the top to the bottom in the rest of them.

The experimental setup consists of plate type heat exchanger, rotameter, and thermocouples, pumps and tanks fig 1. The channel configuration is characterized by the corrugated channel height, the respective values of 1 m. In the plate type heat exchanger designed for 3 plate pack length with 100^OC work temperature and design pressure 25 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 10000 kg/hour. 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 $63\text{-}73^0C$ 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 1hp 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 1hp pump. The flow of cold and hot fluids was varied using control valves (c1 and c2) respectively for cold and hot fluids (milk and cold ammonia liquid). 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&C2-Control valve for hot and cold fluid, A1&A2-Area flow meter,
T1&T2-Test fluid inlet and out let temperature, T3&T4-Hot fluid inlet and outlet temperature,

Figure 1 Schematic of Experiment set up

Experimental Procedure

Pasteurization and sterilization process is one of the major heat treatment for dairy products. If the treatment destroys all microorganisms and enhanced product microbiologic safety with increase shelf time of products. 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 Fig. 1, using hot water about 63-73^{0}C as hot service fluids and the cold service fluid used milk as a hot fluid and ammonia liquid is a cold liquor 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.

RESULT AND DISCUSSION

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.

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

$$Q = m \times cp \times \Delta T$$

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.

$$Rh = \frac{\text{cross sectional area of the channel}}{\text{Perimeter of the channel in contact with the fluid}}$$

$$Rh = 2b$$

Reynolds number

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

$$N\ \mathrm{Re} = \frac{^\circ vDe}{\text{«}}$$

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)

$$\Delta T = \frac{(Tho - Tci) - (Thi - Tco)}{\ln \frac{(Tho - Tci)}{(Thi - Tco)}}$$

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

$$U = \frac{Q}{A \times \Delta T}$$

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

$$Q = U \times A \times \Delta T$$

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:

- The temperature and flow transients in the plate type heat exchanger are negligible.
- The heat losses to the surroundings are negligible.
- The fluids exist only in the liquid phase within the exchanger.
- The overall heat transfer coefficient is constant throughout the exchanger.

The overall heat transfer coefficient for a clean surface is

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

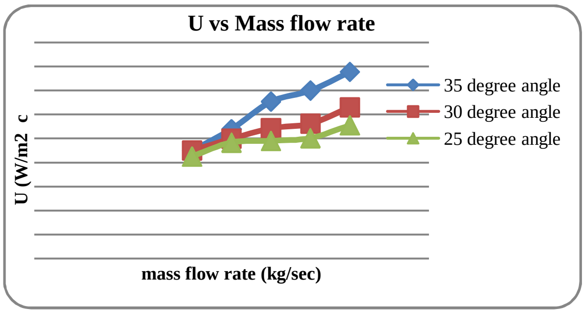


Fig. 2 The effect of mass flow rate in the plate heat exchanger with Different angles

Pressure drop

The total pressure drop in a plate heat exchanger is composed of the friction pressure drop of the channels (ΔPf) and the port pressure drop (ΔPp). We assumed that the pressure drop due to the elevation (gravity) change is negligible. The frictional pressure drop is calculated using the following equation:

$$\Delta p = \frac{2f}{ph_o} \cdot \frac{G\text{ ^}2}{\circ} NP$$

Pressure drop in a PHE consists of three contributions:

- frictional pressure drop within the plate passages
- pressure drop due to elevation change
- Pressure drop in inlet and outlet manifolds (port).

The frictional channel pressure drops for both fluids are obtained using the following equations:

$$\Delta p_f = 1 + \frac{2f\,Lp}{Dh} \cdot \frac{(G)^2}{\rho} NP$$

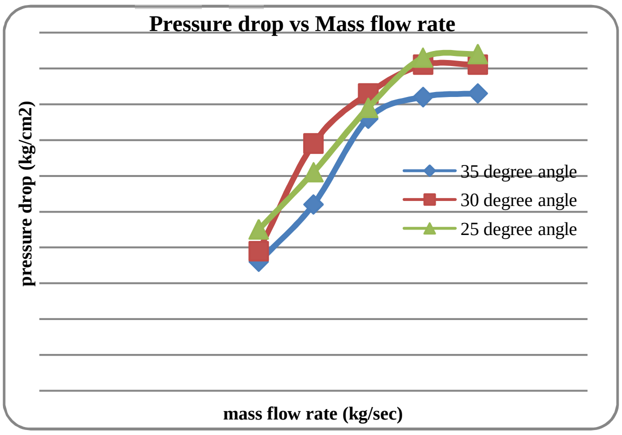


Fig.3 The effect of pressure drop in the plate heat exchanger with Different angles

Factors affecting for milk fouling

Fouling depends upon various parameters such as heat transfer method, operating conditions, heat transfer surface characteristics, hydraulic and thermal conditions and quality of milk. These factors can be broadly classified in to five major categories are milk composition, operating conditions in plate type heat exchangers type and characteristics of heat exchangers, presences of micro organisms, and location of fouling.

If we can follow of three methods are recognized for reducing of fouling in plate heat exchanger:

- Surface modification (surface coating)
- Preheating
- Cleaning

Surface modification

In this experimental study, Nano-composite coatings were used to reducing of fouling an inside the corrugated plate heat exchangers. It should be involved in pasteurization and sterilization of milk. An antifouling coating with low surface energy and reduce the precipitate formation. The main goal of the project work is done for application of new surface coatings (nanotechnology) to avoid fouling and improve treatment efficiency, simplify cleaning processes with lesser resources and chemical use, and increase the product quality.

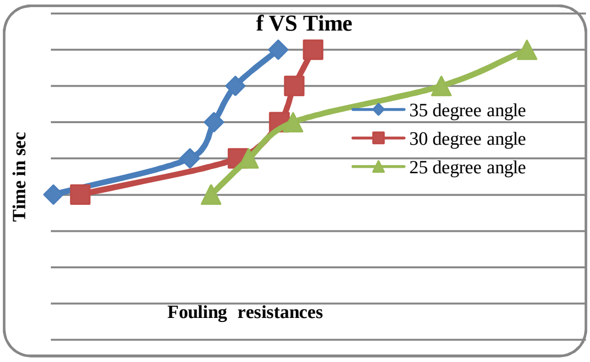
The test used for the investigation of milk adhesion and the stability of the coatings on corrugated plates. A number of coatings and surface treatments were tested. Heat exchanger plates coated with different nano-composites as well as electro polished plates installed in the heating section of the pasteurizer were tested. Significant differences were observed between coated and uncoated plates. The coated plates showed that reduced deposit buildup in comparison with the uncoated stainless steel plates. The time required for cleaning place with the coated plates was reduced by 75% compared to standard stainless steel plates.

Preheating

Normally the desired processing temperature are reducing directly after pasteurization, but sometimes it is necessary to cool and store the temporarily, before the final processing is done. Milk can be preheated before the heat treatment operations. It should be enhanced heat transfer efficiency and reduce fouling and also required for minimum time consumptions.

Cleaning

Cleaning process is must in milk pasteurization and sterilization process in the corrugated plate type heat exchanger from a dairy industry. In this process is done by circulating of detergents in a plate surfaces.



Fi.4 Effect of time vs fouling resistance

To achieve efficient cleaning, the corrugated plate type heat exchanger must be designed not only to meet the required temperature program, but also with cleaning in mind. If some passages in the heat exchanger are very wide range several parallel channels, the turbulence during cleaning may not be enough to remove fouling deposits efficiency. It has been consider that maintaining of cleaning process in the milk heat treatment operations in a corrugated plate type heat exchanger.

CONCLUSION

An experimental investigation has been conducted to measure the heat transfer coefficient and the pressure drop of milk and ammonia liquor in plate heat exchanger (PHEs) with chevron angles of 25^o, 30^o, and 35^o degrees. The effect of Chevron angles variation on the heat transfer coefficient is investigated. It found that, as the corrugation angle is reduced from (35^o, 30^o, 25 ^{o}), the flow passage become more tortuous and offers greater hydrodynamic resistance. The heat transfer carried by the fluid in a corrugated plate heat exchanger increased by increasing the total number of the corrugated plates due to the increase of the effective heat transfer area. With increasing the Chevron angle the friction factor increase, hence increasing the pressure drop. Heat transfer coefficient was studied for milk and ammonia. 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.

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Nomenclature

Abbreviations

PHE plate heat exchangers, PHEs plate heat exchangers, LMTD log mean temperature difference,

Symbols

A= heat transfer area of plate [m2]
b =mean channel spacing [m]
Cp= constant pressure specific heat [J/kg K]
D =diameter [m]
f =friction factor
G =mass flux [kg/m2s]
Ge =non-dimensional geometric parameter
G= gravitational acceleration [m/s2]
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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