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Experimental Studies in Plate Heat Exchanger

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ABSTRACT

At present plate heat exchanger's (PHE's) are being used extensively in the chemical, process and allied industries due to their numerous advantages. Heat transfer and associated frictional pressure drop in PHE are investigated experimentally in this study. The applied PHE is 14 plate, 2 fluid and single pass-flow heat exchanger in which fluids flow in counter flow direction. Heat transfer and pressure drop data were obtained for water flow rates varying between 0.0168 kg/s to 0.3378 kg/s. In this flow range increasing flow rates from 0.0168kg/s to 0.3378 kg/s (Increase in Reynold number from 85 to 1640) caused an increase in the pressure drop from 88 Pa to 10957 Pa. Empirical correlations are proposed to correlate the present data for the heat transfer coefficient and friction factor in terms of Reynolds number and Prandtl number.

Keywords: *Plate heat exchanger, Chevron plates, Heat Transfer, Pressure drops, Correlations, Experimentation.*

NOMENCLATURE

A	Total heat transfer area, m^2
Ae	Cross sectional area for flow between plates, m^2
Cpc	Specific heat of cold fluid, J/kg –K.
Cph	Specific heat of hot fluid, J/kg –K.
De	Equivalent diameter of plate, m.
H	Difference in height of manometric fluid in manometer, cm (h= hot , c =cold)
Lv	Length of plate, m.
Mc	Mass flow rate of cold fluid, LPM.
Mh	Mass flow rate of hot fluid, LPM
P	Frictional pressure drop, Pa
Pc	Corrugation pitch, m
Pr	Prandtl number, dimensionless
Q	% Variation in heat transfer between hot side and cold side.
Qc	Energy lost by cold fluid, W
Qh	Energy lost by hot fluid , W
Re	Reynold number, dimensionless
Tci	Inlet temperature of cold fluid, K
Tco	Outlet temperature of cold fluid, K
Thi	Inlet temperature of Hot fluid, K
Tho	Outlet temperature of Hot fluid, K
U	Overall heat transfer coefficient, W/m-K.
f	Corrected friction factor, dimensionless
f1	Friction factor calculated having property effect, dimensionless
β	Chevron angle of plate with vertical, degree.
μ	Dynamic viscosity (h = hot, c = cold),

N-s/m^2

ρ Fluid density, kg/ m^3

Abbreviations

LMTD Log mean temperature difference

LPM Liters per minute

I. INTRODUCTION

To improve the efficiency of any production process in a chemical or process industry, energy has to be recovered from a high temperature process stream to heat a colder stream by suitable heat transfer equipment. The choice of most suitable type of heat exchanger is vital to minimize the total plant costs including capital, maintenance and operating costs. According to market analysts [1], plate heat exchanger has a market share of 13.1%. This corresponds to second position after shell and tube heat exchanger, which holds 39.9%. The demand for plate heat exchangers is constantly increasing due to its numerous advantages [1], such as:

- Low space requirement due to compact size, low weight;
- High overall heat transfer coefficient due to intensive turbulence induced by the corrugated plate surface;
- Low fouling tendency due to high shearing forces and turbulence;
- Easy maintenance and dismantling for inspection or cleaning.

Although PHE are commercially available, pressure drop and heat transfer data is rather limited in the literature. An extensive literature considers the geometry of PHEs and various plate types. In 1986, Shah and Focke [2] summarized all pertinent information on PHE. They outlined step-by-step procedure for rating and sizing problems. They also discussed correlations obtained by various researchers in terms of Reynold number.

In 1992, Zaleski and Klepacka [3] proposed a calculation method for PHE. Based on procedure, they presented some useful charts. In 1996, Martin [4] has shown that for chevron configuration pattern, the inclination angle of the crest and furrows of that sinusoidal pattern relative to the main flow direction has been the most important design parameter with respect to fluid friction and heat transfer. Leveque equation was used for predicting heat transfer coefficient. It is shown by comparison that this prediction is in good comparison with experimental observation quoted in literature. In 1999, Marcus [1] throws light on various plate heat exchangers and their fabrication material with respect to typical application. In 2000, Sterlow [6] presented a general calculation method for the steady state simulation of PHE of any type required. In 2001, Bellas etal [7] carried out experimental investigations on the pressure drop and the heat transfer for propylene /water ice slurry flowing in commercial PHE. In this study experimental investigations on heat transfer and pressure drop for a water – water PHE have been presented.

II. EXPERIMENTAL SETUP

A Plate heat exchanger is assembled in an experimental rig for performance study as shown in Fig..1 and the various components of the test rig are listed in Table 1. The flow type is counter-current with U-flow arrangement. Hot fluid was allowed to flow in vertically upward direction while cold fluid in downward direction through PHE. Water is used as a heat transfer media in the PHE. The plate dimensions are 357 × 92 mm with 32 mm port diameter on the four corners providing 0.03284 square meter area for heat transfer on each side of plates. Plates have mean channel flow gap of 2.4 mm and corrugation pitch of 12 mm.

Chevron angle for plates is 60^0 with vertical. The material used for construction of plates is 0.6 mm AISI 316 sheet. The gaskets are made from 5-mm thickness Nitrile rubber sheet. Copper - Constantan thermocouples (T-type) with least count of 0.1^{0}C, were used to measure temperatures. Rotameters were used for flow measurement with 0.5 LPM as the least count. The uncertainty in friction factor due to measuring instruments resolution comes out to be 5%. All thermocouples and rotameters were calibrated before experimentation.

III. DATA ANALYSIS

The experimental procedure used for obtaining heat transfer and pressure drop data is as follows:

1. The hot water flows in upward direction through seven plates. Hot water inlet to PHE was taken from heating tank. Outlet was given back to heating tank forming a closed circuit (Fig. 1)
2. The cold fluid flows in downward direction through six plates. Cold water inlet was taken from cooling tower. Outlet from PHE was given back to cooling tower (Fig. 1).
3. For experimentation, flow in one of the circuits was kept fixed and flow rate in other circuit was varied.
4. Heater input was controlled by rheostat. It also helped in quickly attaining steady state. At steady state Thi, Tho, Tci, Tco, Mc, Mh, Hh, Hc were measured.

Above procedure was repeated for various flow rates in hot and cold water circuits. An energy balance check was applied to ensure the correctness of the data. In PHE, the total heat exchange between hot and cold fluid should be approximately the same, as heat exchanger in experimental rig was kept well insulated to prevent heat transfer between exchanger and surroundings.

$$Qh=Mh\ Cph\ (Thi-Tho) \quad (1)$$

$$Qc=Mc\ Cpc\ (Tco-Tci) \quad (2)$$

$$Qm = \frac{Qh + Qc}{2} \quad (3)$$

% Variation in heat transfer

$$Q = \frac{Qh - Qm}{Qm} \quad x \quad 100 \qquad (4)$$

Only those data points, for which Q fall within 20 % were considered for analysis. From known measured pressure drop, frictional pressure drop and then corresponding friction factor was calculated from following expression [6] :

$$p = \frac{f1 \quad Lv}{De} \frac{Mh^{2}}{(NAe)^{2}} \frac{1}{2\rho h} \qquad (5)$$

N= Number of flow channels.
f1 friction factor calculated at given properties of fluid.
The corrected friction factor f devoid of property correction effect is obtained as [2]

$$f = f1\left(\frac{\mu h}{\mu w}\right)^{m} \qquad (6)$$

Where m= constant [2]
Friction factor data is plotted against Reynold number.
To obtain a correlation for friction factor, similar to that cited in the literature i.e. $f = C1\ Re^{C2}$, a graph (Fig. 2) is plotted fitting power trendline to data points. The correlation obtained is as follows:

$f = 0.993\ Re^{-0.2208}$ (84 [Re[1640 & $\beta = 60^{0}$) (7)

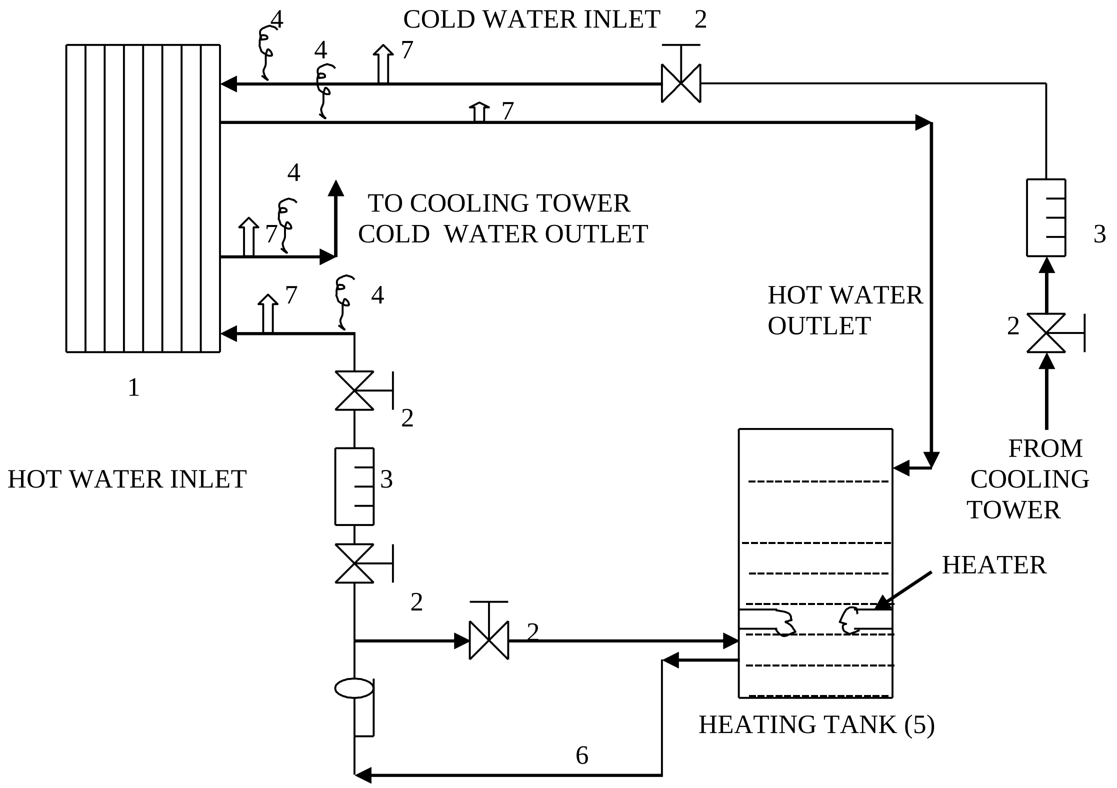

Fig.1 Schematic of experimental rig
Table 1 Experimental Rig Components

S.NO.	PART	QUANTITY	SPECIFICATION
1	Plate Heat Exchanger	1	U-type
2	Globe Valve	5	12.7 mm diameter
3	Rotameter	2	10 LPM, 20 LPM
4	Thermocouple	4	Copper -Constantan
5	Heating Tank	1	7 kW
6	Centrifugal pump	1	0.373 kW
7	Differential Manometer	2	Inclined mercury manometer

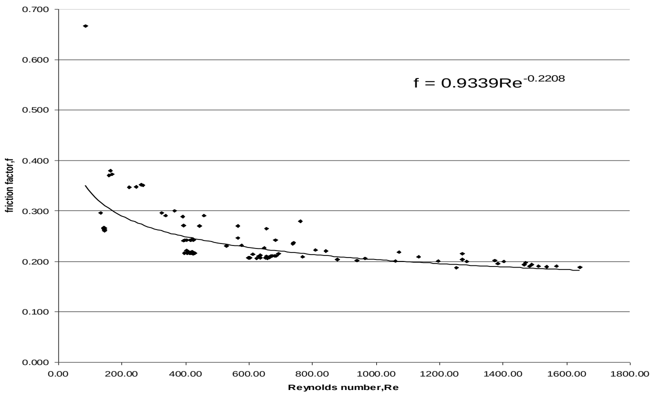

Fig. 2 Power law trend line fitted to friction factor data

IV. ANALOGY BETWEEN HEAT TRANSFER AND FRICTION FACTOR

Leveque analogy was used initially to relate friction factor and heat transfer. The Leveque equation [4] is well known equation for the heat transfer through developing thermal boundary layers in a hydrodynamic developed laminar duct flow. The Leveque equation applies nicely to PHE [4].

The generalized Leveque equation is

$$Nu = 0.404\left(\frac{f.\mathrm{Re}^2.\mathrm{Pr}.d}{L}\right)^{\frac{1}{3}} \qquad (8)$$

Where $\frac{d}{L} = \frac{De}{Pc}.\sin 2\beta$ (9)

De=4.68 mm
Pc=12 mm
β = 60
d/L=0.337

Using above values in Leveque equation, following correlation for heat transfer is obtained.

$Nu=0.28\ Re^{0.59}\ Pr^{1/3}$ (10)

To verify above correlation, heat transfer coefficients were calculated from above correlation and then again from it heat transfer Qr is calculated by using

Qr=U Ae LMTD (11)

It was found that for present experimental data variation between Qr and Qm comes out to be 67.8 %. Hence above heat transfer correlation obtained by Leveque analogy does not suit the present experimental data. A second approach is used by considering Qm as energy transfer in process and calculating heat transfer coefficients values from it. Then experimental data is fitted to a standard form of heat transfer correlation as follows :

$Nu = C\ Re^{2/3}\ Pr^{1/3}$ (12)

Using the data, the calculated value of C comes out to be 0.151. Therefore the suggested correlation for heat transfer coefficient is :

$Nu=0.151\ Re^{2/3}\ Pr^{1/3}$ (13)

V. CONCLUSIONS

Experimental measurements have been carried out in the present study to develop the correlations for friction factor and heat transfer characteristics for chevron type of PHE.

$f=0.993\ Re^{-0.2208}$ (84[Re[1640 (14)

$Nu=0.151\ Re^{2/3}\ Pr^{1/3}$ & $\beta = 60^0$) (15)

Also validity of Leveque analogy has been tested. Leveque analogy does not fit so precisely to present experimental data and hence it can only be used when no other information is available. Friction and heat transfer data obtained here can be used for future analysis of chevron type of heat exchanger with $\beta=60^0$.

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