COMPARATIVE ANALYSIS OF SPIRAL HEAT EXCHANGER AND GASKETED PLATE TYPE HEAT EXCHANGER

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Abstract: Present paper reports theoretical analysis of Spiral heat exchanger(SPHE) and Gasketed plate heat exchanger (PHE), to investigate its efficacy of heat transfer. Experimental investigation of effect of chevron angle of plate in Gasketed PHE on thermal and hydraulic performance is carried out. The Spiral heat exchanger when compared with Gasketed plate heat exchanger (PHE), the performance of PHE is found better than SPHE. Overall heat transfer coefficient (U) is increased by 86.8% by GPHE over SPHE. Performance of PHE is investigated for two different plate chevron angles, 65° and 30°. Overall heat transfer coefficient is increased by 26% for chevron angle 65° as compared to 30°. Also, pressure drop is increased by 12.77% when chevron angle increased from 65° to 30°.

Keywords: Spiral Heat Exchanger, Plate Heat Exchanger, Chevron angle.

1. INTRODUCTION

The Spiral Heat Exchangers (SHE), which has a helical (coiled) tube configuration and a pair of flat surfaces that are coiled to form two channels in a counter-flow direction. **M. P. Nueza et al. [1]** studied the design of the spiral heat exchangers. They made it clear that the heat transfer rate of the spiral heat exchanger is more than that of the other exchangers (Double Pipe Heat Exchanger, Tubular Heat Exchanger, Shell and Tube Heat Exchanger). The Spiral Heat Exchanger used in the industry has a limitation because of its limited temperature and pressure of 500°C and 25 bar, the cleaning of this type of heat exchanger is difficult whereas its maximum flow rate is limited up to 350 m^3/hr **[2].** Considering these limitations of Spiral type heat exchanger, some other type of HE is to be suggested. Plate type Heat Exchanger is advantageous considering its compact size, high efficiency, easy for cleaning, requires less heat transfer area (less than 20-30%). Various experimental and computational investigations are carried out to analyse performance of Gasketed plate type heat exchanger [1,2,3,4,5,6]. **Khan et al. [3]** have experimentally investigated effect of Reynolds number, Prandtl number and Chevron angle on heat transfer coefficient and pressure drop. They reported the effect of the above factors on heat transfer coefficient and proposed new correlation as a function of Nusselt number, Reynolds number, Prandtl number and chevron angle. **Xiao-Hong Han et al. [4]** experimentally and numerically investigated the temperature, pressure, and velocity in the different regions of the flow in chevron corrugated plate heat exchanger. **Paisarn Naphon et al. [5]** observed the effect of constant heat flux on heat transfer coefficient and pressure drop in a corrugated channel. A significant effect was observed due to the recirculation zones formed due to the corrugated surface. **Ting Chen [6]** observed the variation in heat transfer coefficient and effectiveness using two chevron angles of different angle with water and also with Nano fluid. Nano fluid technology has been rapidly developing over the last two decades. In this paper, the performance of a lithium bromide (Li-Br) solution with and without nanoparticles in plate heat exchanger (PHE) for various chevron angles and mass flow rates was investigated. The results showed that 60°chevron angle plate has 100% higher heat transfer coefficient than 30° corrugated plates and 60°plate has 70% higher effectiveness than 30° corrugated plates. **Abdullah Yildiza & Mustafa Ali Ersözb [7]** compared the theoretical results of Energy and Exergy analyses of a plate type heat exchanger experimentally. Hot mass flow rate was kept constant and the cold mass flow rate was varied during experimental investigation**. Naphon [8]** discussed effect of varying cold and hot fluid mass with shell and helically coiled tube unit with two different coil diameters. As the hot mass flow rates of water increases the cold-water outlet temperature increases. The friction factor decreases when hot mass flow rates increases. A significant effect of inlet and outlet mass flow rates and hot water temperature is observed on the effectiveness. The heat transfers by analytical and experimental method had a difference of 12%. **ZhenHua Jin et al. [9]** designed and estimated the pressure drop of PHE. The investigation concluded that the pressure drop in PHE is comparatively lesser than the shell and tube heat exchanger. **Aydın Durmus et al. [10]** he investigated the heat transfer in plate heat exchanger and he found that the heat transfer rate in plate heat exchanger is much more than that of conventional heat exchangers.

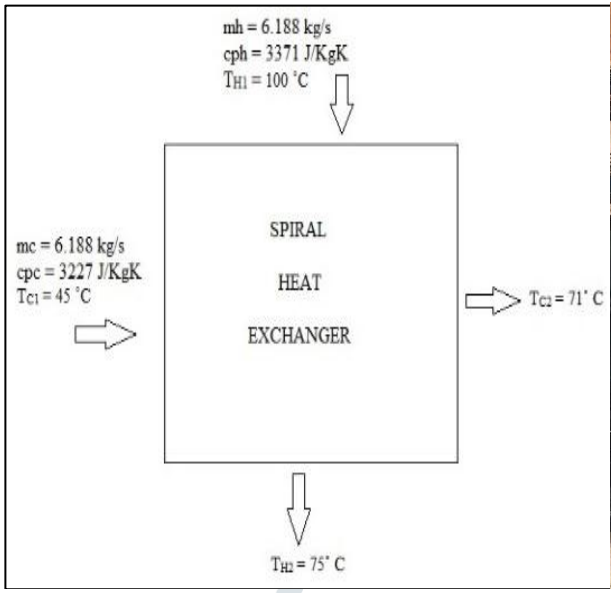
Considering advantages of plate type heat exchanger present work is focused on theoretical analysis of spiral and Gasketed plate type heat exchanger in view of possible replacement of spiral heat exchanger by Gasketed plate type heat exchanger. For this analysis, spiral heat exchanger presently used in Jindal South West (JSW) Pvt. Ltd. Dolvi Works, Maharashtra is considered. Also, experimental investigation of effect of chevron angle on thermal and hydraulic performance is carried out. For this study two chevron angles selected are 65° and 30°.

2. METHODOLOGY

2.1 Theoretical Analysis

The Spiral Heat Exchanger in used in the JSW Steel and Power Dolvi Works in ammonia decomposition system. The Spiral HE uses Ammonia liquor for its hot and cold fluid side at different concentrations i.e. Rich ammonia liquor and Lean ammonia liquor. The ammonia which is the working fluid contains various particles such as dust, dirt and contaminants, when gets deposited inside the HE reduces the rate of heat exchanger. Performance of Spiral heat exchanger and Gasketed plate type heat exchanger is analyzed theoretically for the actual data of HE

which is shown in Fig. 1. Photograph of spiral HE is shown in Fig. 2



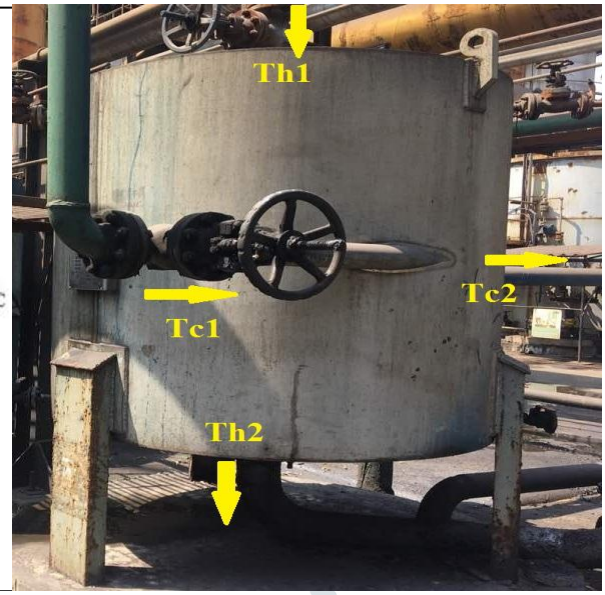


Figure 1: Schematic diagram of Spiral Heat Exchanger **Figure 2: Photograph of Spiral Heat Exchanger**

2.1.1 Spiral Heat Exchanger

The theoretical analysis of the spiral heat exchanger is done by the using following equations,

$Q_H = \dot{m}_H C_{pH} (T_{H1} - T_{H2})$ (1)

$Q_C = \dot{m}_C C_{pC} (T_{C2} - T_{C1})$ (2)

$Q_{avg} = \frac{Q_C + Q_H}{2}$ (3)

$LMTD(\Delta T_{lm}) = \frac{\Delta T1 - \Delta T2}{\ln \Delta T1/\Delta T2}$ (considering counter flow) (4)

Overall heat transfer coefficient is calculated using following equation,

$\frac{1}{U} = \frac{1}{h_C} + \frac{1}{h_H} + \frac{t}{K} + R_i + R_o$ (5)

Reynolds number calculation for hot fluid to determine the heat transfer coefficient,

$R_{eH} = \frac{G\,De}{u}$ (6)

$G = \frac{\dot{m}H}{H\,x\,s}$ H =1.5 m, s = 0.01 m (fixed value) (7)

$D_e = 2 \times s$ (8)

If Re of the fluid is turbulent, the correlation as given by Jamshid Khorshidi, Salman Heidari [14] issued as given below

$h_H = [\,1+3.54 \times \frac{De}{Dh}\,] \times 0.023 \times C \times G \times (R_{eH})^{-0.2} \times (P_r)^{-2/3}$ (9)

To Calculate the area for spiral type heat exchanger following equation is used,

$Q_{avg} = U \times A \times (\Delta T_{lm})$

2.1.2 Gasketed Plate Type Heat Exchanger

Data used for the spiral heat exchanger as shown in Fig. 1, is used for the analysis of Gasketed plate type heat exchanger. Area of heat transfer estimated from theoretical analysis of spiral heat exchanger is used as input parameter for analyzing PHE. Dimensions of the plate are selected as given bellow.

Plate dimensions

Material	Stainless Steel (3016L)
Thermal conductivity (k)	16.2 w/mK
Thickness	0.5 mm
Dimensions	395 x 122 mm

Port diameter	32 mm
Chevron angle (ß)	65° (w.r.t. vertical)
Enlargement ratio (Ø)	1.17
Effective area per plate	433.93 cm^2
Single plate heat transfer area (A_1)	0.03375 m^2
Number of plates	959 (A_{Spiral}/ A_1)

Following are the theoretical correlations of the plate type heat exchanger,

Pitch, $p = \frac{L}{N}$

Now, The effective number of plates (N_e),

$N_e = N - 2$

Mean channel flow gap (b)
$b = p - t$

Effective channel width(L_w),
$L_w = L_h + D_p$

Calculating the hydraulic diameter for plate type heat exchanger,
$D_h = \frac{2\,x\,b}{ø}$
Number of channels per pass(N_{cp}),
$N_{cp} = \frac{N-1}{2Np}$
N_p = Number of passes

$G = \frac{mch}{Ncp \text{ x } b \text{ x } Lw}$

Where, $mch = \frac{m}{Ncp}$

$R_{eh} = \frac{Gh \text{ x } Dh}{uh}$

Correlation used for estimating heat transfer coefficient on hot and cold side is given bellow,

$N_u = C_h \text{ x } (R_e)^n \text{ x } (P_r)^{0.33}$ C_h and n are dependent on chevron angle of the plates [11]

$N_u = \frac{hh \text{ x } Dh}{k}$
Now as we know the values of hot side and cold side heat transfer coefficients, the overall heat transfer coefficient of the plate type heat exchanger is given by,

$\frac{1}{U} = \frac{1}{h_C} + \frac{1}{h_H} + \frac{t}{K} + R_i + R_o$

$Q = U \text{ x } A \text{ x } (\Delta T_{lm})$

Experimental methodology

Experimental investigation of effect of chevron angle of plate on thermal and hydraulic performance is carried out. Photograph and schematic of experimental setup of plate type heat exchanger is shown in Fig. 3 and 4 respectively. Mass flow rates of hot and cold fluid is varied from 1 to 4 lpm. Temperatures are recorded using thermometer flow rate is monitored using rotameter and differential pressure is recorded using mercury manometer. Two plate configurations are used with chevron angle, 65° and 30°. Photograph of the corrugated plates are shown in Figure 5. Recorded temperature and flow rate is used for the analysis using the equations mentioned in the methodology

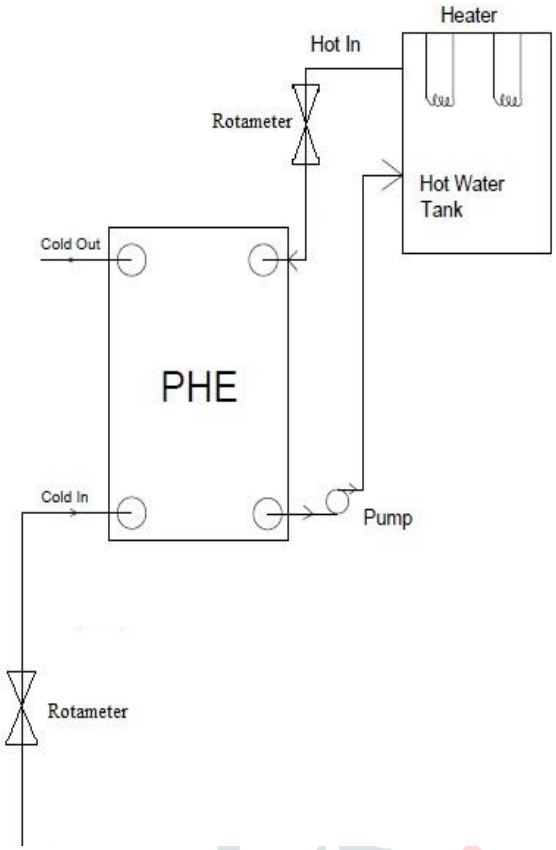


Figure 3: Schematic layout of experimental Setup of Gasketed PHE **Figure 4: Photograph of Gasketed PHE**

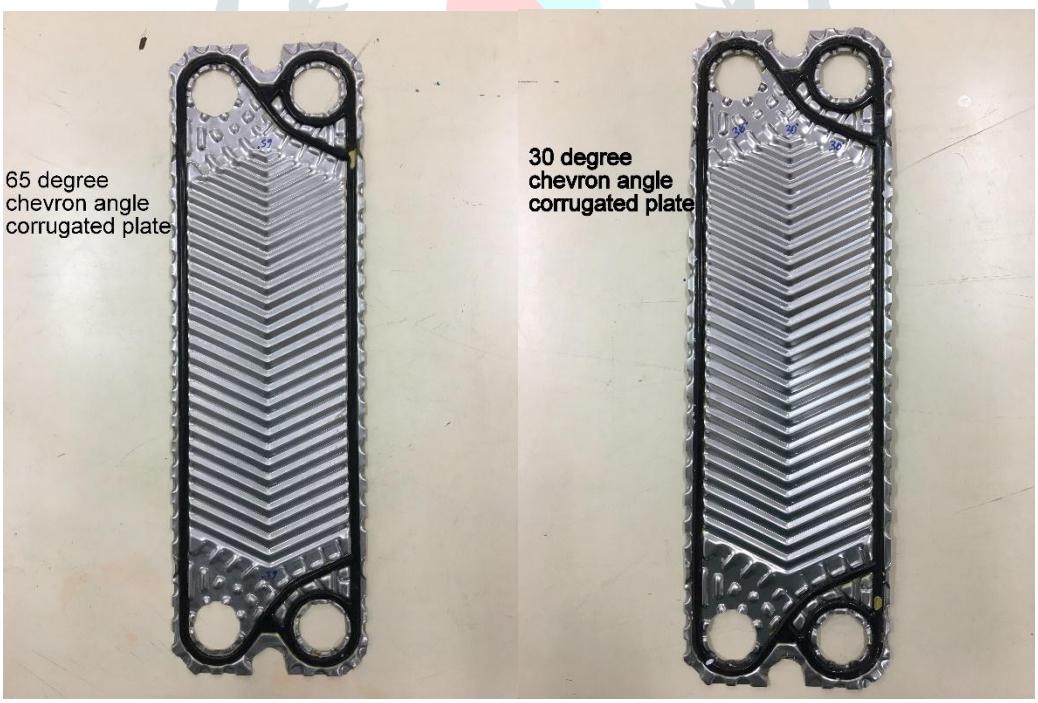


Figure 5: Photograph of plates of plate heat exchanger

3. RESULTS AND DISCUSSION

3.1 Theoretical results

Comparison of Spiral and Plate Heat Exchanger

Using the industry data and equations mentioned in the methodology the overall heat transfer coefficient is estimated as641W/m^{2}Kand corresponding area of the Spiral Heat Exchanger calculated is 32.36 m^2. However, we have estimated overall heat transfer coefficient of SHE at different Re number as shown in Fig. 6. Reynolds number is varied by varying mass flow rate. Overall heat transfer increases with increase in Reynolds number. With selected plate dimensions as mentioned in Table we calculated the Number of plates for the same heat transfer area (32.36 m^2) as 959.Using these plates, Overall Heat Transfer coefficient estimated for Plate Type Heat Exchanger is 1341 w/m^{2}K. Variation of U

with Reynolds number for PHE is shown in Fig. 7. Thus, comparison of U for spiral and PHE shows that performance of PHE is better than the SPHE as the Overall heat transfer coefficient is higher for lower value of Reynolds number in GPHE.

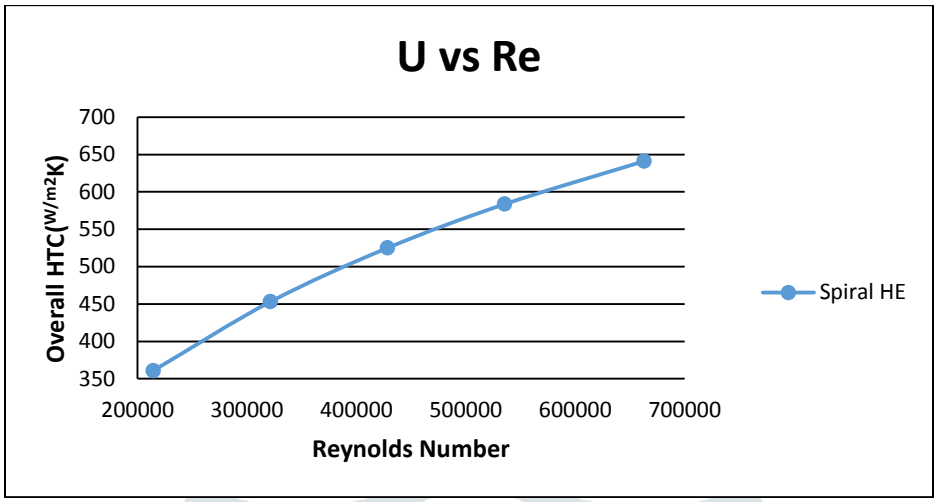


Figure 6: Variation of Overall Heat Transfer Coefficient with Reynolds Number for Spiral HE

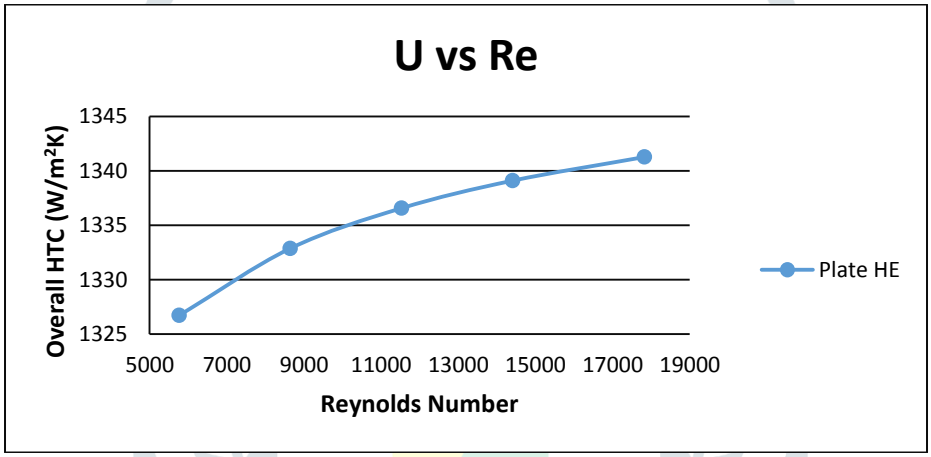


Figure 7: Variation of Overall Heat Transfer Coefficient with Reynolds Number for Plate HE

Observations were taken by varying the hot mass flow rates and the cold mass flow rates at 5 minutes 10 minutes and 15 minutes so as to ensure continuous flow of the fluid through the heat exchanger and its plates and throughout the system.

The variation of overall heat transfer coefficient with the Reynolds number on cold fluid side at varying mass flow rates on cold fluid side keeping the hot fluid side constant, the same is carried out both for 65°& 30° plates and is shown in a graphical manner below,

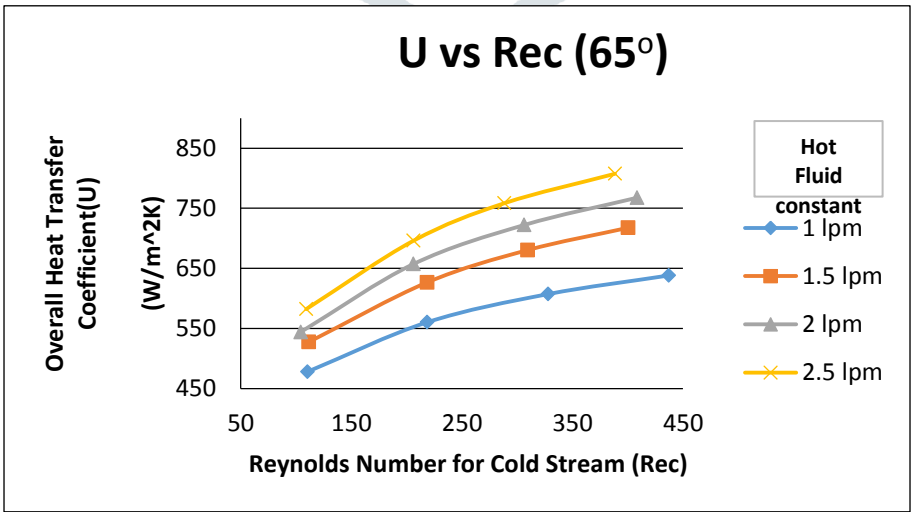


Figure 8: Variation of Overall Heat Transfer Coefficient with Reynolds Number for 65°plates (Mh=constant)

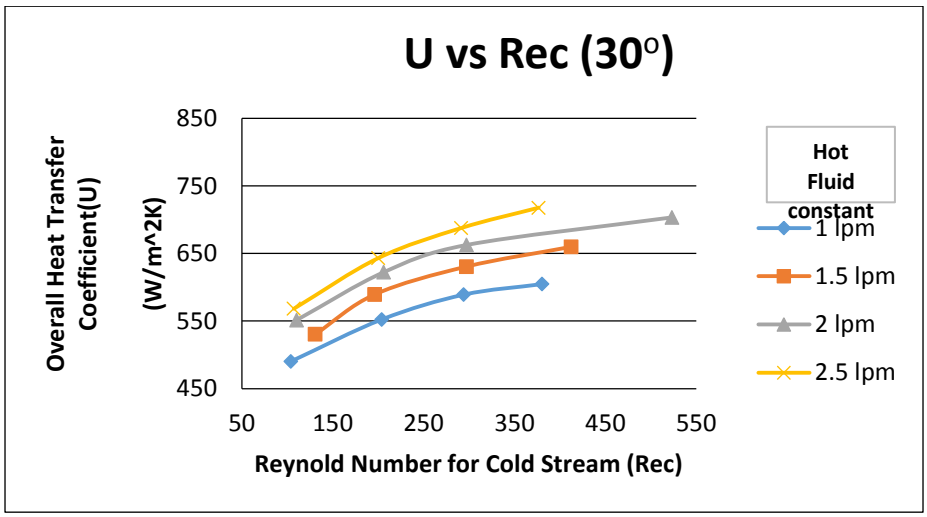


Figure 9: Variation of Overall Heat Transfer Coefficient with Reynolds Number for 30° plates (Mh=constant)

The variation of overall heat transfer coefficient with the Reynolds number on hot fluid side at varying mass flow rates on hot fluid side keeping the cold fluid side constant, the same is carried out both for 65°& 30° plates and is shown in a graphical manner below,

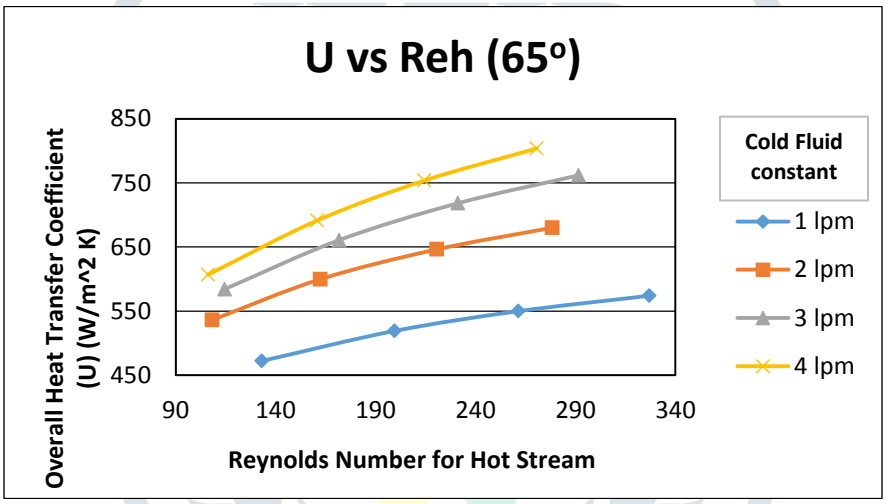


Figure 10: Variation of Overall Heat Transfer Coefficient with Reynolds Number for 65° plates (Mc=constant)

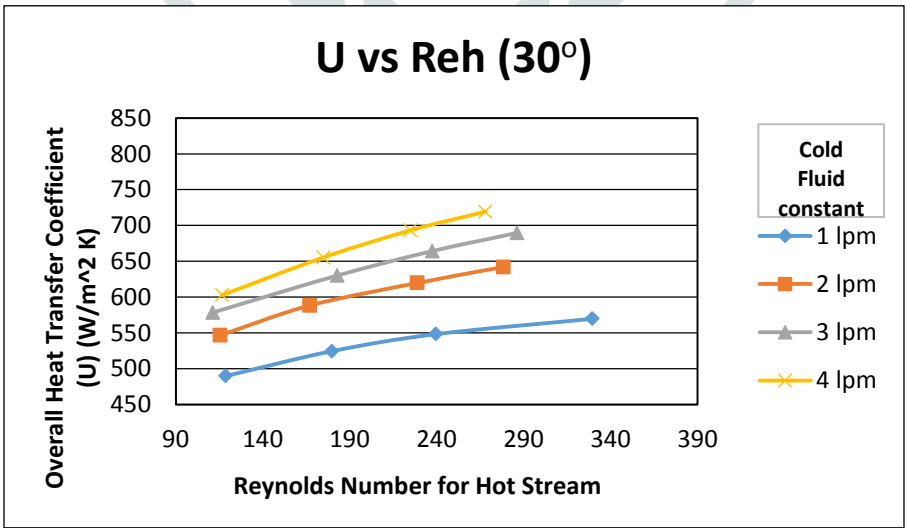


Figure 11: Variation of Overall Heat Transfer Coefficient with Reynolds Number for 30° plates (Mc=constant)

As we have done the analysis of pressure changes according to time, especially those associated with the changes in mass flow rates of the working fluid. Pressure is the amount of force applied perpendicular to the surface of an object per unit area. Below to investigate the changes in the pressure drop of the working fluid the graph is plotted for the pressure drop both for 65 and 30-degree plates with the mass flow rates varying from 1-10 for cold fluid side and the results are shown,

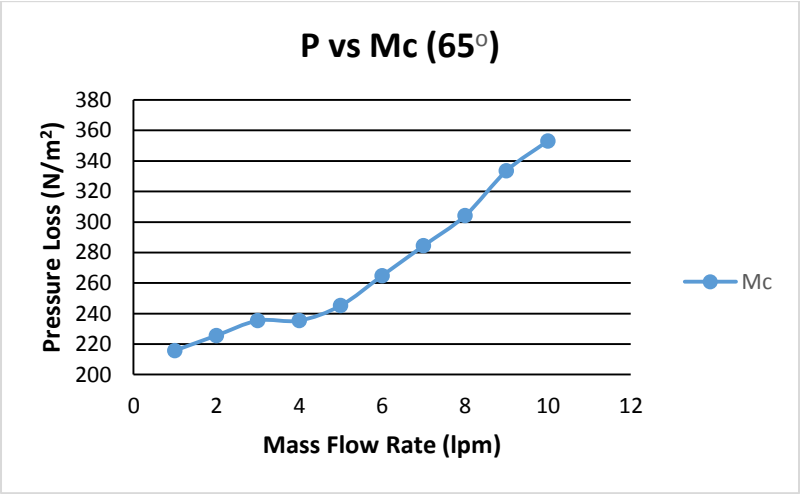


Figure 12: Variation of Mass Flow Rate with the Pressure changes for 65-degree plates

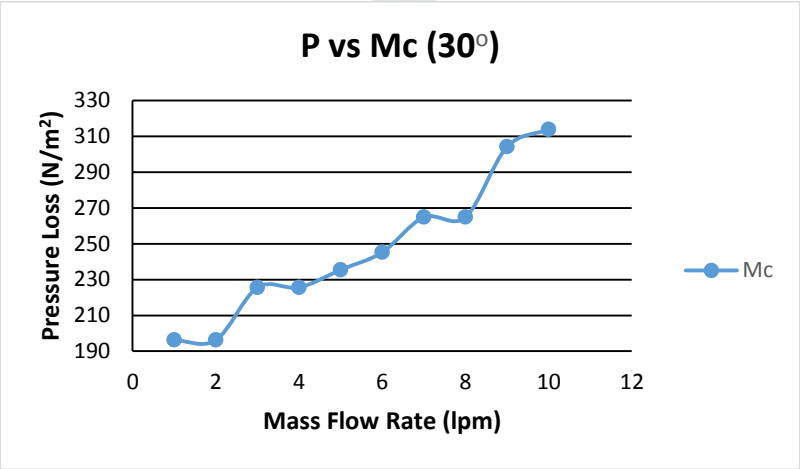


Figure 13: Variation of Mass Flow Rate with the Pressure changes for 30-degree plates

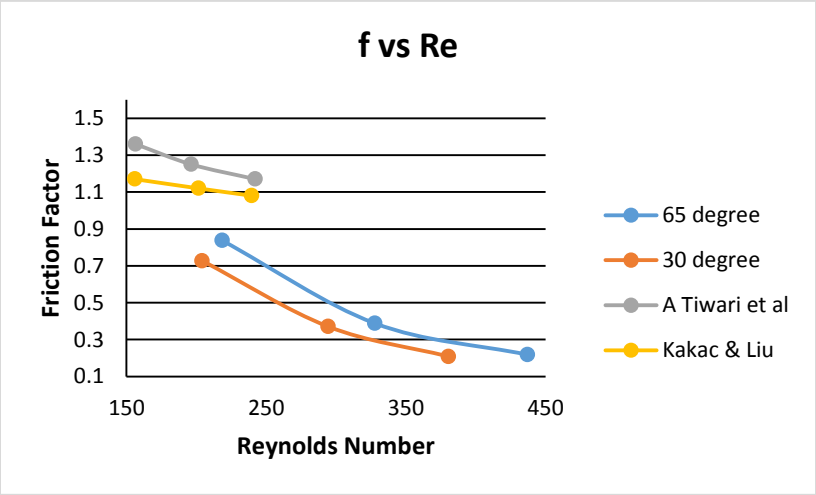


Figure 13: Variation of Friction factor with the Reynolds number

CONCLUSION

Present investigation confirms that GPHE has an advantage over SHE as it is seen that heat transfer with GPHE is increased by 86.8%. Plate geometry changes the rate of heat transfer. Plate with chevron angle 65° increases rate of heat transfer by 26% as compared to 30° chevron angle. This is mainly due to the change in flow characteristics. But increasing chevron angle increases the pressure drop which will increase requirement of pumping power. Thus, GPHE with proper plate geometry is a better option than SHE in certain applications.

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NOMENCLATURE

m_h = Mass flow rate of hot fluid, (kg/s)
m_c = Mass flow rate of cold fluid, kg/s
C_{ph} = Specific heat of hot fluid, J/KgK
C_{pc} = Specific heat of cold fluid, J/KgK
D_e = Equivalent diameter of flow channel, m
D_h = Hydraulic diameter, m
h_h = Heat transfer coefficient on hot fluid side, W/m^2K
h_c = Heat transfer coefficient on cold fluid side, W/m^2K
Q = Heat transfer, W
K = Thermal conductivity of the material, W/mK
T_{h1} = Inlet temperature of hot fluid, ˚C
T_{h2} = Outlet temperature of hot fluid, ˚C
T_{c1} = Inlet temperature of cold fluid, ˚C
T_{c2} = Outlet temperature of cold fluid, ˚C
t_w= Wall thickeness of spiral, m
R_{eh} = Reynolds number of hot fluid side
R_{ec} = Reynolds number of cold fluid side
ΔT_{lm} = Log Mean Temperature Difference, ˚C
Q_h = Hot fluid side heat transfer, W
Q_c = Cold fluid side heat transfer, W
A = Area of heat exchanger, m^2
s = Thickness of the duct, m
ϱ = Density (Kg/m^3)
v = Velocity (m/s)
d = Diameter (m)
u = Dynamic viscosity (Ns/m^2)
G = Mass velocity (Kg/m^2s)
m = Mass flow rate (Kg/s)
H = Hieght of spiral heat exchanger (m)
u_f = Dynamic viscosity at T_{avg} (Ns/m^2)
u_w = Dynamic viscosity at wall temperature (Ns/m^2)
P_r = Prandtl number
N_e = Effective number of plates
L_{eff} = Effective flow length (m)
b = Mean channel flow gap (m)
L_w = Effective channel width (m)
N_{cp} = Number of channels per pass
p = Plate pitch (m)

D_p = Diameter of the port on the plate (m)
R_i = Internal fouling resistance (m^2K/W)
R_o = External fouling resistance (m^2K/W)
ΔE_h = Exergy loss at hot fluid side (KW)
ΔE_h = Exergy loss at hot fluid side (KW)
S_{hi} = Entropy of hot water inlet temperature, (J/K)
S_{ho} = Entropy of hot water outlet temperature, (J/K)
S_{ci} = Entropy of cold water inlet temperature, (J/K)
S_{co} = Entropy of cold water outet temperature, (J/K)