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PERFORMANCE COMPARISON OF CORRUGATED PLATE HEAT EXCHANGER WITH FLAT PLATE HEAT EXCHANGER – A THEORITICAL ANALYSIS

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ABSTRACT

A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This is the chief advantage over an orthodox heat exchanger in that the fluids are bare to the much larger surface area because the fluids spread out the plates. This eases the heat transfer, and increases the speed of the temperature change to a great extent. This research work is focused on analyzing the corrugated plate heat exchanger for water as a working fluid. This research concern with theoretical performance investigation of corrugated plate heat exchanger with evaluation of convective heat transfer coefficient, overall heat transfer coefficient, and comparison of previous data with flat plate heat exchanger. The plates used for this research work is formed of stainless steel having a thickness of 1mm. The geometry of the plate is of sinusoidal and every plate is 7mm apart. It is designed to withstand with 85^{o}C temperature. The main intention of this work is to study the effects of these parameters on performance of the corrugated plate heat exchanger.

Key Words*: *Corrugation Angle, Local Heat Transfer Co-Efficient, Overall Heat Transfer Co-Efficient, Plate Heat Exchanger

I. INTRODUCTION

Heat exchangers are one of the widely used devices in industries. There are various types heat exchangers are available and used in various applications like process, petroleum, food industry, milk pasteurization, air conditioning, refrigeration, among others. The original idea for the plate heat exchangers was patented in the latter half of the nineteenth century, the first commercially successful design being introduced in 1923 by Dr. Richard Seligman. The basic design remains unchanged, but continual refinements have boosted operating pressures from 1 to 25 atmospheres in current machines. Recent developments have introduced the double wall plate. The plates are grouped into passes with each fluid being directed evenly between the paralleled passages in each pass. An important aspect to take into account when evaluating the heat exchanger is the formation of corrugation within the heat exchanger. Greater heat transfer enhancement is obtained from chevrons for a given increase in pressure drop.

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II. RESEARCH OBJECTIVES

Exchangers are easily one of the most important and widely used pieces of process equipment found in industrial sites. Regardless of the particular industry in question, it will likely require some type of temperature regulation, and for that exchangers are likely to come into play. Exchangers may be used for either heating or cooling, therefore increasing the effectiveness and heat transfer rate is very important in the field of application to enhanced performance and to save the money and space also. To analyze that in this research our aim is to investigate effect of corrugation in plate heat exchanger with parallel flow arrangement with regard to local heat transfer co-efficient, overall heat transfer coefficient, effectiveness and its performance comparison with flat plate heat exchanger of same configuration. The main objective of this research work is to

1. Enhance the local heat transfer co-efficient
2. Enhance the overall heat transfer co-efficient
3. Enhance the effectiveness of heat exchanger

To achieve these objectives we have to achieve

1. High the turbulence in the flow
2. Greater surface contact area between two fluids

III. DESIGN OF CORRUGATED PLATE HEAT EXCHANGER

In this research work performance of the corrugated plate heat exchanger is compared with flat plate heat exchanger. The reference design data for the comparison is taken from the reference paper [1] which is as follows:

Flat plate	Dimensions
Length of plate	400mm
Width of plate	250mm
Thickness of plate	1mm
Plate spacing	7mm

Table 1: Dimensions of flat plate [1]

3.1 Design of Corrugated Plate

Plates are available in a variety of corrugated patterns. The basic aim of providing corrugation to the plates is to get high turbulence in the flow, which results in a very high heat transfer coefficient compared to those obtained in flat plate in exchange for similar duties.

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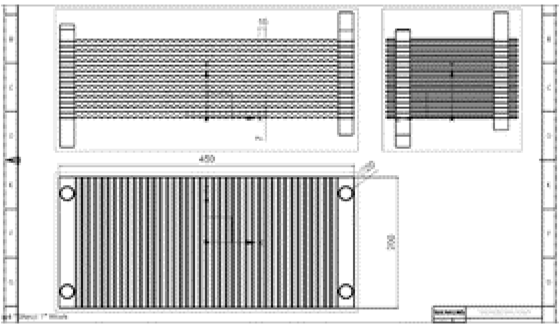

Fig 1: 2 D modeling of corrugated plate

These corrugated patterns also result in increased effective surface areas and provide additional strength to the plates by means of many contact points over the plates to withstand differential pressure that exists between the adjacent plates. For deciding the corrugated plate dimensions we studied many research works which gives the effect of change in heat transfer performance with change in chevron angle. As the corrugation angle increases, pressure drop offered by the channel enhanced and the friction factor decreases. The increase in pressure drop can be resulted into increase in turbulence taking place in the channel. As the corrugation angle increases, the channel becomes sharper and induces turbulence even at a low flow rate.

The plates which are used in this research work have following specifications:
The material used for corrugated plate is stainless steel-grade 304

Corrugated Plate	Dimensions
Length of plate	400mm
Width of plate	250mm
Thickness of plate	1mm
Chevron angle	45^0
Depth of corrugation	4mm
Pitch of corrugation	10mm
Plate spacing	7mm

Table 2: Dimensions of the corrugated plate

3.2 Design of piping for plate heat exchanger

Piping is an outer part of the heat exchanger which do not effect on thermal performance, but the flow is passing from that so friction losses may occur which reduce the performance level of heat exchange so proper design of piping is necessary. To get higher heat transfer Reynolds number would be higher. The Reynolds number depends upon the density of the fluid, the velocity of the flow, hydraulic diameter of pipe, the viscosity of the fluid. Density and viscosity are fixed at a particular temperature so our focus is on other two parameters the mass flow rate is fixed which depends on area of pipe and velocity of flow in a pipe, the velocity must lie in the

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turbulent zone so the area of the pipe is a critical parameter. From calculation, the diameter for hot fluid is 20mm and diameter of cold pipe is 25mm.

3.3 Heat Transfer Analysis

Assumptions:

1. The heat exchanger is studied as a steady flow device due to its continuous operation without altering operating parameters.
2. No phase change occurs; both fluids are single phase and do not mixed.
3. Change in kinetic energy and potential energy is negligible.
4. The specific heat of the water is constant.
5. The outer surface of the heat exchanger is perfectly insulated so no heat loss takes place. [2]

3.4 Thermal Design:

Hot water inlet temp	85º C
Hot water outlet temp	65º C
Cold water inlet temp	30^0 C
Mass flow rate of hot water (m_h)	0.3 kg/sec
Mass flow rate of cold water (m_c)	0.3kg/sec

Table 3: Input data for plate heat exchanger [1]

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Nomenclature		**Subscripts**	
Q	heat duty	*h*	hot fluid
m	mass flow rate (kg/s)	*c*	cold fluid
c_p	specific heat at constant pressure (J/kgK)	*p*	constant pressure
ΔT	temperature difference between inlet and outlet	*1*	inlet condition
t	thickness of plate (m)	*2*	outlet condition
A	flow area for water (m^2)		
A_p	effective plate heat transfer area (m^2)		
Φ	plate area enlargement factor		
W_p	plate width (m)		
L_p	plate length (m)		
D_e	hydraulic diameter(m)		
b	plate spacing (m)		
N	number of water chambers		
V	velocity of hot water (m/s)		
ρ	density of water (Kg/m^3)		
Re	Reynolds Number		
Pr	Prandtl Number		
μ	dynamic viscosity (Ns/m^2)		
k	thermal conductivity (W/mk)		
N_u	Nusselt Number		
h	hot fluid heat transfer coefficient (W/m^2K)		
U	overall heat transfer co-efficient (W/m^2K)		
θ_m	logarithmic mean temperature difference (^0C)		

Heat Duty (Q):

Mathematically it is given as,

Heat rejected by hot water

$Q = m_h c_{ph} \Delta T_h$

Q = 25158 W

Heat absorbed by cold water

$Q = m_c c_{pc} \Delta T_c$

$Q = m_c c_{pc} (T_{c1} - T_{c2})$

$25158 = 0.3 \times 4179 \times (T_{c2} - 30)$

$T_{c2} = 50^0C$

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All the calculations are carried out by considering mean temperature of hot and old fluids.

Hot water mean temp = 75^0 C
Cold water mean temp = 40^0 C

Hydraulic Diameter:

The corrugations must be taken into consideration in calculating effective heat transfer area
$A_p = \Phi.W_p.L_p$
The enlargement factor of the plate is the ratio between the plate effective heat transfer area, A_p and the designed area (product of length and width W_p, L_p), and lies between 1.15 and 1.25.

Property	Unit (metric)	Hot water (mean temperature)	Cold water (mean temperature)
Heat Capacity	J/kgK	4193	4179
Thermal conductivity (k)	W/mk	0.668	0.6316
Dynamic viscosity (μ)	Ns/m^2	0.0003746	0.0006566
Density (ρ)	Kg/m^3	1000	1000

Table 4: Thermo physical properties of fluid

For the effective heat transfer area, the hydraulic diameter of the channel is given by the equivalent diameter, D*e*:

$D_e = 0.012$ m
The flow area for water
$A = NW_{pb}$

For hot water:
$N_h = 5$, $W_p = 0.25$ m, b = 0.007m
$A_h = 0.00875m^2$

For cold water:
$N_c = 6$, $W_p = 0.25$ m, b = 0.007m
$A_c = 0.0105$ m^2

Velocity of Water:

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$$V = \frac{m}{A\ \rho}$$

For hot water:

m_h = 0.3Kg/s, A_h = .00875m2, ρ_h = 1000 Kg/m3

V_h = 0.03428 m/s

For cold water:

m_c = 0.3 Kg/s, A_c = 0.0105m^2, ρ_c = 1000 Kg/m^3

V_c = 0.02857 m/s

Reynolds Number:

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

For hot water:

ρ_h = 1000 kg/m^3, V_h = 0.03428m/s, D_e= 0.012 m

μ_h = 0.0003746Ns/m^2

Re = 1098.13

For cold Water:

ρ_c = 1000 Kg/ m^3, V_c = 0.02857m/s, D_e = 0.012 m

μ_h = 0.0006566 Ns/m^2

Re = 522.14

Prandtl Number:

$$Pr = \frac{\mu\ Cp}{k}$$

For hot water:

μ_h = 0.00037465 Ns/m^2, C_{ph} = 4193 J/Kg K

k_h = 0 .668 W/mK

Pr_h = 2.35

For cold water:

μ_c = 0.0006566 Ns/m^2, C_{pc} = 4179 J/Kg K

k_c = 0.6316 W/mK

Pr_c= 4.35

Nusselt Number:

$N_u = 0.662\ Re^{0.5}\ Pr^{0.33}$ [3]

Heat transfer coefficient for hot water:

h_h = 1618.946 W/m^2K

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Heat transfer coefficient for cold water:

h_c = 1237.54 W/m^{2}K

Overall Heat Transfer Co-Efficient:

The overall heat transfer coefficient is given by

$$\frac{1}{U} = \frac{1}{hh} + \frac{t}{kp} + \frac{1}{hc}$$

U = 667.92 W/m^{2}K

Logarithmic Mean Temperature Difference (LMTD):

When the temperature difference varies within the exchanger, logarithmic mean temperature difference method is used. LMTD is defined as that temperature difference which, if constant, would give the same rate of heat transfer as actually occurs under variable conditions of temperature difference.

The flow is parallel so the formula for the LMTD

$$= \left[\frac{[(Th1 - Tc1) - (Th2 - Tc2)]}{ln\left[\frac{(Th1 - Tc1)}{(Th2 - Tc2)}\right]}\right]$$

= 30.78^0 C

Area required:

Q = U A Θ_m and hence, area A = 1.22 m^2

The total area required for the heat duty 25188 W is 1.22 m^2. The area provided by single plate is 0.1 m^2 so number of plates required for the heat transfer is 12.

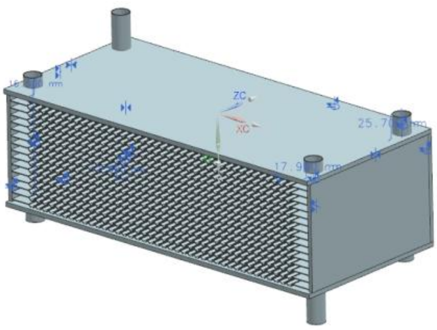

Fig. 2: 3 D model of plate heat exchanger

IV. CONCLUSION

This main objective of this research work is to define the effect of corrugation in flat plate heat exchanger with the parallel flow arrangement, on heat transfer coefficient, overall heat transfer coefficient, effectiveness, mass flow rate and Reynolds number. The analysis has been carried out to find the surface area and number of plates required for the following data:

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Heat duty = 25158 W

Inlet and temperature of hot fluid = 85^0 C Outlet temperature of hot fluid = 65^0 C

Inlet temperature of cold fluid = 30^0 C

Mass flow rate of hot and cold water = 0.3 kg/s

Property	Flat plate heat exchanger	Corrugated plate heat exchanger	Percentage increment
Heat transfer coefficient for hot water (W/m^2K)	1270.17	1618.946	27.45%
Heat transfer coefficient for cold water (W/m^2K)	1041.41	1237.54	18.83%
Overall heat transfer coefficient (W/m^2K)	549.76	667.92	21.49%
Reynolds Number for hot Water	914.89	1098.13	20.02%
Reynolds Number for cold Water	456.71	522.14	14.33%
Surface area required (m^2)	1.486	1.2	19.24%
Number of plates required	14	12	

Table 5: Comparison between flat plate and corrugated plate heat exchanger

The performance comparison is made in the present research work for corrugated plate heat exchanger and flat plate heat exchanger. The table shown represents a comparison of various operating parameters and geometrical parameters for both heat exchangers. The increase in Reynolds number for both the fluids indicates the increase in turbulence of the flow which enhances the heat transfer. Also the heat transfer rate provides directly proportional to surface area for heat transfer, so the rate of heat transfer increased as surface area increased.The above table shows 27.45% increment in Heat transfer coefficient for hot water and 18.83% increment in Heat transfer coefficient for cold water. This ultimately leads to 21.49% increment in overall heat transfer coefficient increment in comparing to flat plate heat exchanger. Number of plates required for corrugated plate heat exchanger is 12, rather than 14 for flat plate heat exchanger for the same heat duty.

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V. FUTURE SCOPE

The future scopes of this research work are experimental analysis can be done. Fluid Analysis can also be done and thermal analysis can be done.

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