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Heat Transfer Performance Analysis of Water Nano Particles Combination for Corrugated Plate Heat Exchanger

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Abstract: *In a conventional plate heat exchanger, increase in heat transfer area directly affects the size of heat exchanger by making it bulky. To overcome this limitation and to test the capability of compact heat exchanger namely corrugated plate heat exchanger, there is a need to increase the heat transfer coefficient of the base fluid. Preferably, addition of Nano particles along with the provision of corrugations on the plates will lead to an increase in effectiveness of the heat exchanger. This study is carried to enhance heat transfer of water by addition of Nano fluids and test the test rig for parallel flow arrangement and counter flow arrangement for different mass flow rates of hot fluid. design of heat exchanger is done based on sizing, that is determination of heat transfer parameters, number of thermal plates required and physical dimensions. It is observed that there is a slight drop in effectiveness with increase in heat capacity ratio. For water as a working fluid the value of effectiveness varies from 0.66 to 0.80 while that of for Nano fluids the value of effectiveness varies from 0.70 to 0.82.*

Keywords *Corrugated PHE, Counterflow, Effectiveness, Nano Fluids, Sizing etc. Corrugated PHE, Counterflow, Effectiveness, Nano Fluids, Sizing etc.*

INTRODUCTION

Plate heat exchanger (PHE) originally received particular attention from the dairy industry due to their suitability in hygienic application. Soon their use became wide spread in the food, juice, beverage and pharmaceutical industries due to the ease of cleaning and the thermal control required for sterilization and pasteurization Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperature while keeping them without mixing with each other. These exchangers are classified according to construction, flow arrangement; number of fluids, compactness, etc. The use of heat exchanger gives higher thermal efficiency to the system. In many applications like power plants, petrochemical industries, air conditioning etc. heat exchangers are used. Plate heat exchanger is generally used in dairy industry due to its ease of cleaning and thermal control. The plate heat exchangers are built of thin metal heat transfer plates and pipe work is used to carry streams of fluid. Plate heat exchangers are widely used in liquid to liquid heat transfer and not suitable for gas to gas heat transfer due to high pressure drop. The flow of heat in a process can be calculated as, $Q=hA\Delta T$ where , Q is to heat flow, h is heat transfer coefficient, A is the heat transfer area, ΔT is the temperature difference that results in heat flow. It can be stated from this equation that increased heat transfer can be achieved by: increasing ΔT, increasing A, increasing h. A greater temperature difference ΔT can lead to increase the heat flow but ΔT is often limited by process or material constraints. Maximizing the heat transfer area (A) leading to increase in the size of heat exchanger which ultimately leads to unwanted increase in weight and cost. And Heat transfer enhancement can also be achieved by increasing the heat transfer coefficient h either by using more efficient heat transfer methods, or by improving the transport properties of the heat transfer material. So in order to overcome above problems, addition of Nano-particles in the base fluid is recommended for the purpose of improving heat transfer.

METHOLOGY

Table 1: Thermo Physical properties of fluid

Property	Unit (metric)	Hot water (mean temp)	Cold water (mean temp)
Heat capacity(Cp)	J/kgK	4197	4178
Thermal conductivity(k)	W/mK	0. 668	0. 6316
Dynamic viscosity (μ)	Ns/m^2	0. 000378	0.000370
Density (ρ)	Kg/m^3	974.851	994.034

Fig. 1- Experimental Setup

Experimental setup consists of tanks, pumps, Rotameter, U tube manometer, temperature indicators, corrugated plate heat exchanger. test the performance of heat exchanger for parallel and counter flow arrangement with water as a working fluid. The heat exchanger has total 13 plates and it is constructed using Stainless Steel AISI 316. Each plate is flat and has thickness of 0.5 mm. The total heat transfer area is 0.2548 m2. Thermometers are placed to measure inlet and outlet temperatures of hot and cold water. following trials are taken

1. Test on corrugated plate heat exchanger with parallel flow arrangement (with water)
2. Test on corrugated plate heat exchanger with counter flow arrangement (with water)
3. Test on corrugated plate heat exchanger with parallel flow arrangement (with water and Nano-fluids)
4. Test on corrugated plate heat exchanger with counter flow arrangement (with water and Nano-fluids)

DESIGN

2.1 Heat duty (Q):

Heat rejected by hot water,

$Q= m_h Cp_h \Delta T_h$ ………………………………… (2. 1)

$Q= m_h Cp_h (T_{h1} - T_{h2})$

$=0.25\times4194\times(85-65)$

Q =20970W

Where, m_h =mass flow rate of hot water in Kg/s,

Cp_h=specific heat capacity of hot water J/Kg K

ΔT_h = temperature difference between inlet and outlet of hot water in K

Heat absorbed by cold water,

$Q = m_c Cp_c \Delta T_c$ ………………………………. (2. 2)

$= m_c Cp_c (T_{c2} - T_{c1})$ 20970

$=0.25\times4178\times(T_{c2} - 25)$ T_{c2}

$= 45.07^0C$

Where, m_c =mass flow rate of cold water in Kg/s,

Cp_c= specific heat capacity of hot water in J/Kg K

ΔT_c=temperature difference between inlet and outlet of cold water in K

*2.2 Thermo physical properties at fluid mean temperature***:**

1. Hot water mean temp = (85+65)/2 = 75 ^0C

2. *Cold water mean temp* = (25+45.07)/2 = 35.03 ^0C

2.3 The hydraulic diameter:

$D_e=2b/\psi$

$=2\times0.00224 / 1.16$

D_e = 0.00386 m

The flow area for water:

$A=NWb$…… ………………. (2.3)

Where,

A= flow area for water in m^2, N=number of water chambers

W =width of plate in m b =distance between two plates in m

2.3.1 For hot water

$A_h = N_h W b$ …… …………. (2.4)

Here,

N_h= 6, W=0.090 m, b =0.00224 m

$A_h=6\times0.0.090\times0.00224$

$A_h=0.0012\ m^2$

2.3.2 For cold water

$A_c = N_c W b$…… …………… (2.5)

Here,

N_h= 7, W=0.090 m, b =0.00224 m

$A_c=7\times0.090\times0.00224$

$A_c=0.001411\ m^2$

*2.4 Velocity of water***:**

$V= m \div (A\ \rho)$ …………………………(2.6)

Where

V= velocity of hot water in m/s, m=mass flow rate in Kg/s

A= flow area for water in m^2, ρ = density of water in Kg/m^3

2.4.1 For hot water

$V_h= m_h A_h \rho_h$………………. (2.7)

Here,

m_h=0.25 Kg/s, A_h =0.0012 m^2, ρ_h =974.851 Kg/m^3

=0.25/ (974.851×0.0012)

V_h =0.02137 m/s

2.4.2 For cold water

$V_c = m_c A_c \rho_c$…………………(2.8)

Here,

m_c=0.25 Kg/s, A_c =0.001411 m^2, ρ_c = 994.034 Kg/m^3

=0.250.001411×994.11

=0.1783 m/s

2.5 Reynolds number

2.5.1 For hot water:

$Re_h = \rho_h V_h De/\mu_h$ .... (2.9)

Here,

ρ_h = 973.851 Kg/ m^3, Vth = 0.2137 m/s, De= 0.00386 m, μ_h = 0.000378 Ns/m^2

= (973.851× 02137× 0.00386)/0.000378

Re_h=2127.34

2.5.2 For cold water:

$Re_c = \rho_c V_c D_c/\mu c$......................... (2.10)

Here,

ρ_c = 993.034 Kg/ m^3, V_c = 0.1783 m/s, D_e = 0.00386 m

μ_h = 0.000720 Ns/m^2

= (993.034× 0.1783× 0.00386)/0.000720

Re_c =950.18

2.6 Prandtl number

2.6.1 For hot water,

$Pr_h = \mu_h Cp_h/k_h$ .... (2.11)

Here,

μ_h= 0.000378 Ns/m^2, Cp_h= 4194 J/Kg K, k_h =0.668 W/mK

= (4194×0.000378)/0.668

Pr_h=2.3732

2.6.2 For cold water,

$Pr_c = \mu_c Cp_c/k$ .... (2.12)

Here,

μ_c= 0.000720 Ns/m^2, Cp_c= 4178 J/Kg K

k_c =0.6316 W/mK

=4178×0.0007200.6316

Pr_h=4.7627

2.7 Nusselt Number

Here Re < 2000 so taking relation for laminar flow,

$N_u = 0.662\, Re^{0.5} Pr^{0.33}$.................. (2.13)

2.7.1 For hot water

$Nu_h = 0.662\, Re_h^{0.5}$..................... (2.14)

Convective heat transfer coefficient for hot water (h_h):

$h_h = (0.662)\,(k_h/D_e)\, Reh^{0.5} Pr_h^{0.33}$

Here,

k_h=0.668W/mK, Re_h=2127.32, Pr_h=2.3732

=0.662× (0.668/0.00386) × $(2127.32)^{0.5}$× $(2.3732)^{0.33}$

h_h=7027.90$W/m^2.K$

Where,

h_h is the hot fluid heat transfer coefficient

2.7.2 For cold water

$Nuc = 0.662\, Re_c^{0.5} Pr_c^{0.33}$ .... (2.15)

Convective heat transfer coefficient (h_c):

$h_c = (0.662)\, k_c/D_e)\, Re_c^{0.5} Pr_c^{0.33}$... ...... (2.16)

= (0.662) × (0.6316/0.00386) × $(950.18)^{0.5}$× $(4.7627)^{0.33}$

h_c=5588.65W/m^2K

Where, h_c is the cold fluid heat transfer coefficient

2.8 Overall heat transfer co efficient:

The overall heat transfer coefficient for a clean surface is given by

$1/U=1/h_h+t/k_p+1/h_c$.................... (2.17)

Here,

h_h =7027.90 W/m^2. K, h_c = 5588.90 W/m^2. K

K_p = 17.5 W/m^2K t = 0.0005m

= (1/7027.90) +(0.0005/17.5) +(1/5588.90)

$1/U$= 0.0003497

U = 2858.81$W/m^2.K$

2.9 Logarithmic Mean Temperature Difference (LMTD):

Θ_m =[[($T_{h1}-T_{c2}$) −($T_{h2}-T_{c2}$)] / ln[($T_{h1}-T_{c2}$)/($T_{h2}-T_{c2}$)]] .... (2.18)

= [[(85−45.07) −(65−45.07)]/ ln [85−45.0765−45.07]]

Θ_m= 28.78 ^{0}C

2.10 Area required

$Q=UA\Theta_m$... ....…….… (2.19)

20970=2858.81×A×28.78.78

A= (20970 / 2858.81×28.78)

A=0.2548 m^2

Area for single plate = 0.231×0.090=0.020m^2

Total no of plates = $Total\ area$ / $Area\ of\ single\ plate$

= 0.2548 / 0.020

= 13

In this design total area of heat transfer obtained is 0.2548m^2 and total numbers of plates required are 13.

CONCLUSION

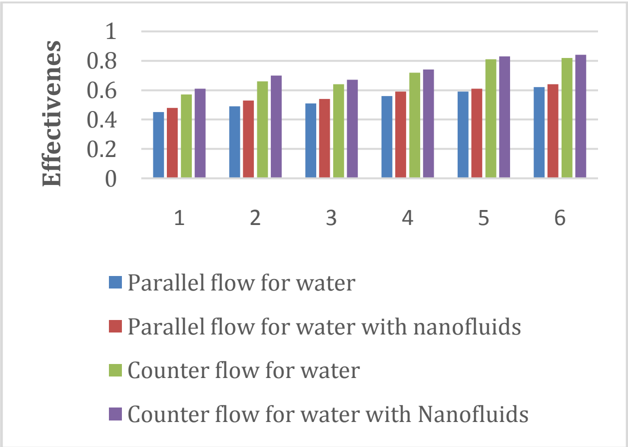

Fig.2- Comparison of effectiveness for water and Nano fluids

The main focus of this project is to understand the effect of nano particles when added with working medium and to investigate experimentally its effect on various performance parameters of PHE. The following are the findings of this experimental investigation:

1. Convective heat transfer coefficient increases with Reynolds number and mass flow rate for both parallel and counter flow arrangement. This is due to the fact that flow becomes more turbulent and cause for turbulence can be attributed to plate geometry i.e., corrugations as well as high flow velocity.
2. Maximum temperature drop achieved for this heat exchanger is in the range of 240C – 270C, which is comparatively higher. This can be attributed to enhanced thermos physical properties as well as plate geometry.

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