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Design and experimental analysis of pipe in pipe heat exchanger

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ABSTRACT: *Pipe in pipe heat exchanger are used in industrial process to recover heat between two process fluids. The project carried out design of pipe in pipe heat exchanger having tube with fin and without fin. The fins were taken in the form of semi-circular type arranged in altenating way with spacing of 50mm.The fins were only provided on the inner tube for creating turbulence of cold water. The number of fin were 18 and its height and thickness 10 and 1.6mm respectively. Experiment were performed for heat exchanger with fins and without fins. The experiment were performed for different flow rates of hot and cold fluid Different parameters like Overall heat transfer,Nusselt number,Convective heat transfer coefficient,Pressure drop,friction factor were obtained and compared for simple inner tube and finned tube.*

Keywords: *Heat Exchanger, Pipe in Pipe, Semi-circular fins, Heat transfer, Effectiveness*

I. Introduction

In this double-pipe heat exchanger a hot process fluid flowing through the inner pipe transfers its heat to cooling water flowing in the annulus. The system is in steady state until conditions change, such as flow rate or inlet temperature. These changes in conditions cause the temperature distribution to change with time until a new steady state is reached. The new steady state will be observed once the inlet and outlet temperatures for the process and coolant fluid become stable. In reality, the temperatures will never be completely stable, but with large enough changes in inlet temperatures or flow rates a relative steady state can be experimentally observed.

The objective of any such equipment is to maximize the heat transferred between the two fluids. A design which increases the heat transferred, but simultaneously could keep the pressure drop of the fluid flowing in the pipes to permissible limits, is very necessary.

Various literatures were studied for checking effect of different fins on heat transfer enhancement and pressure drop. Mansoor siddique et.al [1] performed a Experimental study of turbulent single-phase flow and heat transfer inside a micro-finned tube. Wen-Lih et.al [2] performed Numerical study on heat transfer characteristics of double tube heat exchangers with alternating horizontal or vertical oval cross section pipes as inner tubes. N.targui et.al [3] performed Analysis of fluid flow and heat transfer in a double pipe heat exchanger with porous structures. Ebru Kavak Akpinar [4] investigates experimently heat transfer enhancement in a concentric double pipe heat exchanger equiped with swirl elements. The heat transfer rate in this increased by 130%. Shou-Shing Shieh *et.al* [5] proposed heat transfer coefficients of double pipe heat exchanger with helical type roughened surface.

In the current Design focus is on optimizing the area of the heat exchanger irrespective of the different flow rates of the utility that can be used. Using this pressure drop is not minimized to the fullest extent. We have considered the design of a double pipe heat exchanger in which its cost is optimized by considering three main parameters – the inner and outer diameter of the heat exchanger and the flow rate of the utility.

The first step in project work is theoretical design of pipe in pipe heat exchanger under different consideration and design criteria. There are different methods used for calculating the size of heat exchanger using same input parameter for all methods. Those methods are LMTD method, ϵ - NTU method. The material used for the inner tube is copper because it has very high thermal conductivity. The material for shell is Mild steel.

II. Indentations And Equations

Symbols	**Name**
Aa	Annulus area (m^2)
Ac	Cross-sectional area (m^2)
Ao	Overall area (m^2)
Cp	Specific heat capacity (J/kgK)
C*	Heat capacity ratio
d	Diameter of tube (m)
D	Diameter of shell (m)
De	Equivalent diameter (m)
D_H	Hydraulic diameter (m)
f	Frictional coefficient
h	heat transfer coefficient ($W/m^2\ K$)
K	Thermal conductivity ($W/m\ K$)
L	Length of tube (m)
m	Mass flow rate (kg/s)
Nu	Nusselt's no.
P	Pump Power (W)
Pr	Prandtl's no.
Q	Heat transfer (J/s)
Re	Reynolds's no.
t	Thickness (m)
T	Temperature (K)
Uo	Overall Heat transfer ($W/m^2\ K$)
V	Velocity (m/s)
ΔTm	Logarithmic mean temperature difference (K)
ΔP	Pressure drop
μ	Viscosity
ε	Effectiveness
ρ	Density
NTU	Number of transfer unit

Subscript:

a	Annulus section
c	Cold water
h	Hot water
i	Inside
o	Outside
p	Pipe section
1	Inlet
2	Outlet

2.1 EQUATIONS:[6][7]

Energy balance equation

$$Q = m_h C_{ph} (T_{h1} - T_{h2}) = m_c C_{pc} (T_{c2} - T_{c1}) \quad (1)$$

Nusselt No. for hot water when fins are not used

$$Nu_h = \frac{\left(\frac{f}{2}\right)(Re_h)(Pr_h)}{1+8.7(f)^{\frac{1}{2}}(Pr_h-1)} \quad (2)$$

Where $f = (1.58 lnRe - 3.28)^{-2}$

Nusselt No. for cold water when fins are not used

$$Nu_c = \frac{\left(\frac{f}{2}\right)(Re_c)(Pr_c)}{1+8.7(f)^{\frac{1}{2}}(Pr_c-1)} \quad (3)$$

Where $f = (3.64 LOG_{10} Re_c - 3.28)^{-2}$

Heat transfer Effectiveness

$$\in = \frac{C_c}{C_{min}} \frac{((T_{c2})-(T_{c1}))}{((T_{h1})-(T_{c1}))} \quad (4)$$

Number of Transfer unit

$$NTU = \frac{1}{(1+C^{*2})^{1/2}} ln \left[\frac{2-\varepsilon[1+C^{*}-(1+C^{*2})^{1/2}]}{2-\varepsilon[1+C^{*}+(1+C^{*2})^{1/2}]}\right] \quad (5)$$

Where $C^* = \frac{C_{min}}{C_{max}}$

Pressure drop for tube side

$$\Delta P_p = \frac{4f*2L*N_{hp}*\rho*V_h^2}{2*d_i} \quad (6)$$

The power required by the pump to overcome the pressure drop is

$$P_p = \frac{\Delta P_p * m_h}{\eta_p * \rho_h} \quad (7)$$

The pressure drop in the annulus is

$$\Delta P_a = \frac{4f*2L*N_{hp}*\rho*V_c^2}{2*D_h} \quad (8)$$

Pressure drop in the bend can be calculated as:[6]

$$\Delta P_b = \frac{K\rho V_h^2}{2} \quad (9)$$

Where $K = \frac{4 f_b L}{D_h} + K^*$

Nusselt No. for inner tube having fins can be calculated as

$$Nu_h = \frac{\left(\frac{f}{2}\right)(Re_h)(Pr_h)}{1.07+12.7(f/2)^{\frac{1}{2}}(P_r^{2/3}-1)} \quad (10)$$

Where $f = (1.58 lnRe - 3.28)^{-2}$

Nusselt No. for the annulus section with fins can be obtained as

$$Nu_c = 1.86\left(\frac{Re_c*Pr_c*D_h}{Lt}\right)^{1/3} * \left(\frac{\mu_c}{\mu_w}\right)^{0.14} \quad (11)$$

The overall heat transfer coefficient:

$$\frac{1}{U_o} = \frac{A_t}{A_i h_i} + \frac{A_t * \ln(d_o/d_i)}{2\pi K * 2L_t} + \frac{1}{\eta_o h_o} \quad (12)$$

III. Experimental Setup

In this pipe in pipe heat exchanger a hot process fluid flowing through the inner pipe transfers its heat to cooling water flowing in the annulus. A hair pin is used which is bend to 180 degree and keep outside the annulus section. Heat exchanger gives better heat transfer by using fin either in tube side or in shell side or in both sides. Here semi-circular fin is used for the heat transfer enhancement. The material used for fin is mild steel which is welded on tube by using gas welding. The number of fin used per tube is 18. The fin are arranged in alternate manner i.e. one on top side and other on bottom side with 5 cm of spacing of successive fins. The height of fin is taken as 10 mm and the thickness of fin is taken as 1.6 mm.

Figure 1: Experimental set-up

Figure 2: Inner tube having semi-circular fins

IV. Results And Discussions

For comparison of result obtained from experiment of pipe in pipe heat exchanger with fin and without fin graph is plotted between different parameter.

1) <u>Nu vs Re (Hot and cold side)</u>

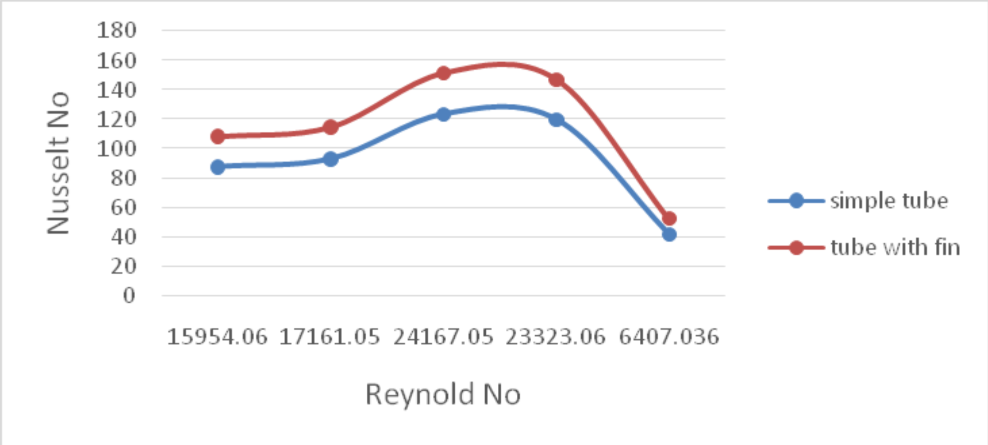

Figure 3: Nu vs Re (Hot Side)

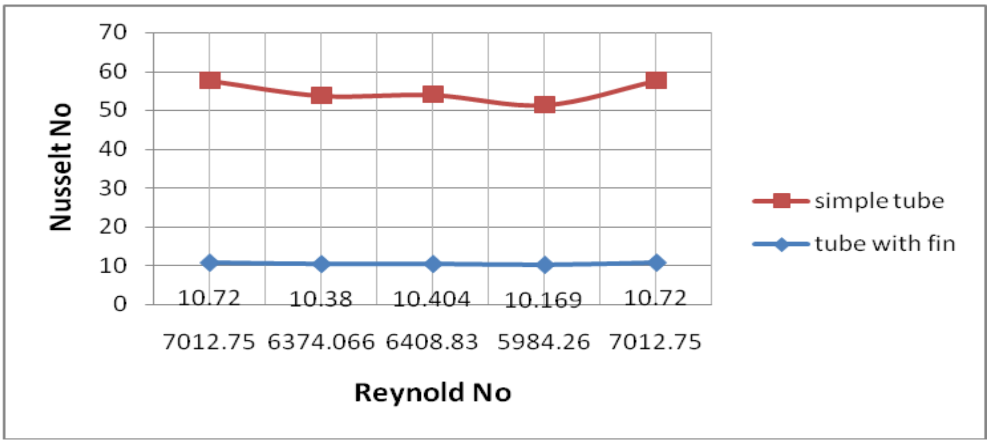

Figure 4: Nu vs Re (Cold Side)

The fig shows the graph of Nu vs. Re with simple tube and tube with fin at different mass flow rate. From above graph it is concluded that after using the fin on tube Nusselt number increase compare to simple tube, which indicate that tube with fin give more convective heat transfer compare to simple tube whereas on cold side the nusselt no for simple tube is higher than finned tube because of having lesser heat transfer surface area.

2) <u>h vs. v (hot and cold side)</u>

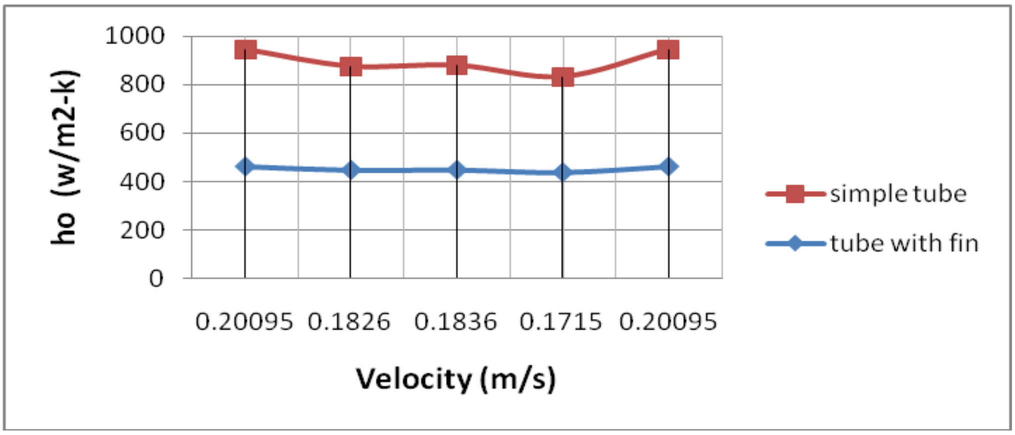

Figure 5: ho vs Vc

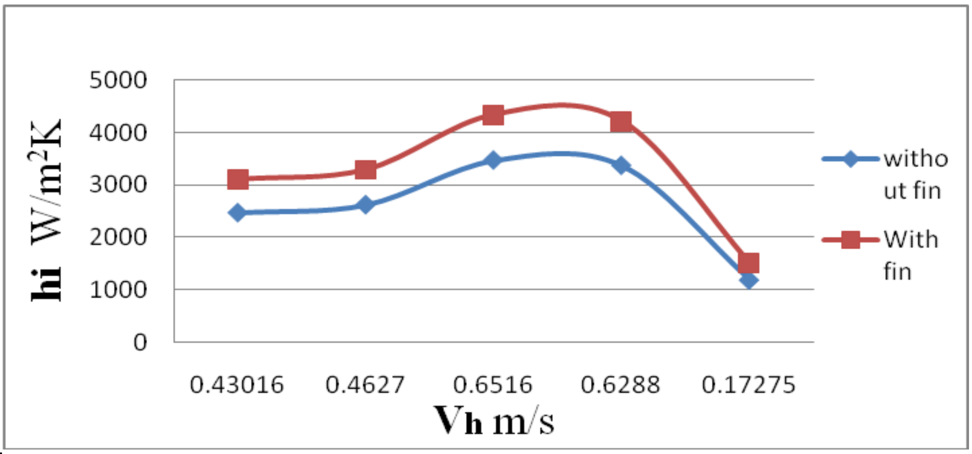

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Figure 6: hi vs Vh

The graph of "ho vs. Vc", "hi vs. Vh" respectively with simple tube and tube with fin at different mass flow rate. It can be concluded from the graph, the convective heat transfer coefficient is higher for simple tube as compared to finned tube in cold side because heat transfer surface area for finned tube is more. Whereas in hot side the finned tube showing better convective heat transfer coefficient.

***f* vs Re (Hot side)**

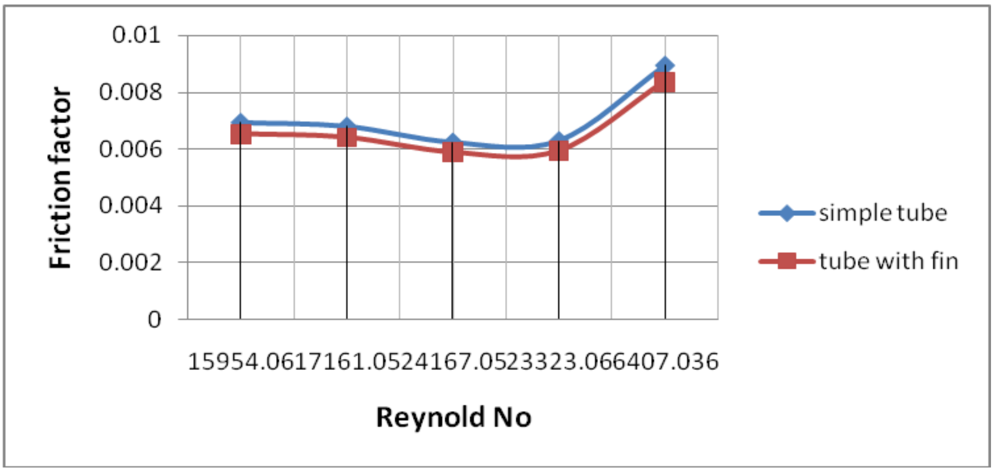

Figure 7: *f* vs Re (Hot Side)

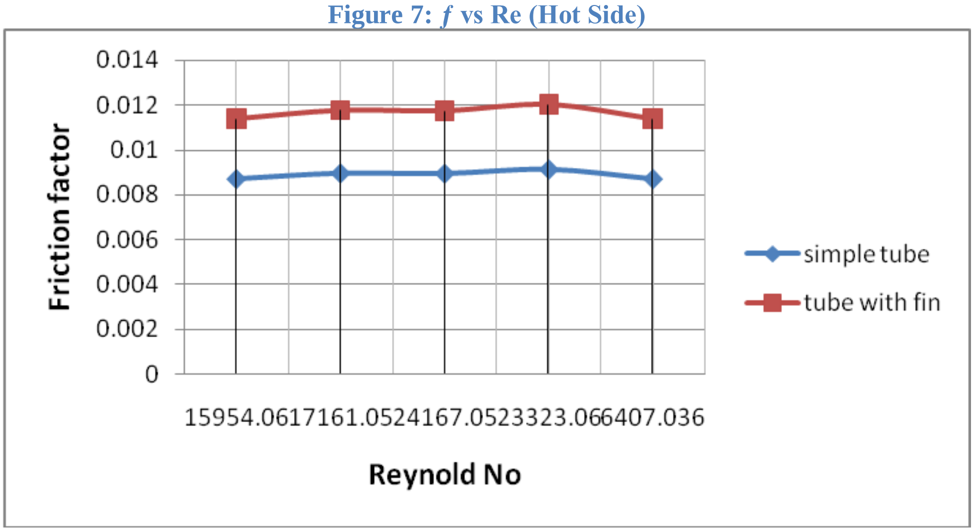

Figure 8: *f* vs Re (Cold Side)

The graph of "*f* vs. Re" for hot and cold side respectively with simple tube and tube with fin at different mass flow rate. From above graph it is concluded that in hot side the friction factor for simple tube is higher as compared to finned tube where as in cold side the friction factor for finned tube leads the simple tube because the fin induced more friction.

Pressure drop vs Re

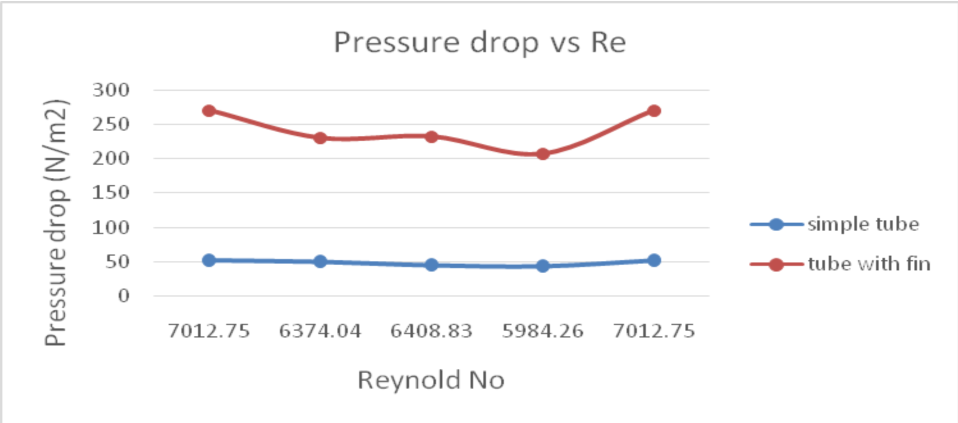

Figure 8: Pressure drop vs Re

The graph drawn for simple tube and tube with fins at different mass flow rate. From above graph it is concluded that after using the fin on tube Pressure drop increase due to circular fin restrict the flow of water compare to simple tube.

V. Conclusions

For R_e = 17161.05, the overall heat transfer coefficient using semi-circular fin decreases is more than 300 % which shows that huge increases in overall heat transfer area. However, the heat transfer enhancement coefficient behaves oppositely, as this quantity increases with increases in heat transfer area. For mass flow rate 0.3832 kg/sec, the decreases in convective heat transfer coefficient for the cold side is around 220 % more than for simple tube hence showing better heat transfer. While for hotter side the value increases around 125%. The increases in friction factor for the cold side for finned tube is around 140 % more than simple tube for R_e = 15954.24 while for the hot side the value of friction factor remains approximately same for both tube. The pressure drop due to friction in cold side for the finned tube is around 450 % more than the simple tube.

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