Experimental Investigation and Comparison of Bend Tube Parallel & Counter Flow and Cross Flow Water to Air Heat Exchanger

Dipayan Mondal, Md. Owal Ikram, Md. Fazla Rabbi, Md. Nawsher Ali Moral*

Abstract—This present work represents the experimental investigation and comparison among the parallel flow, counter flow and cross flow arrangements. A characteristic of heat exchanger design is the procedure of specifying a design, heat transfer area and pressure drops and checking whether the assumed design satisfies all requirements or not. Here bend tube heat exchanger used for parallel and counter flow arrangements and cross flow heat exchanger was chosen not only for occupying less space and better performance but also for comparing the performances. The primary aim of this design is to obtain a high heat transfer rate without exceeding the allowable pressure drop. The type of design that is utilized determines the coefficient of heat transfer and thus has an effect upon the surface area needed to obtain the desired level of heat exchange. The flow pattern through most heat exchangers is a combination of counter flow, cross flow and parallel flow. But in bend tube heat exchanger, parallel flow and counter flow are considered therefore counter flow is the most effective configuration for minimizing the needed heat transfer surface area. Within the experimental limit the gain in temperature for parallel flow was to a maximum value of 12^0C and the maximum logarithmic mean temperature difference (LMTD), efficiency and effectiveness were found 29.13^0C, 42.24% and 0.69 respectively. And for counter flow the gain in temperature was to a maximum value of 13^0C and the maximum logarithmic mean temperature difference (LMTD), efficiency and effectiveness were 29.36^0C, 48.59%and 0.86 respectively. Again in cross flow heat exchanger the gain in temperature was to a maximum value of 10^0C and the logarithmic mean temperature difference (LMTD) was found from 34.63^0C to 8.37^0C. The efficiency and effectiveness were found to maximum of 23.11% and 0.96 respectively.

Index Terms— Bend Tube, Parallel & Counter flow, Cross flow, Water to air heat exchange, Temperature distribution, Performances measurement

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1 INTRODUCTION

A Heat exchanger is an equipment or device built for efficient heat transfer from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. It transfers heat from a hot fluid to a cold one [1]. In most heat exchangers, heat transfer between fluids takes place through a separating wall or into and out of wall in a transient manner. In many heat exchangers the fluids are separated by a heat transfer surface and ideally they do not mix or leak. Such exchangers are referred to as indirect transfer type heat exchanger and also referred to as surface heat exchanger. The example of such heat exchanger is automobile radiators [1-2]. In a few heat exchangers, the fluids are in direct contact for exchanging heat. In the direct contact heat exchangers, heat transfer takes place between two immiscible fluids such as a gas and a liquid [1-6]. In general if the fluids are immiscible, the separation wall may be eliminated and the interface between the fluids replaces a heat transfer surface as in a direct contact heat exchanger. A heat exchanger consists of heat elements such as a core of a matrix containing the surface and fluid distribution such as headers manifolds, tank and inlet or outlet nozzle. Usually there are no moving parts in a heat exchanger. However there are exceptions such as a rotary regenerative exchanger, scraped surface heat exchanger [3-9].

Heat exchangers are one of the most critical components in any liquefaction/refrigeration system. Its effectiveness governs the efficiency of the whole system. The major requirement of these heat exchangers, working in the cryogenic temperature range, is to have high effectiveness [5]. In the recent past, Atrey has shown in his analysis that decrease in heat exchanger effectiveness from 97% to 95% reduces the liquefaction by 12%. The design of heat exchangers, therefore, is very important from the system performance point of view. The design should take various losses, occurring during the exchange of heat and the performance of the heat exchanger is governed by various parameters like mass flow rates, pressures and temperatures of working fluids etc. [16].

The simplest form of heat exchanger is the double-pipe heat exchanger, which consists of a pipe that runs inside another larger pipe. Types of double-pipe heat exchangers vary in the number of tubes used and in the shape of those tubes.

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Concentric tube heat exchangers are the simplest type of heat exchanger. The transfer of heat occurs between the fluid that flows inside the smaller pipe and the fluid in the space between the two pipes, through the surface of the smaller pipe [4-9].

Many types of heat exchanger have been developed for use at such varied levels of technological sophistication and sizes as steam power plants, chemical processing plants, petrochemical plants, petroleum refineries, and natural gas processing, building heating and air conditioning and so on. Common appliances containing a heat exchanger include air conditioners, refrigerators, and space heaters. These devices are also used in chemical processing and power production [1-10]. In parallel flow arrangement, the hot and cold fluids are flows through the same direction but opposite in counter flow arrangement. In cross-flow arrangement, the hot and cold fluids are flows at the right angle to each other. Unlike a rotary heat exchanger, a cross-flow heat exchanger does not exchange humidity and there is no risk of short-circuiting the airstreams [1-2].

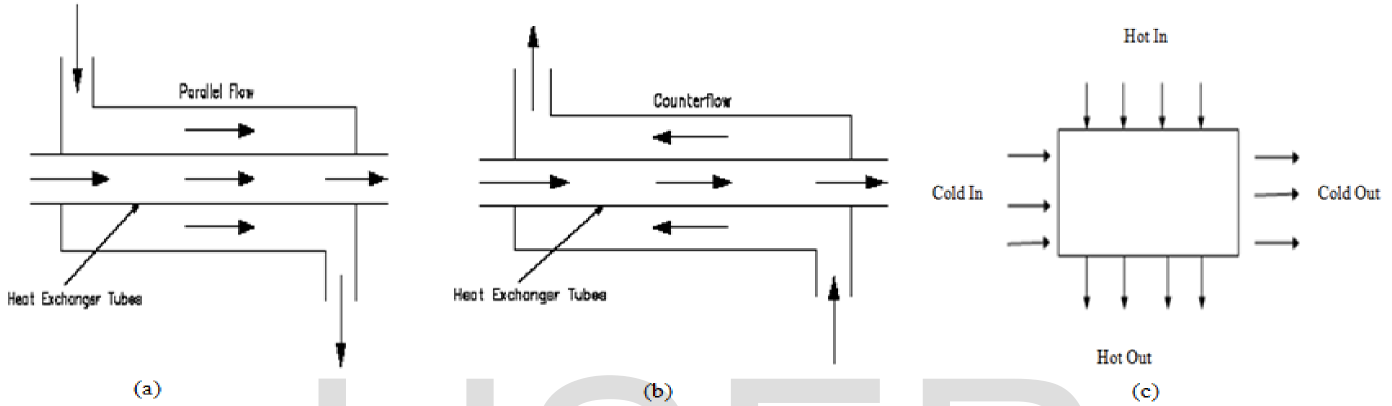


Fig.1: Arrangements for (a) Parallel flow; (b) Counter flow and (c) Cross flow.

2 RELATED WORKS

The following experimental works were done:

“Effect of Flow Arrangement on the Heat Transfer Behaviors of a Microchannel Heat Exchanger” [11] “Influence of Ionic Fluid in Parallel flow in Shell and Tube Heat Exchanger” [12] “Performance evaluation of counter flow heat exchangers considering the effect of heat in leak and longitudinal conduction for low-temperature applications” [13] “Analysis of a Counter Flow Parallel-plate Heat Exchanger” [14] “Thermal performance analysis of cross-flow unmixed-unmixed heat exchanger by the variation of inlet condition of hot fluid” [15]

Nomenclature

D	Diameter of the small tube (m)
d	Diameter of the large tube (m)
D_m	Effective diameter (m)
m	Mass flow rate(Kg/s)
K	Thermal conductivity (W/m .^{0}C)
Q	Total heat transfer rate (W)
L	Length of heat exchanger (m)
A	Surface area of heat transfer (m^2)
C_p	Specific heat of the fluid (J/kg. ^{0}C)
T	Temperature (^{0}C)
T_f	Film temperature (^{0}C)
ΔT	temperature difference in heat exchanger (^{0}C)
h	Convective heat transfer coefficient (W/m^2.^{0}C)
U	Overall heat transfer coefficient (W/m^2.^{0}C)
ΔT_{ln}	Logarithmic Mean Temperature Difference (LMTD) ^{0}C

Dimensionless Parameters

Re	Reynolds number
Nu	Nusselt number
Pr	Prandalt number
F	Correction Factor

Greeks

ε	Effectiveness of heat exchanger
η	Efficiency (%)
ρ	Density of Fluid (kg/m^3)

Subscripts

h	hot water
c	cold air
i	inside
o	out side

3 MATERIALS AND DESIGN CRITERIA

3.1. Materials used and stepwise construction

In bend tube heat exchanger, firstly Galvanized Iron pipe were cut into small pieces and the copper tube were bended using sand and inserted concentrically into the Galvanized Iron pipe. Then the outer Galvanized Iron pipe was welded with Elbow and T for the bended area. Again for cross flow heat exchanger, copper tube was bended using sand and then the copper tube was placed into the wooden frame. Galvanized Iron pipe was holed by 1.5mm drill bit. Then it was hanged up along the copper tube surrounding the sheet metal with the wooden frame. Gate valve and blower were used to control the mass flow rate of hot water and cold air to the pipe on the both cases. Separate thermocouples are used on both for measuring the hot water and cold air temperatures with the digital meter.

3.2. Design Condition

3.4. Governing Equation

The total amount of heat transfer is denoted by; $Q = mC_p\Delta T$; Where, m is total mass flow, kg.s^{-1}; C_p is the specific heat of the fluid, J.kg^{-1}. ^{0}C $^{-1}$; ΔT is the temperature difference in heat exchanger, ^{0}C [1].

The overall heat transfer coefficient U is calculated with the following relations [6]; $Q = UA\Delta T_{ln}$; Where Q =Total heat transfer (W); U = Overall heat transfer coefficient (W/(m^2.^{0}C)); A = Heat transfer surface area (m^2); ΔT_{ln} = log mean temperature difference (^{0}C).

Heat transfer for pulsating flow in a curved pipe was numerically studied by Guo et al. for fully developed turbulent flow for the Reynolds number range of 6000 to 18000 [1]. The Nusselt No. is given below;
$Nu = 0.328\,\mathrm{Re}^{0.58}\,\mathrm{Pr}^{0.4}$
But now Dittus-Boelter correlation [1] is used; $Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$ .The heat transfer coefficient (h) [6] is calculated from the relation below; $Nu = \frac{h \times D_m}{k}$; where $D_m = d_i - D_0$ is mean effective diameter of larger pipe.

The design conditions are usually specified for estimating heat transfer between inside and outside. It was desired to determine the exit temperatures of the fluids for various entrance conditions. Particular set of conditions depends on many factors other than heat transfer aspects- like cost, space requirements, personal opinions of the designer etc.

3.3. Selection of Fluid

In bend tube heat exchanger, two kinds of fluid both of unmixed are used in where the cold fluid, supply air passes throw the galvanized iron pipe and at every point it gains heat. The hot water enters through the cupper pipe of heat exchanger from the hot water tank and at every point it losses heat and finally it leaves the tube at a certain lower temperature [1-10].

Again in cross flow heat exchanger, two kinds of fluid both of unmixed are used in where the cold fluid, supply air passes inside the copper tube and at every point it gains heat. The supply hot water enters the galvanized iron pipe at a certain higher temperature and exit the pipe at a certain lower temperature [1-10].

The LMTD is calculated from the expression [7-10];

$$\Delta T = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}$$

The effectiveness is calculated from the following relations;
Effectiveness for the parallel flow [1],

$$\varepsilon = \frac{1 - \exp[(-\frac{UA}{C_{\min}})(1 + \frac{C_{\min}}{C_{\max}})]}{(1 + \frac{C_{\min}}{C_{\max}})}$$

Effectiveness for counter flow [8],

$$\varepsilon = \frac{1 - \exp[(-\frac{UA}{C_{\min}})(1 - \frac{C_{\min}}{C_{\max}})]}{1 - (\frac{C_{\min}}{C_{\max}})\exp[(-\frac{UA}{C_{\min}})(1 - \frac{C_{\min}}{C_{\max}})]}$$

Again, for forced convection and flow inside the cylinder, Nusselt number is given by $Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$ .This equation is called Dittus-Boelter equation which can be used only when $\mathrm{Re} > 10000$ [1-10].
Again for forced convection and flow over the cylinder, Nusselt number is given by $Nu = (0.04\,\mathrm{Re}^{0.5} + 0.06\,\mathrm{Re}^{2/3})\,\mathrm{Pr}^{0.4}$
This equation is called Whitaker correlation which can be used only when $40 < \mathrm{Re} > 100000$ [1].

The heat transfer coefficient (h) [6] is calculated from; $Nu = \frac{h \times Di}{k}$; where, D_i=diameter of copper tube.

The LMTD is calculated from the expression [5];

$$\Delta T = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}$$

3.5. Design Criteria

Table 1: Heat Exchanger design parameters

Design Parameters	Bend tube Heat Exchanger	Cross flow Heat Exchanger
Small tube Inside& Outside diameters (Material: copper tube)	$D_i = 0.0127m$ & $D_0 = 0.014m$	$D_i = 0.0127m$ & $D_0 = 0.014m$
Large tube Inside& Outside diameters (Material: GI pipe)	$d_i = 0.0381m$ & $d_0 = 0.045m$	$d_i = 0.0381m$ & $d_0 = 0.045m$
Hot water & cold air mass flow rate	$m_h = 0.027kg/s$ & $m_c = 0.024kg/s$	$m_h = 0.027kg/s$ & $m_c = 0.00564kg/s$
Inlet and outlet temp. of hot water	$T_{h1} = 80^0C$ & $T_{h2} = 60^0C$	$T_{h1} = 80^0C$ & $T_{h2} = 65^0C$
Inlet and outlet temp. of cold air	$T_{c1} = 27^0C$ & $T_{c2} = 40^0C$	$T_{c1} = 30^0C$ & $T_{c2} = 40^0C$
Number of holes on the GI pipe		3 Row each of 18 holes and Diameter of the each hole $= 0.0015m$

For Bend tube Heat Exchanger: On the basis of the film temperature of water; $R_e = \frac{4m_h}{\pi D_i \mu} = 6562.45$

Dittus-Boelter correlation; $Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} = 37.56$ &

$Nu = \frac{h_i \times D_i}{k}$; and then find $h_i = 1986.61 w/m^2.^0C$

Again for cold air; $D_m = d_i - D_0 = 0.0241m$ and then

$R_e = \frac{4m_c}{\pi D_m \mu} = 63556.56$

Dittus-Boelter correlation; $Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} = 139.29$ &

$Nu = \frac{h_0 \times D_m}{k}$; and then find $h_o = 154.49 w/m^2.^0C$

Now, $U = \frac{1}{\left(\frac{D_0}{D_i}\right) \times \left(\frac{1}{h_i}\right) + \left(\frac{1}{h_0}\right)} = 142.30 w/m^2.^0C$ &

$$\Delta T = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)} = 36.39^0C$$

Again, $Q = m_h C_{ph}(T_{h1} - T_{h2}) = 2262.789w$ and using Correction factor, $F = 0.96$ with the help of $Q = FAU\Delta T_{\ln} = F(\pi D_0 L)U\Delta T_{\ln}$ it is found $L = L_s = 10.35m$

For Cross flow Heat Exchanger: On the basis of film temperature of water; if drill bit diameter is d then,

$$u = \frac{4 \times m}{12 \times \pi \times \rho \times d^2} = \frac{4 \times 0.027}{12 \times \pi \times 979.77 \times 0.0015^2} = 1.27 m/s^2$$

& $R_e = \frac{u \times D_c}{\upsilon} = \frac{1.27 \times 0.013}{0.421 \times 10^{-6}} = 39216.15$

Whitaker correlation; $Nu = \left(0.04\,\mathrm{Re}^{0.5} + 0.06 R^{2/3}\right)\mathrm{Pr}^{0.4}$ &

$Nu = \frac{h_i \times Di}{k}$; and then find $h_i = 76580.02 w/m^2.^0C$

Again for cold air; $R_e = \frac{4m_c}{\pi D_i \mu} = 30594.85$

Dittus-Boelter correlation; $Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} = 80.49$ &

$Nu = \frac{h_0 \times D_i}{k}$; and then find $h_o = 160.98 w/m^2.^0C$

Now, $U = \frac{1}{\left(\frac{1}{h_i}\right) + \left(\frac{1}{h_0}\right)} = 154.48 w/m^2.^0C$ &

$$\Delta T = \frac{\Delta T_i - \Delta T_e}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)} = 37.44^0C$$

Again, $Q = m_h C_{ph}(T_{h1} - T_{h2}) = 1697.09w$ and using Correction factor, $F = 0.96$ with the help of $Q = FAU\Delta T_{\ln} = F(\pi D_c L)U\Delta T_{\ln}$ it is found $L = 7.51m$; A suction type air blower was used for the both cases having capacity $1hp, 5200rpm$

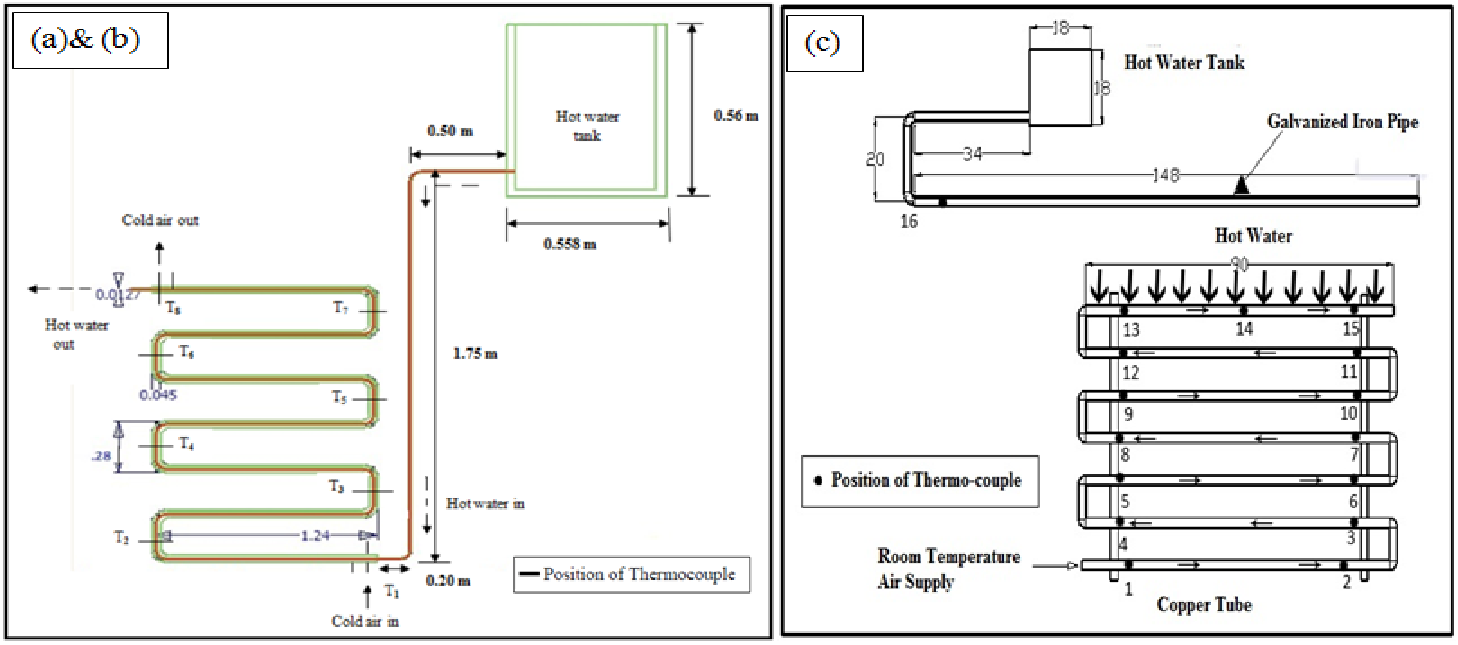


Fig. 2. Schematic diagram (a) for parallel flow; **(b)** for counter flow (water flow direction is reversed of fig. a); (c) for cross flow heat exchanger.

4 RESULTS AND DISCUSSIONS

Under the steady condition, data were collected and recorded and hence the mass flow rate of hot water was varied and the mass flow rate of cold air was fixed.

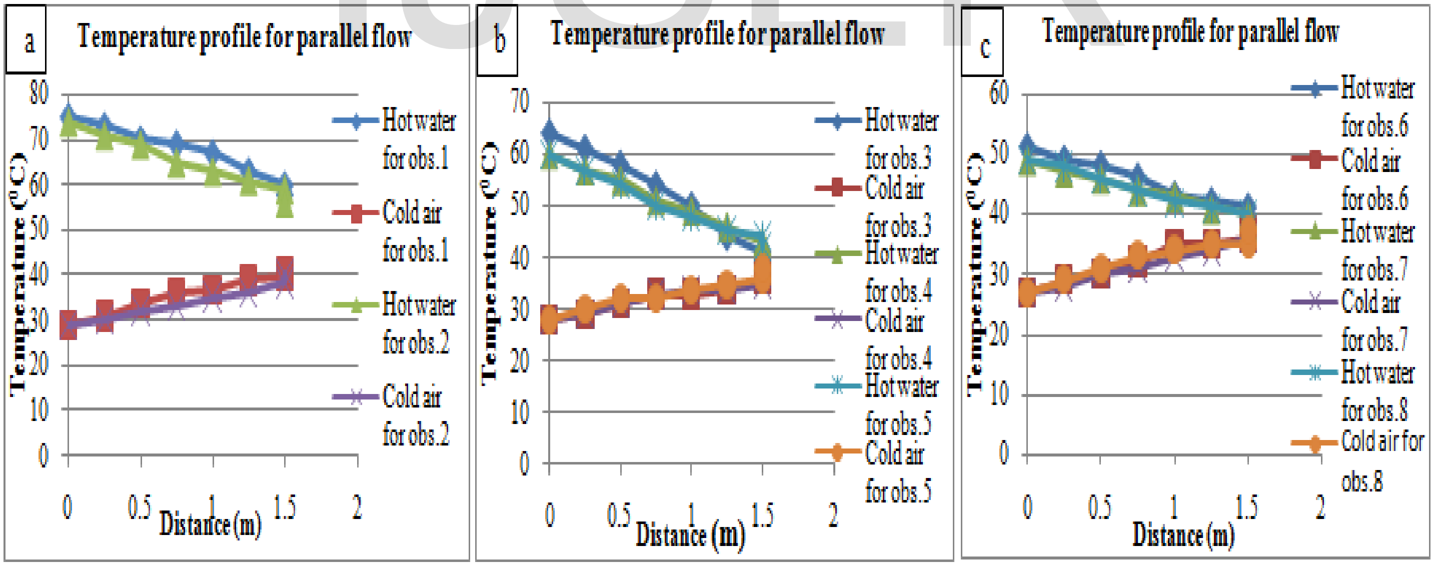


Fig.3: Temperature distribution curves for parallel flow for (a) observation 1 to 2; (b) observation 3 to 5; (c) observation 6 to 8.

From the above representation for parallel flow, it is observed that the temperature of hot water was varied from 75^{0}C to 49^{0}C and the cold air temperature was varied from 29^{0}C to 27^{0}C and it was also observed to pass total length, the hot water temperature was decreased from 58^{0}C to 38^{0}C and the air temperature was increased from 41^{0}C to 37^{0}C.

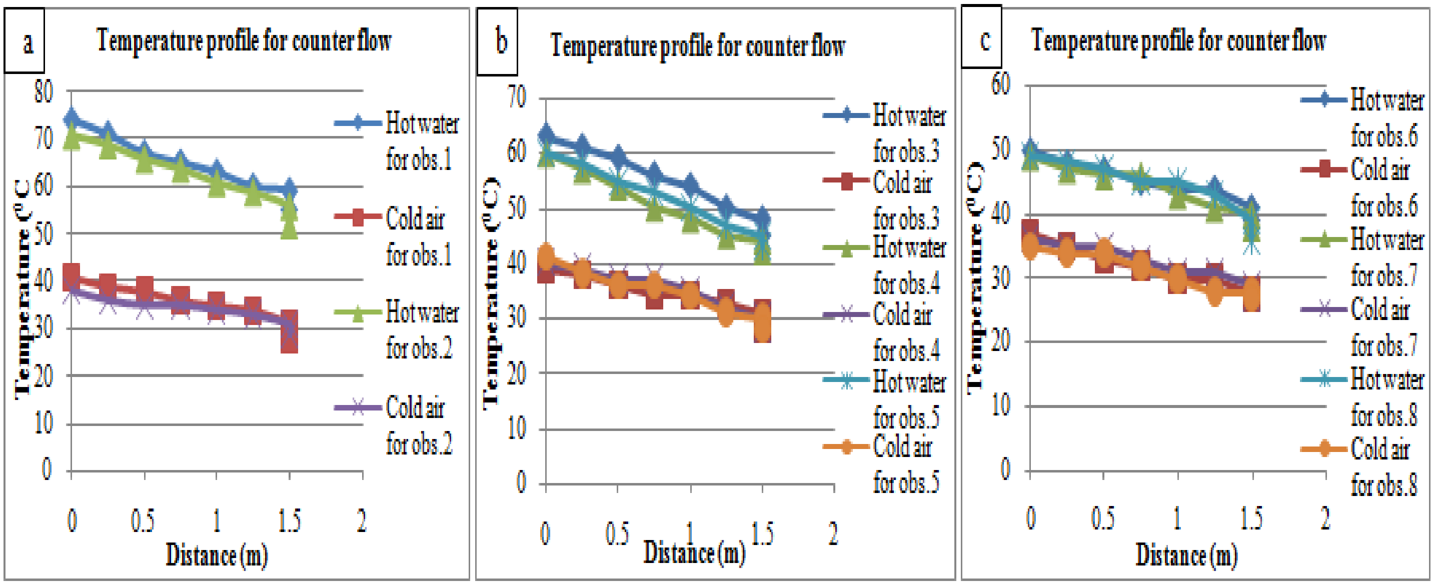
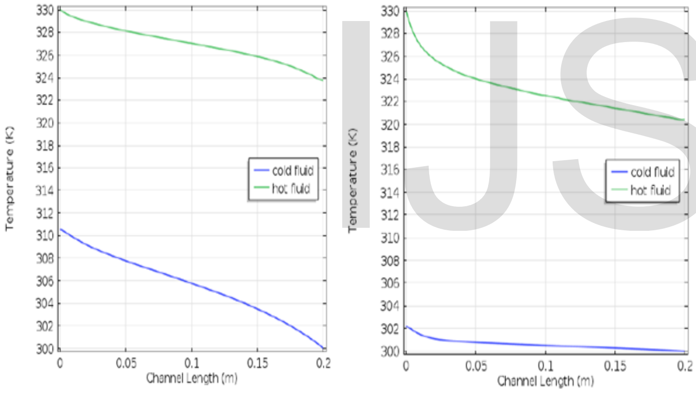


Fig. 4: Temperature distribution curves for counter flow for (a) observation 1 to 2; (b) observation 3 to 5; (c) observation 6 to 8.



Average fluid temperatures along the channel length

Average fluid temperatures along the channel length for the case with modified inlet velocities

Fig. 5: Temperature distribution curves of related work for counter flow [14].

Again for counter flow from the above figure, it is observed that the temperature of hot water was varied from 74^{0}C to 49^{0}C and the cold air temperature was varied from 29^{0}C to 27^{0}C and it was also observed to pass total length, the hot water temperature was decreased from 55^{0}C to 36^{0}C and the air temperature was increased from 35^{0}C to 41^{0}C.Whatever the nature of temperature profiles almost same both of this project and the referenced work.

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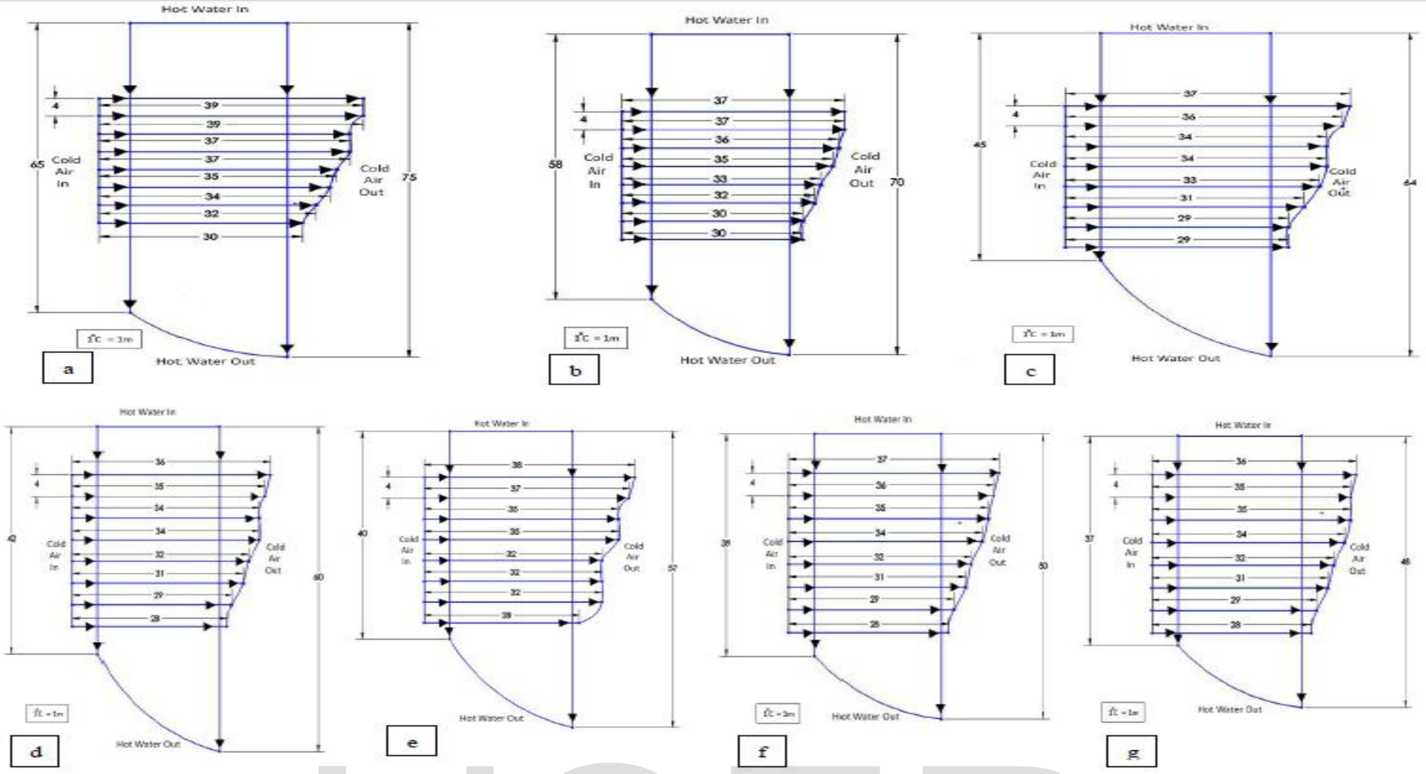


Fig. 6. (a to g)Temperature distribution curve for observation 1 to 7

From the representation for cross flow arrangements, it is observed that during flow the temperature of hot water was varied from 75^{0}C to 48^{0}C and the cold air temperature was varied from 30^{0}C to 28^{0}C and it was also observed that to pass the entire length of copper tube, the hot water temperature was decreased from 65^{0}C to 37^{0}C and air temperature was increased from 33^{0}C to 38^{0}C.

Presentation of result for parallel flow, counter flow and for cross flow arrangements remaining constant mass flow rate of cold air, m_c=0.0238 kg/s and m_c=0.01 kg/s respectively for bend tube and cross flow heat exchanger.

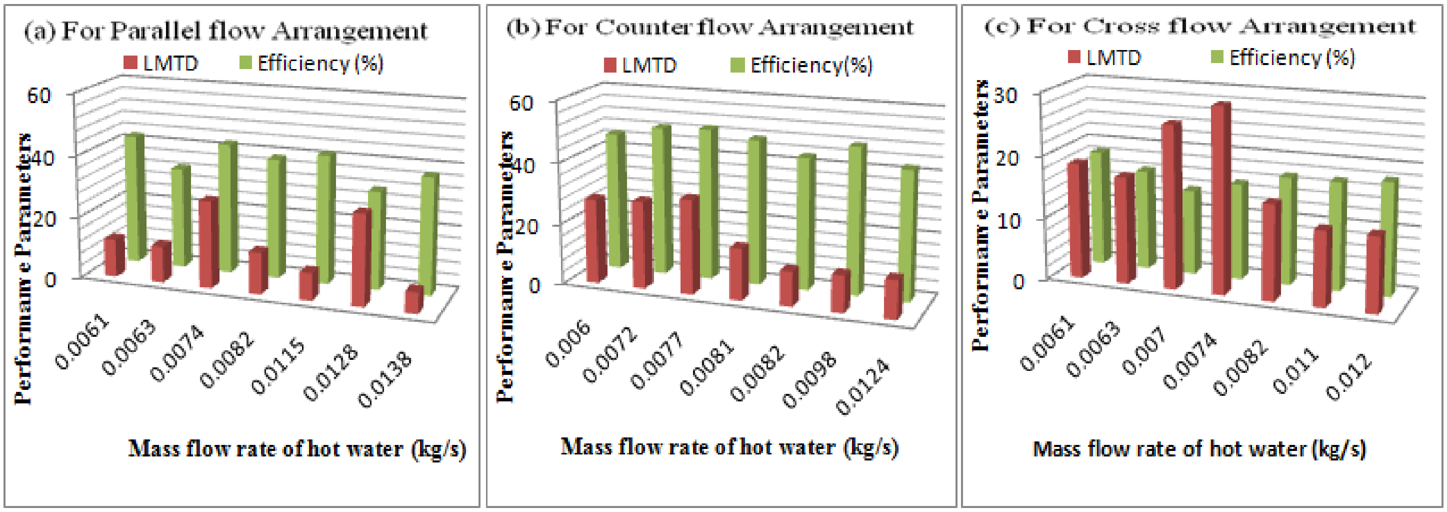


Fig.7: Performance curves for (a) parallel flow; (b) counter flow (c) cross flow arrangements.

From the above graphical representation for parallel flow, the mass flow rate of hot water varied from 0.0138 kg/sec to 0.0061 kg/sec and the measured effectiveness was varied from 0.69 to 0.51; LMTD was varied from 29.13^{0}C to 6.79^{0}C; efficiency was varied from 42.24% to 31.53%. Whereas for counter flow, the mass flow rate of hot water varied from 0.0124 kg/sec to 0.0060 kg/sec and the measured effectiveness was varied from 0.86 to 0.74; the LMTD was varied from 29.36^{0}C to 11.32^{0}C, efficiency was varied from 48.59% to 42%. Again for cross flow arrangement, the mass flow rate of hot water varied from 0.012 kg/sec to 0.0061 kg/sec and mass flow rate of cold air kept constant at 0.01 kg/sec and it is observed that the calculated LMTD was varied from 34.63^{0}C to 10.87^{0}C, efficiency was varied from 18.95% to 13.6% and effectiveness was varied from 0.96 to 0.86.

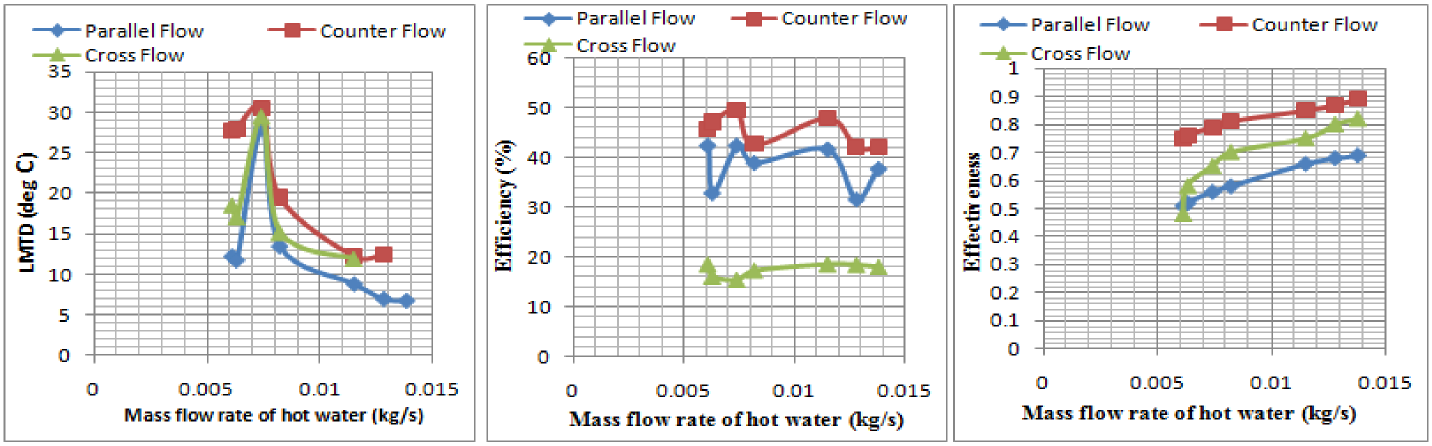
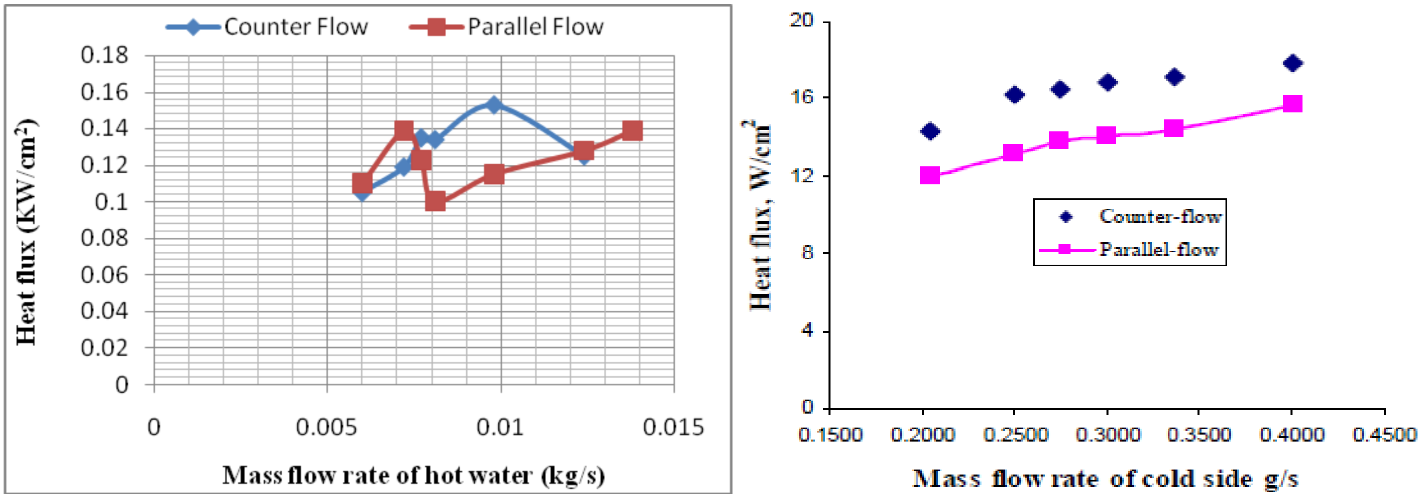


Fig.8: Comparison of the performances among the parallel flow, counter flow and cross flow arrangements.

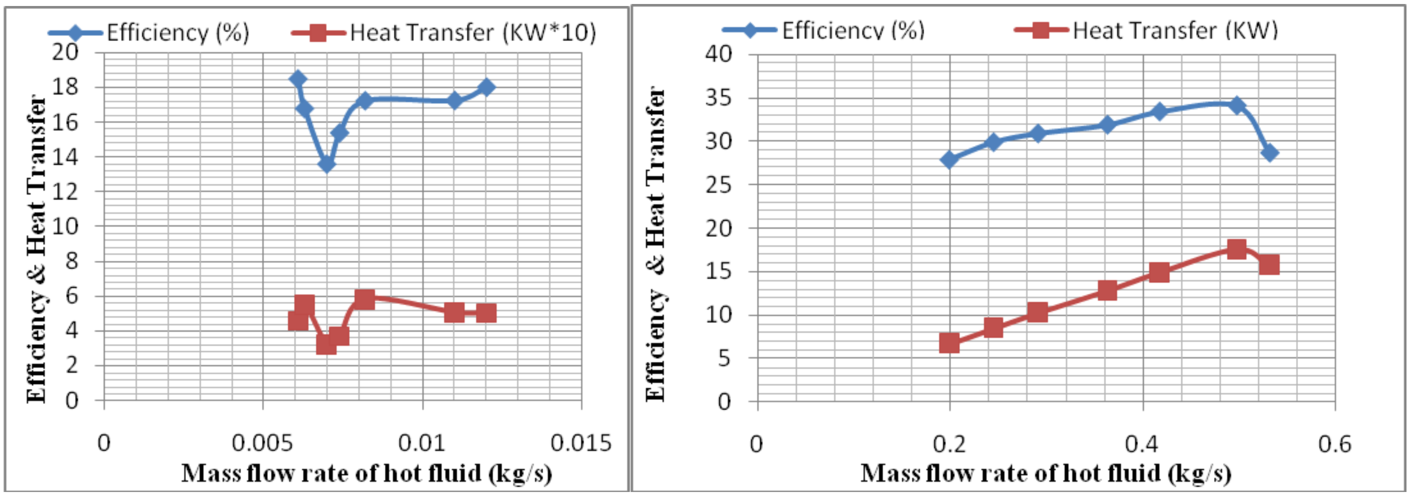
From the above cure it is concluded that the observed LMTD, efficiency and the effectiveness were maximum for the counter flow arrangement for the desired heat exchanger.



(a) (b)

Fig.9: Comparison the Relationship between the heat flux and the mass flow rates (a) for this work and (b) for the referenced work [11].

It is seen that the heat flux increases with the increase of mass flow rate. In our project the heat flux is measured more for the counter flow than the parallel flow arrangements. These are the almost same character of the related work.



(a) Our Work

(b) Related Work [15]

Fig.10: A comparable relationship for cross flow arrangement between our work and the related work [15].

From the above fig.10, it is seen that not only the efficiency but also the heat transfer rate are increased with the increase of the mass flow rate of hot fluid but a reverse direction was found at first on the both of efficiency and heat transfer rate analysis. The initially decreasing phenomena are measured in our work but the decreasing phenomena at last segment were measured at the related work.

It is concluded that not only in parallel flow but also in counter flow the temperature of hot water was decreased with distance almost uniformly and the temperature of cold air was increased with distance. But the difference between the parallel and counter flow characteristics was that the temperature difference was more rapid and effectiveness is also greater in counter flow than that of parallel flow. Again it is found from the competitive study the counter flow arrangement also gives the greater temperature difference; heat flux and the effectiveness than that of cross flow arrangement.

The designed value that was assumed was not obtained during experiment. It was deviated. The mass flow rate of hot water was not maintained as the assumed value due to the low head tank. The mass flow rate of air was obtained by calibrating with previous data which was not maintained as the assumed value. In the bend tube heat exchanger the hot water is passed through the copper pipe which was not always maintained the concentric with Galvanized iron pipe and for the cross flow arrangement the hot water was flow over the copper tube from the galvanized iron pipe which was not contacted all the portion of the copper tube due to the alignment problem. So the temperature difference was not obtained as the assumed value. And the result of this experiment was fluctuated from the design result.

5 CONCLUSION

On the basis of the experimental the gain in temperature for parallel flow was to a maximum value of 12^{0}C, for water flow rate of 0.0128 kg/sec and air flow rate of 0.0238 kg/sec. Within the experimental limit the gain in temperature for counter flow was to a maximum value of 13^{0}C, for water flow rate of 0.0077 kg/sec and air flow rate of 0.0238 kg/sec. Within the experimental limit LMTD was found from 15^{0}C to 30^{0}C.The efficiency and the effectiveness were found to a maximum value of 48.59% and 0.86 respectively. Again for cross flow arrangement, the gain in temperature was to a maximum value of 10^{0}C, for water flow rate of 0.014 kg/sec and air flow rate of 0.01 kg/sec. Within the experimental limit LMTD was found from 34.63^{0}C to 8.37^{0}C.The efficiency, effectiveness and the LMTD were found to a maximum value of 23.11%, 0.96 and 34.63^{0}C respectively. Overall heat transfer coefficient was found to a maximum value 157.67 w/m^{2}. ^{0}C

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