Heat transfer enhancement of double pipe heat exchanger with FDM delta-channel winglet inserts

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Abstract - **For the enhancement in performance of the heat exchanger, it is decided to increase the turbulence and intermixing of flow of hot fluid inside the hot fluid pipe by means of specially design delta winglets that will be placed within the inner tube and these winglets are produced by the 3-d printing process .The winglet serve dual purpose namely- one to increase the surface area and other to improve the interaction between particles and thereby increasing the heat transfer. In this work, 3-D printed delta winglet holder used in Inline, 5 degree inclined and 10degree inclined staggered position in double pipe heat exchanger. It is observed that heat transfer rate of the 10 degree inclined configuration of counter flow is better than that of parallel flow configuration. The thermal analysis shows that the maximum heat flux is 31.80W/mm². The increased heat transfer rate can be attributed to higher turbulence and closer interaction of the working fluids. This is achieved with the complex design of delta winglet to create turbulence. The comparative results also displayed in the paper.**

keywords - **3-D printed delta winglet, Effectiveness, overall heat transfer coefficient etc.**

INTRODUCTION

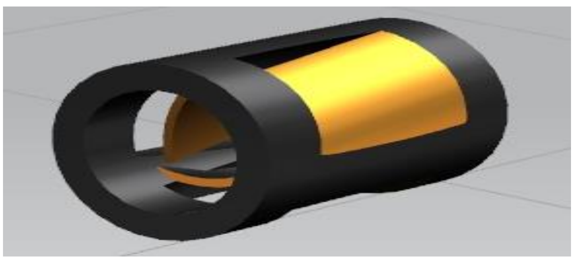
Heat exchangers are the equipment that is commonly used to transfer heat between two flowing fluids at different temperatures without any mixing of fluid with each other. Transfer of the energy from one fluid to another fluid can be done either by conduction, convection or radiation or with all modes of heat transfer. Heat exchangers are very important components in engineering systems, ranging from the heavy industries, such as power or metallurgy, chemical, automotive, through the high technique ones such as electronics, to production of every day consumers goods like refrigeration, air conditioning systems, etc. [1]

Many of authors have given various methods of design, analysis testing & experimental investigation of double pipe heat exchangers with heat transfer enhancement liners. It is found that the number of inserts can be increased by reducing the pitch. The entire tube can be placed in a casing of water to improve heat transfer. The outer tube can be lined with fins to enhance heat transfer. Heat transfer enhancement such as twisted tapes can be used in the inner tube to increase turbulence of hot fluid and thereby the heat transfer rate. [3]

FUSED DEPOSITION MODELING (FDM)

Fused Deposition Modeling (FDM) is a rapid prototyping (RP) process that integrates computer aided design, polymer science, computer numerical control, and extrusion technologies to produce three dimensional solid objects directly from a CAD model using a layer by layer deposition of molten thermoplastics extruded through a very small nozzle.FDM is one of the few commercially available rapid prototyping technologies offering the possibilities of producing solid objects in a range of different materials including metals and composites. The FDM systems, currently fabricate parts in ABS, investment casting wax and elastomeric, and the machines can operate in a user friendly office environment. FDM machines which is used in this study, allows building layer thickness from 0.178 mm to 0.356 mm and the achievable accuracy in the parts is ±0.127 mm.

Advantages of the FDM process
High strength material
Less cost- effective and waterproof
ABS material use for impact resistances and toughness
Multiple material colors are available
The layout of the micro-channel after 3-d Printing and fitting of the brass fins is to be of shape as shown below:



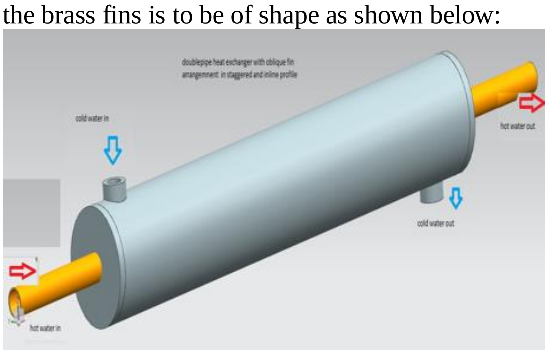


Fig.1 Delta channel FDM insert **Fig 2. Double pipe heat exchanger**

Here surface area is 1.5 times that of conventional straight fins, so rate of heat transfer is more ,cheap manufacturing method, makes heat exchanger less costly

EXPERIMENTAL PROCEDURE

Design & Theoretical Analysis of 3D Printed delta winglet holder

Material : ABS Polymer

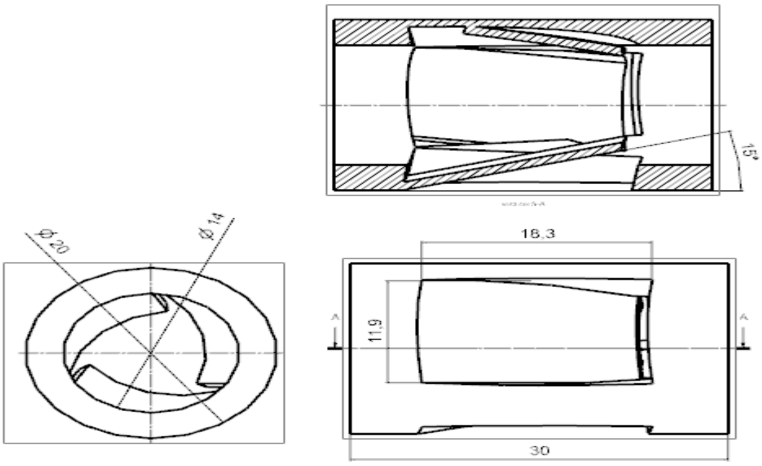


Fig. 3 2-D design of delta winglet holder

Hoope's stress due to oil pressure

Maximum pressure induced in system due to oil =0.12Mpa

Using, fcact = $\frac{p \times d}{2 \times t}$

Where,

p= Design pressure (bar) = 0.12Mpa; d = Inner diameter of pipe (mm) = 14 mm; t = Thickness of pipe (mm) = 2mm

fpact = 8 N/mm²

As fpact < fc all ; (allowable stress 20 Mpa)

3D Printed delta winglet holder is safe.

THERMAL ANALYSIS OF 3-D PRINTED DELTA WINGLET HOLDER

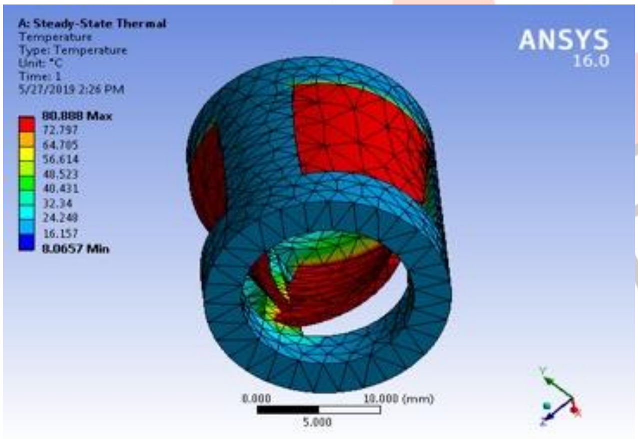


Fig. 4 Temperature variation counter

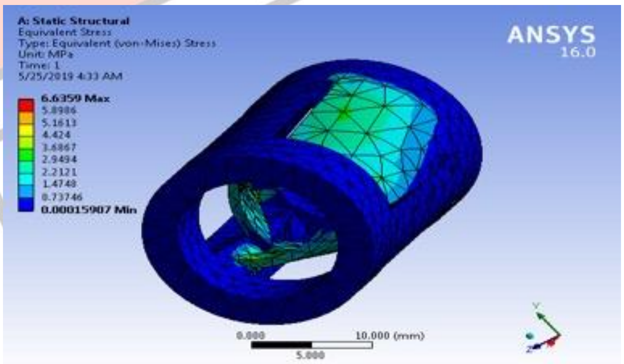
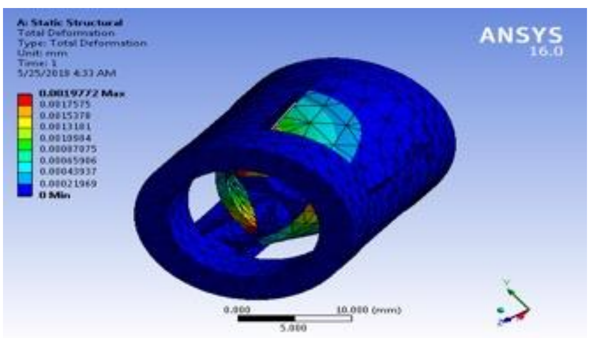


Fig. 5 The maximum von- mises stress induced is 6.6359 Mpa



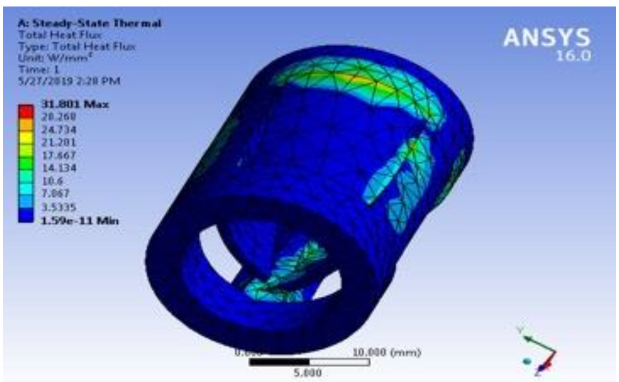


Fig. 6 The maximum deformation seen is 0.0019 mm Fig. 7 Maximum heat flux

Maximum heat flux is 31.80 W/mm²

In thermal module of analysis software ANSYS temperature variation contour is obtained when given boundary condition are applied to the problem. The results obtained from ANSYS software simulation for temperature contour is shown in **Figure. 1** From figure we can say that at the center of water is in contact with inner fins of winglet and therefore maximum temperature exists there. After that it enters the fin section where heat is dissipated towards the body region.

From **figure. 6** shows that The maximum deformation seen is 0.0019 mm. It is concluded that 3-D printed delta winglet holder is structurally safe design. There is no effect of hot water on ABS polymer material.

. EXPERIMENTAL SETUP

Fig.8 Experimental setup

- First the plain tube double pipe heat exchanger was tested.
- Fill the water in tank and Heat the water in the top tank up to desired temperature by using water heater.(usually 80^{o}) measured using temperature gauge.
- Ensure all the parts are in connection and flow arrangement is parallel flow.
- In Parallel flow arrangement hot and cold water circulate at same direction.
- In hot pipe three delta winglet holder are inserted at inclined position and take temperature reading for hot and cold water inlet and outlet temperature.
- Changing the angle of inserts with 5^{o} inclined position , But check properly First insert is in references position and other two insets are inclined at an angle of 5^{o}.
- Same procedure follow for 10^{o} inclined position of insets.
- Take temperature readings for cold water inlet and outlet as well as hot water inlet and outlet temperature
- Ensure all the parts are in connection and flow arrangement is counter flow.
- Fill the water in tank and Heat the water in the top tank up to desired temperature by using water heater.(usually 80^{o}) measured using temperature gauge.
- At the beginning of series of tests, the hot water was circulated through inner tube and cooling water through annulus tube in and counter flow configuration.
- Same procedure follow for counter flow arrangement in inline, 5^{o} inclined and 10^{o} inclined inserts.
- Take temperature readings for cold water inlet and outlet as well as hot water inlet and outlet temperature
- Now, by changing the mass flow rate using valve arrangements and the Above procedure is repeated for no. of observations.

MATHEMATICAL ANALYSIS

1]Mass flow rate = $\frac{(\frac{\text{volume}}{1000})}{\text{time}}$

2]Log mean temperature differences (LMTD)

$\Delta T = \frac{(\Delta T1 - \Delta T2)}{\ln(\Delta T1/\Delta T2)}$

3] Capacity ratio

$$C = \frac{(MCp)small}{(MCp)large} = \frac{(MCp)h}{(MCp)c}$$

4] Effectiveness

$$\text{Effectiveness} = \frac{(\text{Hot water inlet temp} - \text{Hot water outlet temp})}{(\text{Hot water inlet temp} - \text{Cold water inlet temp})} = \frac{(Th\,i - Tho)}{(Thi - Tci)}$$

5] Overall Heat Transfer Coefficient (U)

$$U = \frac{(MCp)h \times (Thi - Tho)}{(0.012 \times \Delta T)}$$

6] Heat transfer rate (Q)

$Q = U\ A\ \Delta T$

RESULTS AND DISCUSSION

To compare the different performance parameter of heat exchanger with 3-D printed delta winglet holder in inline,5 degree inclined and 10 degree inclined configuration some graphs are plotted.

Effect on Log mean temperature differences (LMTD)

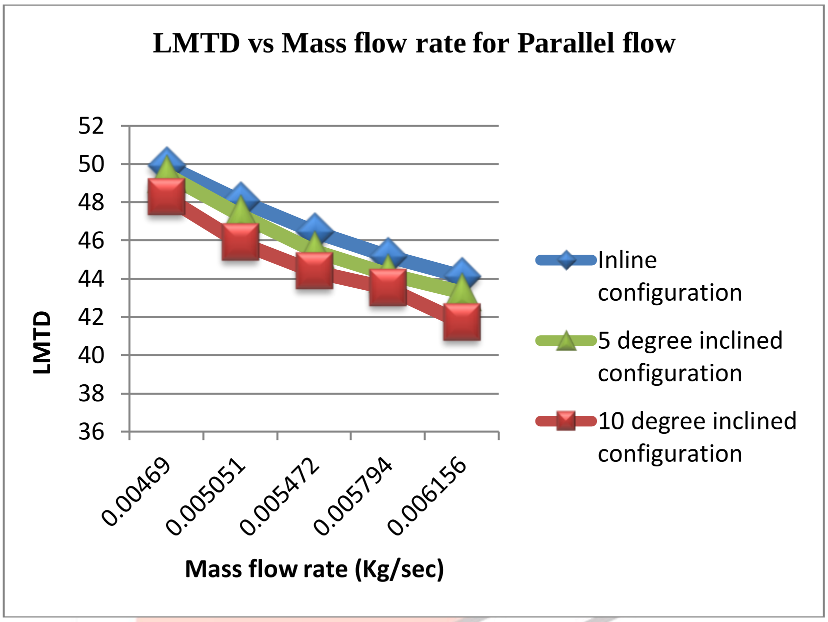


Fig. 9 LMTD vs Mass flow rate for Parallel flow

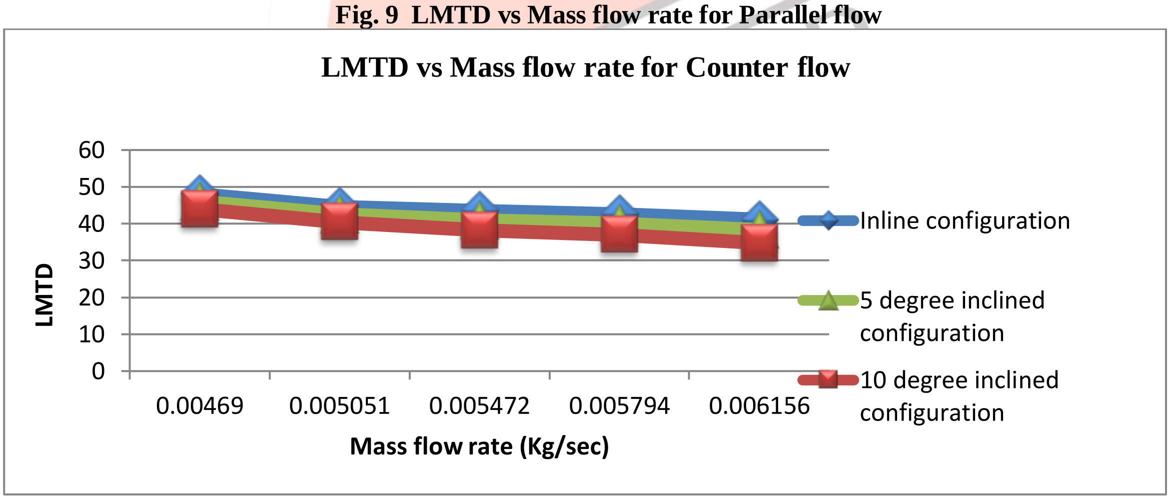


Fig. 10 LMTD vs Mass flow rate for Counter flow

From Figure 9 and Figure 10 it is observed that Log mean temperature differences decreases with increase in mass flow rate. Because the LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the double pipe exchanger. Temperature differences is increases in every configuration.

EFFECT ON EFFECTIVENESS

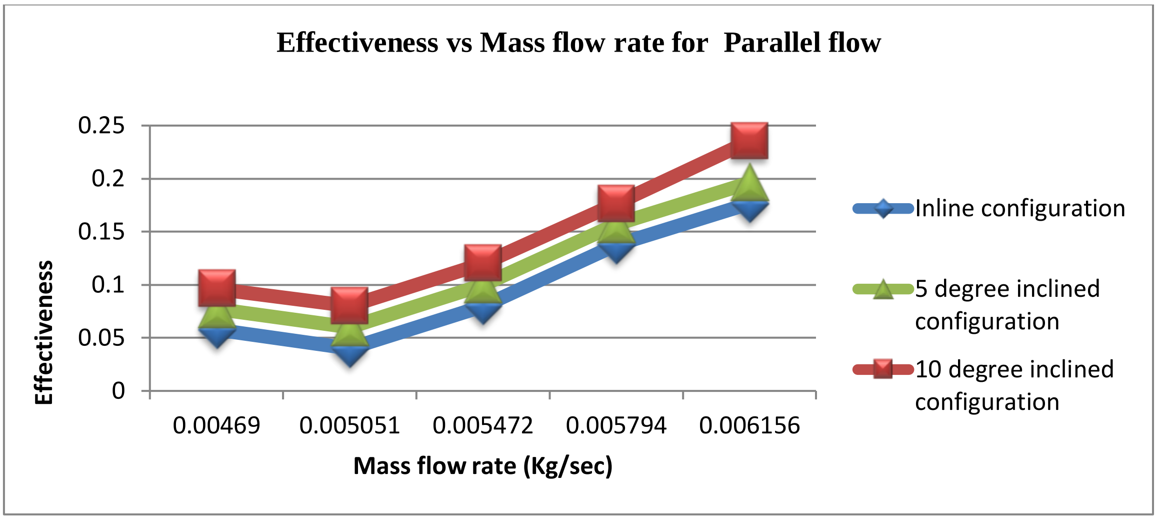


Figure 11 Effectiveness vs Mass flow rate for Parallel flow

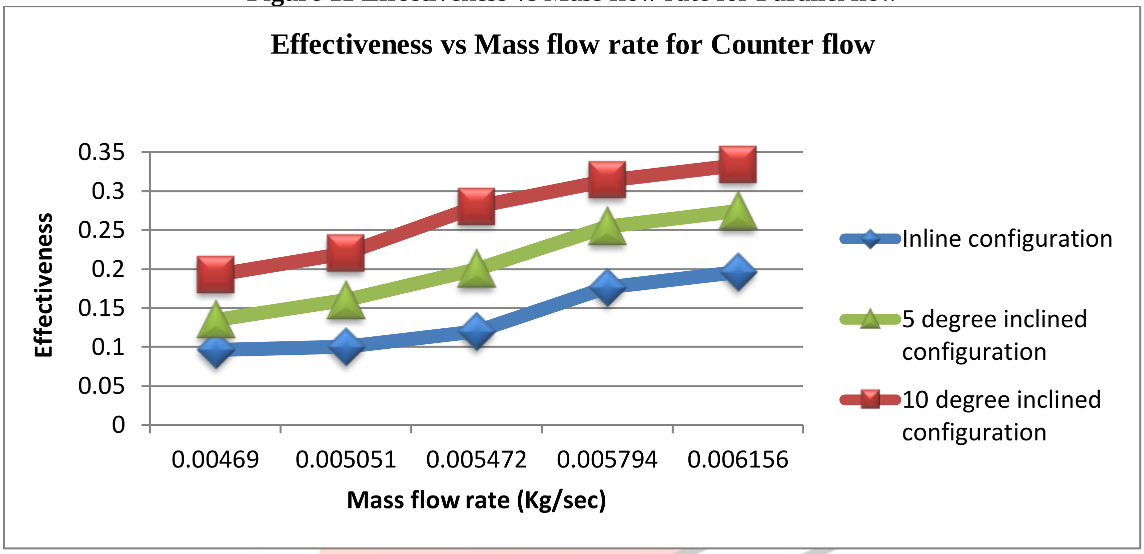


Fig. 12 Effectiveness vs Mass flow rate for Counter flow

Figure 11 and figure 12 shows the variations of effectiveness with different mass flow rate of hot fluid for parallel and counter flow respectively. The plot clearly shows that the effectiveness increases with increasing mass flow rate. So it can be concluded that 3D printed delta winglet holder changing the angle with fixed to the references position it generate more turbulence. The 10 degree inclined configuration of effectiveness is more as compare to other configuration.

EFFECT ON OVERALL HEAT TRANSFER COEFFICIENT ON PARALLEL AND COUNTER FLOW ARRANGEMENT

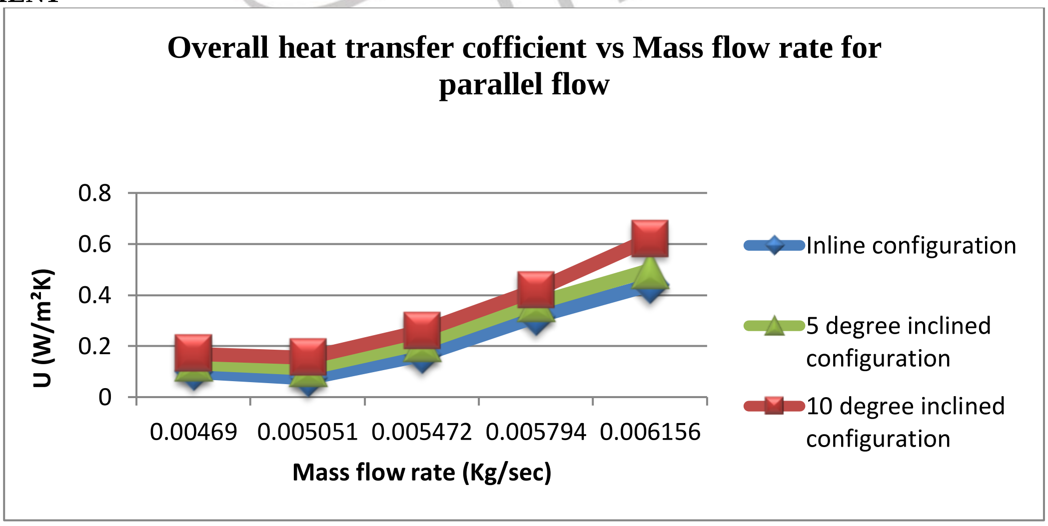


Fig.13 Overall heat transfer cofficient vs Mass flow rate for parallel flow

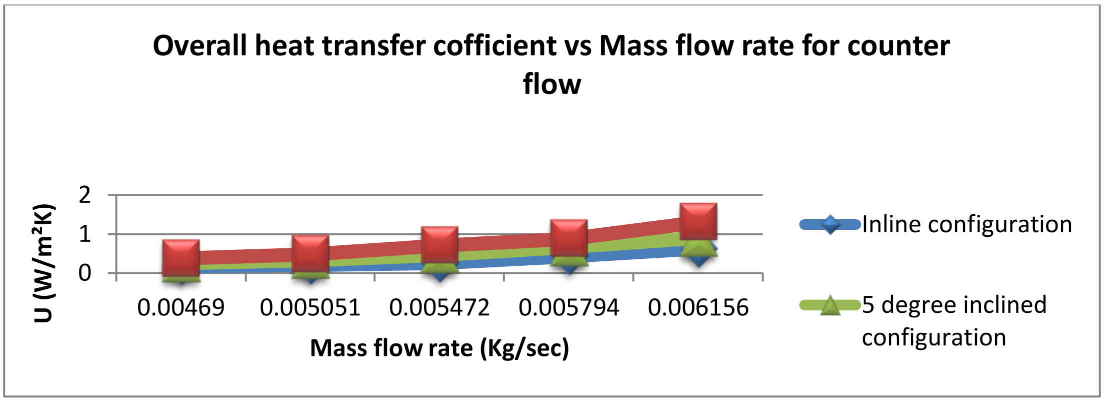


Fig.14. Overall heat transfer coefficient vs Mass flow rate for counter flow

The variations of overall heat transfer coefficient with mass flow rate which is calculated by experimentally observed data for parallel and counter flow heat exchanger is shown in Figure 13 and Figure 14 respectively. The plot clearly shows that the heat transfer coefficient increases by using 3D printed delta winglet holder in both set-ups as compare to heat exchanger is inline configuration. However from two graphs it is also clearly seen that the heat transfer coefficient of delta winglet holder heat exchanger with 10 degree inclined configuration counter and parallel flow is more than 5 degree inclined configuration. So it can be concluded that using of winglet in heat exchanger heat transfer coefficient increases however it also increases when angle of delta winglet increases.

EFFECT ON HEAT TRANSFER RATE

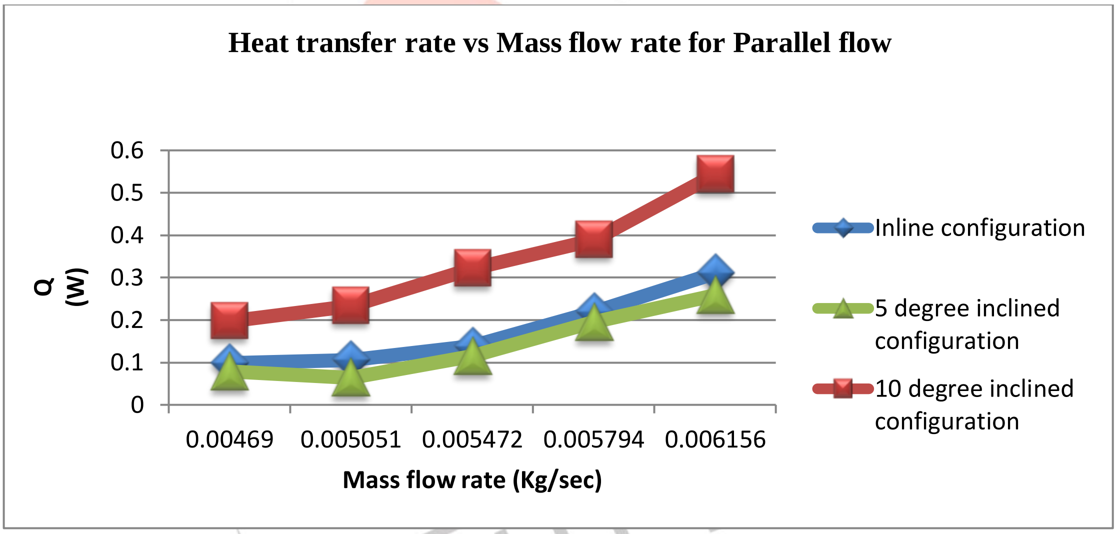


Fig. 15 Heat transfer rate vs mass flow rate for parallel flow

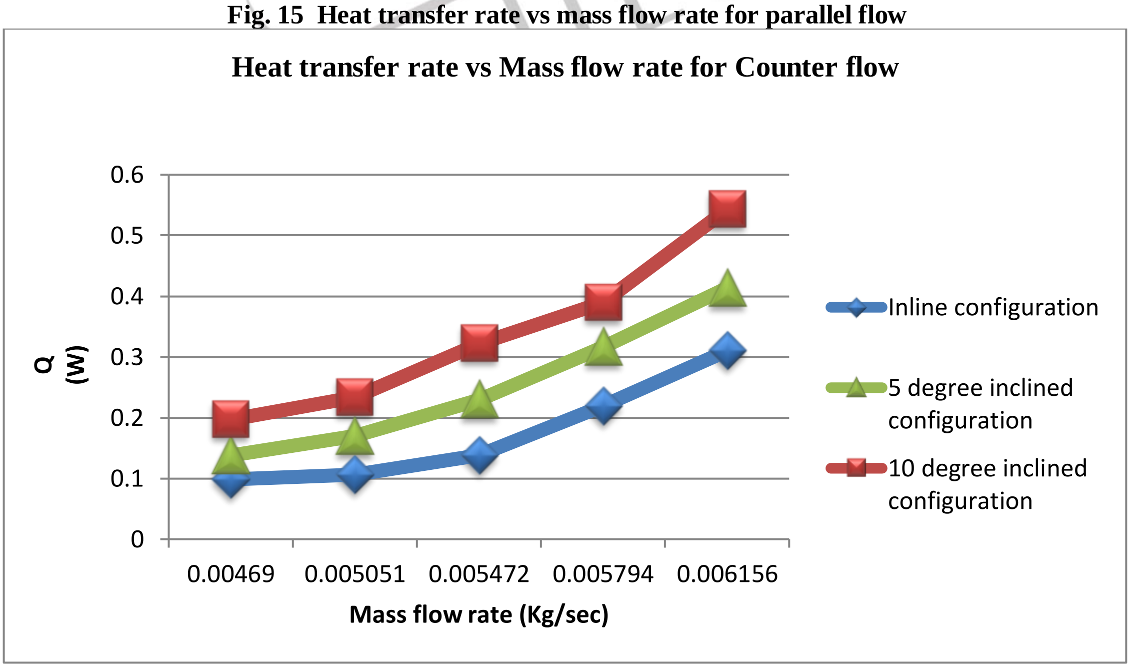


Fig. 16 Heat transfer rate vs mass flow rate for counter flow

The variations of heat transfer rate with mass flow rate which is calculated by experimentally observed data for parallel and counter flow heat exchanger is shown in Figure 15 and Fig. 4.21 respectively. The plot clearly shows that heat transfer rate increases by using 3D printed delta winglet holder in both set-ups as compare to heat exchanger is inline configuration. However from two graphs it is also clearly seen that the heat transfer rate of delta winglet holder heat exchanger with 10 degree inclined configuration counter and parallel flow is more than 5 degree inclined configuration. So it can be concluded that using of winglet in heat exchanger heat transfer rate increases however it also increases when angle of delta winglet increases.

EFFECT ON HEAT TRANSFER RATE COMPARISON ON PARALLEL AND COUNTER FLOW ARRANGEMENT

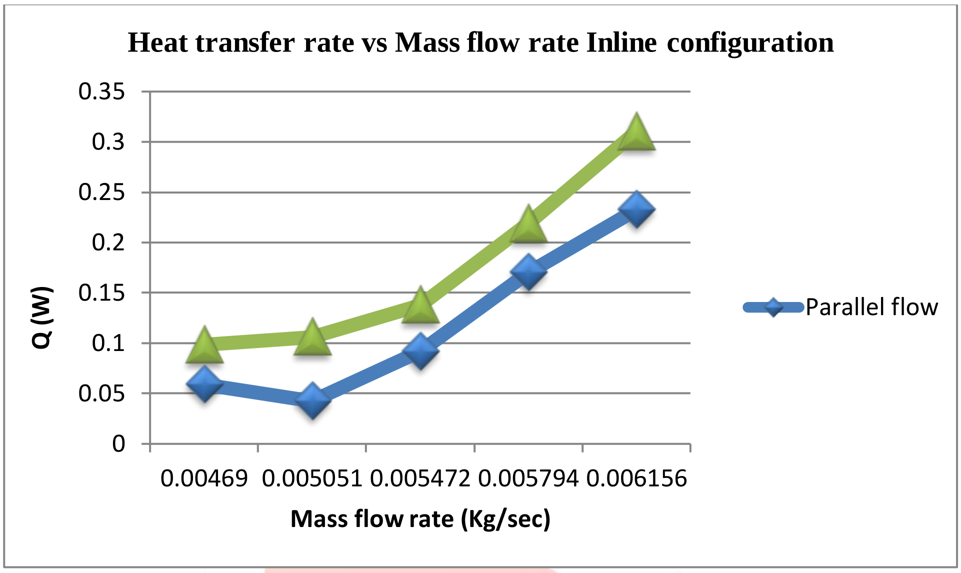


Fig. 17 Heat transfer rate vs Mass flow rate Inline configuration

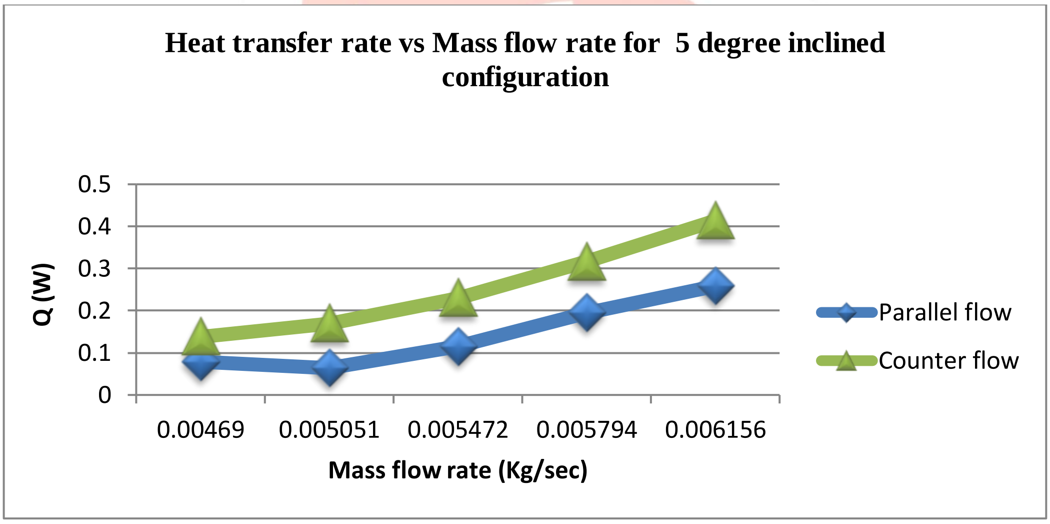


Fig. 18 Heat transfer rate vs Mass flow rate for 5 degree inclined configuration

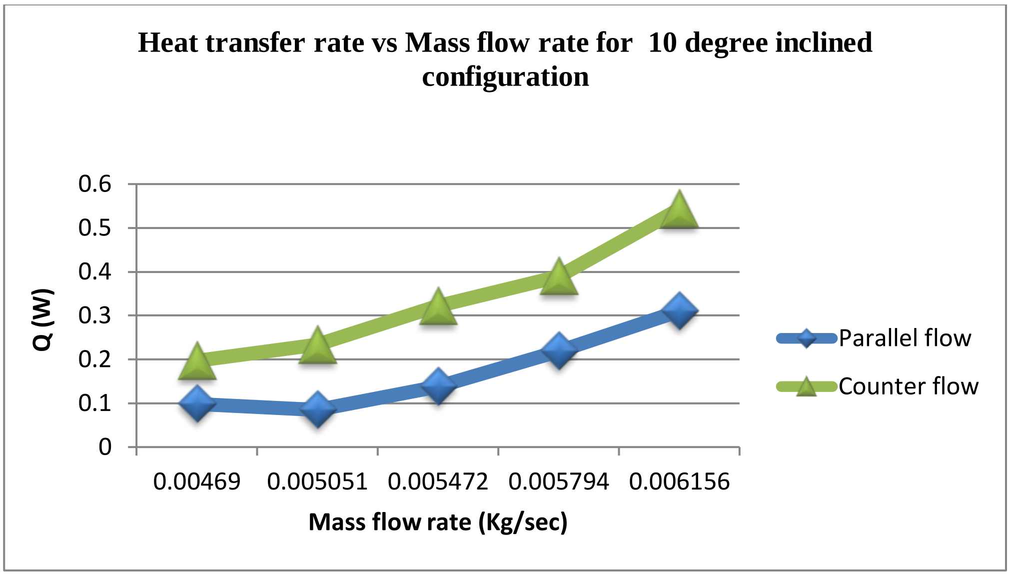


Fig. 19 Heat transfer rate vs Mass flow rate for 10 degree inclined configuration

In Figure17, Figure 18 and Figure19 shows that, The average of heat transfer rate for counter flow in Inline configuration is 0.0275 times that of parallel flow. The average of heat transfer rate for counter flow in 5 degree inclined configuration is 0.0556 times that of parallel flow. The average of heat transfer rate for counter flow in 10 degree inclined configuration is 0.0833 times that of parallel flow.

% INCREASES IN HEAT TRANSFER RATE VS INLINE PARALLEL AND COUNTER FLOW HEAT TRANSFER RATE

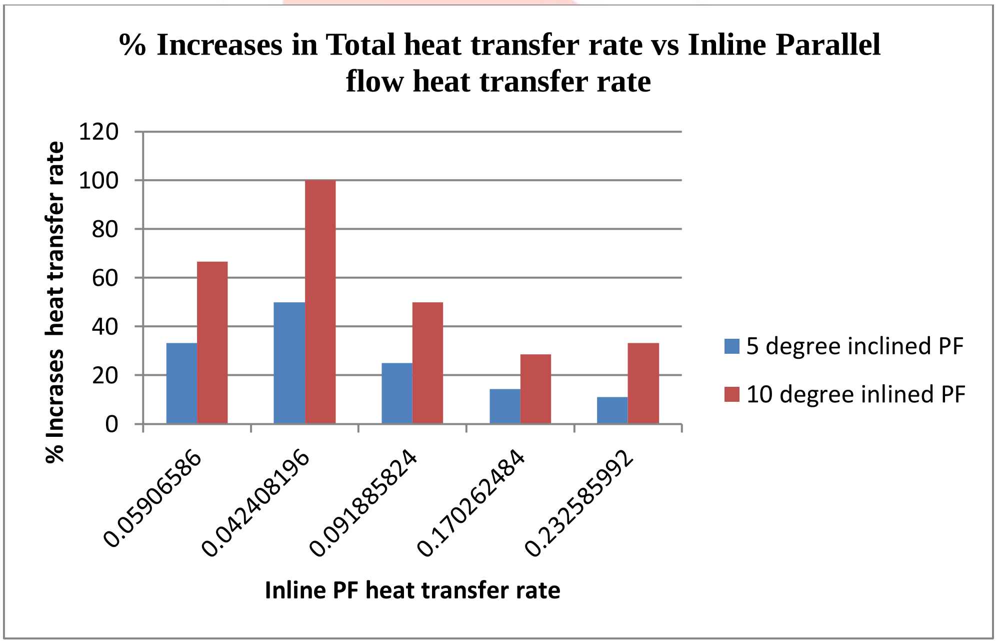


Fig. 20 % Increases in Total heat transfer rate vs Inline Parallel flow heat transfer rate

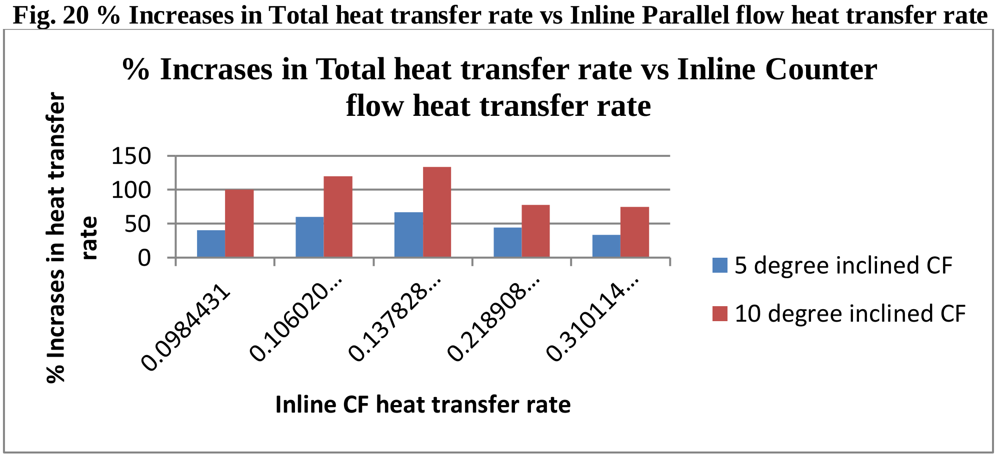


Fig. 21 % Increases in heat transfer rate vs Inline counter flow heat transfer rate

From Figure 21 concluded that
The average increase in heat transfer rate for 5 degree inclined configuration with respect to that of inline configuration is26.74 %, when the flow is parallel in both the configuration.
The average increase in heat transfer rate for 10 degree inclined configuration with respect to that of inline configuration is 55.71 %, when the flow is parallel in both the configuration.

From Figure22 concluded that
The average increase in heat transfer rate for 5 degree inclined configuration with respect to that of inline configuration is 48.88%, when the flow is counter in both the configuration.
The average increase in heat transfer rate for 10 degree inclined configuration with respect to that of inline configuration is 101.22%,when the flow is counter in both the configuration.

CONCLUSION

Experimental analysis of Effectiveness, overall heat transfer coefficient and heat transfer rate of double pipe heat exchanger with delta winglet inline configuration and delta winglet changing angle of 5 degree inclined and 10 degree inclined carried out for both parallel and counter flow. The following conclusion could be made:

- The structural design of the delta winglet shows that a maximum stress is well below the allowable limit so it is safe structurally.
- The thermal analysis shows that the maximum heat flux is 31.80W/mm². The increased heat transfer rate can be attributed to higher turbulence and closer interaction of the working fluids. This is achieved with the complex design of delta winglet to create turbulence.
- LMTD decreases with increase in mass flow rate of water.
- The effectiveness, Overall heat transfer coefficient and heat transfer rate increases with the increases in change in angle of delta winglet holder have better thermal performances than inline configuration of delta winglet holder for both the cases.
- 3-D printed delta winglet holder of 5 degree and 10 degree inclined configurations enhance the average effectiveness by 0.1179 and 0.1415 times in parallel flow and 0.2048 and 0.2878 times in counter flow that of inline configuration respectively.
- 3-D printed delta winglet holder of 5 degree and 10 degree inclined configurations enhance the average overall HTC by 0.2634 and 0.3243 times in parallel flow and 0.5220 and 0.7466 times in counter flow that of inline configuration respectively.
- 3-D printed delta winglet holder of 5 degree and 10 degree inclined configurations enhance the average heat transfer rate by 0.14 and 0.17 times in parallel flow and 0.25 and 0.33 times in counter flow that of inline configuration respectively.
- The average increase in heat transfer rate for 10 degree inclined configuration with respect to that of inline configuration is 55.71 %, when the flow is parallel in both the configuration.
- The average increase in heat transfer rate for 10 degree inclined configuration with respect to that of inline configuration is 101.22%,when the flow is counter in both the configuration.
- From the results it can be concluded that the performance of 10 degree inclined configuration of 3-D printed delta winglet holder double pipe heat exchanger is much better than that of inline configuration of heat exchanger, therefore improvement in the energy saving lead to validate its use in different applications.

FUTURE SCOPE

Other natural working fluids apart from water need to be tested using ABS polymer material in Double pipe heat exchanger.
Heat transfer increasing methods are used in areas such as cooling in condensers and evaporators of air-conditioning equipment, thermal power plant engineering, space research vehicles, automobile, etc. So further to this design, minor modifications in angular variations and placements of the delta winglets can be tested to see if higher heat transfer rates can be achieved.

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