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# HEAT TRANSFER AND FLUID FLOW CHARACTERISTICS THROUGH U-TUBE HEAT EXCHANGER WITH CFD ANALYSIS

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***Abstract :*** The biggest difference about u tube heat exchanger compared with other types of heat exchanger is the tube buddle structure, the longer the tube diameter is , the longer the minimum bending radius is. And the u tube heat exchanger bending radius should not less than two times the outer diameter of the heat exchanger tube. U tube heat exchanger usually designed according to the ASME Code, Section VIII, and division 1. This high load U tube heat exchanger can prevent the stress damage caused by container inflation during the process of heating or cooling. All past studies on this topic was experimental based. The present study is based on CFD (Computational Fluid Dynamics) technique used to find out better design for u-tube heat exchanger. In this study nano fluid with 0.03% of al2O3 particles is used as cold fluid. And 3 different designs of u-tube heat exchanger is designed and analyzed with help of CFD analysis.

***Keywords* – Heat exchanger, Twisted tape insert, Nano Material, Heat transfer mechanism**

## 1. Introduction

Double-pipe heat exchangers (DPHE) are devices that exchange heat between two fluids of different temperatures that are separated by a solid wall. They are utilized in a wide variety of applications including refrigeration, air conditioning, power plants, and petroleum refineries, among others. The DPHE is one of the simplest types of heat exchangers and consists of two concentric pipes of different diameters. One fluid in a double-pipe heat exchanger flows through the smaller inside pipe while the second fluid flows through the annular space between the two pipes.

In a double-pipe heat exchanger, heat is transferred from the hot fluid to the wall separating the two concentric pipes by conduction. Then, heat is transferred through the wall by convection. Finally, heat is transferred from the wall to the second fluid in the annular space by convection. It is desirable to use an inner pipe of a small diameter and made of a material with a high conductivity to minimize the conduction resistance between the two fluids. In addition, it is often assumed that the outer surface of the heat exchanger is perfectly insulated, or adiabatic (i.e. no heat is lost to the surroundings). Finally, heat exchangers can be assumed to be steady-flow devices as they typically operate for long durations of time without changes in their operating conditions. [1]

Due to the simplicity and wide usage of double-pipe heat exchangers in industrial applications, it is highly desirable to improve their effectiveness. This is often done through various heat transfer enhancement techniques. For example, artificially roughening the surface of the pipes (or utilizing fins) can drastically increase the heat transfer rate when the flow is turbulent.

Figure 1: U tube heat exchanger

**THEORY**

The double-pipe heat exchanger is one of the simplest types of heat exchangers. It is called a double-pipe exchanger because one fluid flows inside a pipe and the other fluid flows between that pipe and another pipe that surrounds the first. Flow in a double-pipe heat exchanger can be co-current or counter-current.

In a heat exchanger the log-mean temperature difference is the appropriate average temperature difference to use in heat transfer calculations. The equation for the log-mean temperature difference is

$$\Delta T_{LM} = \frac{(T_{i,o} - T_{o,i}) - (T_{i,i} - T_{o,o})}{\ln\left(\frac{T_{i,o} - T_{o,i}}{T_{i,i} - T_{o,o}}\right)}$$

**Trapezoidal-Cut Twisted Tapes**

The trapezoidal-cut twisted tapes are made of 1.00 mm thick aluminium strips, the width of the strip being 1 mm less than the inside diameter of the test section tube. The strips are twisted on a lathe by manual rotation of the chuck. The twist ratio (y) for this strip is defined as the ratio between one length of twist (or) pitch length to diameter. The full-length twisted tape has its trapezoidal–cut dimensions as 6 mm deep, 6 mm at its base and 10 mm wide at its top. The trapezoidal-cut is taken alternately on both top and bottom of the tape to improve the fluid mixing near the inner walls of the pipe. The schematic of this trapezoidal cut test section is shown in Fig. 2

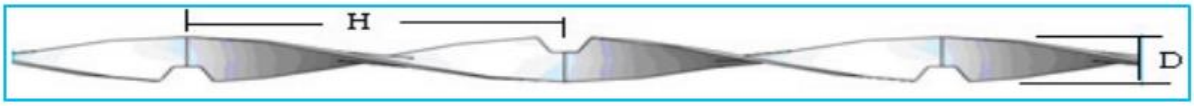


Figure 2: Schematic representation of trapezoidal-cut twisted tape [2]

## 2. Literature Review

[2] The heat transfer coefficients and the corresponding friction factors required for performance analysis are determined taking into account the typical operating conditions of the heat exchangers in turbulent flow regimes with particle volume concentration of 0.01% and 0.03% and twist ratios ranging between 5 and 20. Experimental data is generated at flow rates ranging from 0.0333 kg/s to 0.2667 kg/s. Experimental data is generated with water and nanofluid for Reynolds number in the range 3000<Re<30000, the Nusselt number of entire pipe for 0.03% concentrations of nanofluid with trapezoidal-cut twisted tape inserts of H/D = 5 is enhanced by 34.24% as compared to water. The friction factor of entire pipes for 0.03% concentration of nanofluid with trapezoidal-cut twisted tape inserts of H/D=5 is enhanced by 1.29 times as compared to water. The results of the investigation indicate an enhancement in the performance parameters of the heat exchanger namely heat transfer coefficient and friction factor with an increase in volume concentration of the nanoparticle.

[3] This study aims to investigate hydrodynamic and heat transfer characteristics of a BFB reactor with immersed heat exchange tubes for CO2 methanation using a two-dimensional (2D) gas-solid Eulerian computational fluid dynamics (CFD) model. A reaction kinetics model for Ni-based catalyst was coupled with the CFD model. The 2D-CFD model with the Huilin and Gidaspow drag was validated with experimental data for the bed expansion of Geldart B particles according to gas velocity. It was demonstrated that the heat of reaction was effectively removed in the BFB reactor with a 25% heat exchange area and that the reactor maintained isotherm conditions. The CO2 conversion was 92% in the BFB reactor at 400 °C and 5 bar. The overall heat transfer coefficient from the bed to the heat exchange tubes was estimated at 114 W/m2/K for an inlet gas velocity of 0.13 m/s.

[4] The present study investigates the thermo-fluid characteristics of a double pipe heat exchanger (DPHX) with split longitudinal fins (SLF) on the annulus side. The studied tubes with SLF are a modification of the

conventional longitudinal finned tubes (LF) that allows for consecutive surface interruptions to break the boundary layer and provide an interrupted fluid passage along the flow length. The study is conducted using a high Prandtl number fluid (engine oil) with variable thermo-physical properties. Three-dimensional computational fluid dynamics (CFD) simulations are carried out under laminar flow conditions for configurations with a fin split interval between 0.333 and 0.166 m. A comparative analysis of the SLF configurations against the reference LF configuration is conducted based on fluid flow, heat transfer rate, and required pumping power. Furthermore, by evaluating integrated quantities such as the axially local heat transfer coefficient, total pressure, and bulk fluid temperature, it is noted that the main advantage of SLF is to repeat an entrance region-like effect along the flow length. The results demonstrate that the heat transfer rates in annulus equipped with SLF are higher than those with conventional LF by 31%–48% for the same pumping power and unit weight.

[5] In this study, turbulent flow characteristics of CuO-water nanofluid through heat exchanger pipe enhanced with louvered strips are numerically investigated. Nanoparticles volume fraction ($\phi$) varied from 0 to 2%. The louvered strips are mounted in single and double geometries. The slant angle ($\theta$) and the Reynolds number (Re) are within $15° - 25°$ and between 5000 and 14,000, respectively. (RNG) $k - \epsilon$ model is employed based on the finite volume technique. The results illustrated that strong flow disturbance between the wall and the louvered strip is the main reason for turbulent kinetic energy increment. Besides, the nanoparticles improve the thermophysical properties of the working fluid, which results in better heat transfer. The Nu number increases 15.6% by using nanofluid instead of water at Re = 14000. The highest thermal enhancement parameter of 1.99 is obtained at Re = 14000 by using double perforated louvered strip with $\theta = 25°$. The recirculating flow inside the holes can significantly improve the thermal performance.

[6](Murali, Nagendra and Jaya, 2019) Heat transfer and friction factor characteristics of a circular tube fitted with full length twisted tape trapezoidal cut were studied for the Reynolds number range of 2000-12,000. The secured experimental data from plain tube were validated with standard correlations to make sure the authorization of experimental results. The thermal performance of trapezoidal cut twisted tape increase significantly than the plain tube. Performance ratio is more than unity is reasonable for trapezoidal cut twisted tape. Eventually twisted tape with water as the working fluid was compared with $Fe_3O_4$ Nanofluid as working fluid at a volume concentration of 0.06%.

[7]This paper describes a compound porous media model approach for numerical analysis to investigate the aero-thermal performance and characteristics of a flat top U-tube heat exchanger. The heat exchanger was considered as a combination of three sections; vertically straight tube section, bent tube section, and horizontally straight tube section. The porous media coefficients were obtained by using empirical correlations for the pressure drop and heat transfer for each section. The numerical results of the compound porous media model were compared to those of a conjugate heat transfer (CHT) CFD analysis, considering real tube geometry and experiments in order to validate the proposed compound porous media approach. The validation revealed that the proposed approach provides reasonable flow and heat transfer characteristics as well as the overall aero-thermal performance of the flat U-tube heat exchanger, with a considerable reduction of the required computational power.

[8] Enhancing the heat transfer rate in a double pipe heat exchanger is imperative for decreasing the overall cost of its operation. A popular way to increase the performance of these heat exchangers is using inserts such as twisted tape, perforated twisted tape, twisted tape with peripheral cuts, helical inserts, etc. In this paper, a novel triangular perforated twisted tape with V cut (TPTTV) has been introduced and numerical investigation has been carried out. The proposed inserts is placed in the inner pipe of the double pipe heat exchanger to create a swirl motion and increase turbulence intensity in the flow of the fluid. The simulation

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has been performed in the laminar flow region to turbulent flow regimes. It is found the best thermal–hydraulic performance at the lower pitch value of 50 mm. The effect of the pitch of the TPTTV insert has been extensively studied and the effect of overall heat transfer, Nusselt number, friction factor, and thermal–hydraulic factor has been reported. The value of the thermal performance factor for TPTTV insert is 1.49 which is more than the thermal performance factor of plain twist tape insert.

[9] The double helically coiled tube heat exchanger increases the turbulence and enhances the maximum heat transfer rate than the straight tubes. In this investigation, the heat transfer and pressure drop of the double helically coiled heat exchanger handling MWCNT/water nanofluids have been analyzed by the computational software ANSYS 14.5 version. The computational analysis was carried out under the laminar flow condition in the Dean number range of 1300–2200. The design of new shell and double helically coiled tube heat exchanger was done by using standard designing procedure and 3D modeling was done in Cre-O 2.0 parametric. The Finite Element Analysis software ANSYS Workbench 14.5 was used to perform CFD analysis under the standard working condition. The MWCNT/water nanofluids at 0.2%, 0.4%, and 0.6% volume concentrations have been taken for this investigation. It is studied that the heat transfer rate and pressure drop increase with increasing volume concentrations of MWCNT/water nanofluids. It is found that the Nusselt number of 0.6% MWCNT/water nanofluids is 30% higher than water at the Dean number value of 1400 and Pressure drop is 11% higher than water at the Dean number value of 2200. It is found that the simulation data hold good agreement with the experimental data. The common deviation between the Nusselt number and pressure drop of CFD data and the Nusselt number and pressure drop of experimental data are found to be 7.2% and 8.5% respectively.

[10](Kumar et al., 2018) Inserts are used to enhance the heat transfer rates between the two fluids in heat exchanger tubes. A variety of tube inserts such as twisted tape, wire coil, swirl flow generator have been investigated for their effect on heat transfer rates and fluid friction. This paper reviews the works pertaining to the application of different class of tube inserts in order to comprehend the prevailing mechanism of fluid flow and heat transfer. An attempt has been made to elucidate the fluid flow behaviour sustained by the particular class of insert that controls the heat transfer rates across the thermal boundary layer attached to the tube wall.

## 3. Methodology

Expected Procedure to be followed during the complete study:

Double pipe U-tube heat exchanger is designed as per selected dimension criteria. Further converting file into .STP format then this file is imported in Ansys Fluent for performing the simulation in Ansys. Inlet and outlet of flow is defined by giving name to different sections of both pipes. Meshing is performed for u-tube heat exchanger and connection is checked throughout model of U-tube heat exchanger. Material properties are assigned to different fluid and pipe wall. Boundary conditions were applied on the model according to the base paper. Setting the proper setup for CFD analysis procedure. Evaluating the results after the finish of simulation work.

### 3.1. Design

Double pipe heat exchanger is designed in 3 parts which are: inner tube, annulus tube (outer tube) and trapezoidal cut aluminum strip. And overall length of pipe is selected as 5 m which is curved from middle of the pipe. The inner tube is chromium steel and it has an inner diameter (ID) of 0.019 m, and the annulus tube is made of cast iron with an ID of 0.05 m. The total length of the inner tube is 5m and the bend is equidistant from both ends at a distance of 2.5 m; with radius of 0.160 m. The inner tube is concentric to the annulus tube and fully enclosed by it.

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Figure 3: design 1 with aluminum strip inside inner tube

Design 1 is designed according to the base paper design for validation of double pipe u-tube heat exchanger with the paper. In this design trapezoidal cut strip is placed inside inner tube by which nano fluid is flowing.

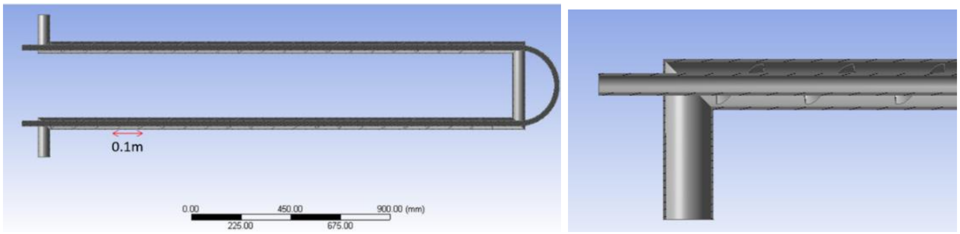


Figure 4: design 2 with spiral strip over inner tube

Design 2 is designed with having spiral cross section over the inner tube which is place for creating turbulence to the hot fluid and by the placement of this, hot fluid can have better contact with the inner pipe.

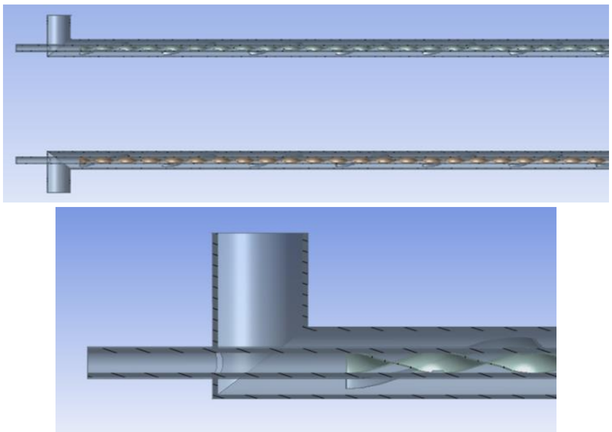

Figure 5: design 3 with both spiral section at outer side of inner tube and aluminum strip inside inner tube

Design 3 is a combination of both design 1 and design 2. In this design both aluminum strip and spiral section at outside of inner tube is provided. Which can direct to better heat transfer rate between both the fluids.

## 3.2. Materials

- **Properties of water**

| Properties | Value |
|---|---|
| Thermal conductivity$(Wm^{-1}K^{-1})$ | 0.6 |
| Density $(Kg/m^3)$ | 998 |
| Specific heat$(J/KgK)$ | 4182 |

- **Properties of steel**

| Properties | Value |
|---|---|
| Thermal conductivity$(Wm^{-1}K^{-1})$ | 16.27 |
| Density $(Kg/m^3)$ | 8030 |
| Specific heat$(J/KgK)$ | 502.48 |

- **Properties of cast iron**

| Properties | Value |
|---|---|
| Thermal conductivity$(Wm^{-1}K^{-1})$ | 52 |

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| | |
|---|---|
| Density $(Kg/m^3)$ | 7200 |
| Specific heat$(J/KgK)$ | 460 |

- **Properties of Nano fluid having 0.03 % $Al_2O_3$**

| Properties | Value |
|---|---|
| Thermal conductivity$(Wm^{-1}K^{-1})$ | 0.665 |
| Density $(Kg/m^3)$ | 1085.65 |
| Specific heat$(J/KgK)$ | 3778.88 |

### 3.3. CFD Model formulation

Fluent Release 19.0 was used for running the CFD analysis for this study. The use of averaged fluid equation of Reynolds is made for solving the continuous air flow issue. The establishment of this used model is made by utilizing discretization scheme of 2nd order. Its use is also made for coupling of pressure and velocity. In accordance of the indication made preciously, for refining the simulations and for obtaining better and satisfying outcomes, the defining of convergence criteria is made as: for the movement and continuity equation, when there is an enough reduction in residuals to make it below 10-3 then the convergence is said to be satisfied. For the energy equation, it is satisfied when the residuals reaches the value below 10-6.

k-omega model is used in this CFD process and energy is turned on. And the equations which are involve in this study are mentioned below:

**Navier-Stokes Equation**

The Navier-Stokes equations govern the motion of fluids and can be seen as Newton's second law of motion for fluids.

$$\rho \frac{D\vec{V}}{Dt} = \rho\vec{g} - \nabla P + \mu\nabla^2\vec{V}$$

where,

$$\frac{D}{Dt}(\vec{V}) = \frac{\partial}{\partial t}(\vec{V}) + u\frac{\partial}{\partial x}(\vec{V}) + v\frac{\partial}{\partial y}(\vec{V})$$

$$\nabla^2(\vec{V}) = \frac{\partial^2}{\partial^2 x}(\vec{V}) + \frac{\partial^2}{\partial^2 y}(\vec{V})$$

**Continuity Equation**

According to the Continuity Equation, if no fluid is added or removed from the pipe in any length then the mass passing across different sections shall be the same. This is in accordance with the principle of conservation of mass which states that matter can neither be created nor be destroyed.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$

**Momentum Equation**

Linear momentum equation for fluids can be developed using Newton's 2nd Law which states that sum of all forces must equal the time rate of change of the momentum, ΣF = d(mV)/dt. This easy to apply in particle mechanics, but for fluids, it gets more complex due to the control volume.

- x – momentum: $$\rho\frac{D}{Dt}(u) = \rho g_x - \frac{\partial P}{\partial x} + \mu\nabla^2(u)$$
- y – momentum: $$\rho\frac{D}{Dt}(v) = \rho g_y - \frac{\partial P}{\partial y} + \mu\nabla^2(v)$$
- z – momentum: $$\rho\frac{D}{Dt}(w) = \rho g_y - \frac{\partial P}{\partial y} + \mu\nabla^2(w)$$

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### 3.4. Meshing

Meshing is the process in which the continuous geometric space of an object is broken down into thousands or more of shapes to properly define the physical shape of the object. The more detailed a mesh is, the more accurate the 3D CAD model will be, allowing for high fidelity simulations. Meshing, also known as mesh generation, is the process of generating a two-dimensional and three-dimensional grid; it is dividing complex geometries into elements that can be used to discretize a domain. Since meshing typically consumes a significant portion of the time in acquiring simulation results, advanced automated meshing tools can provide faster and more accurate solutions.

### 3.5. Boundary condition

The mass flow rate of hot fluid through annulus is kept constant (0.095 kg/s) and the working fluid mass flow rate is varied from 0.033 kg/s to 0.26 kg/s which is varying according to Reynolds number change. And the inlet temperature of cold fluid is selected as atmospheric temperature and hot fluid inlet temperature is selected as 70ºC. Nano fluid is selected as cold fluid and water is selected as hot fluid whereas inner tube pipe material is made of chromium steel and annulus tube is made of cast iron.

## 4. Result and discussion

### 4.1. Validation result

Table 1: validation

| | Base paper | Validate |
|---|---|---|
| Reynolds number | 27000 | 26309.1 |
| Nusselt number | 175 | 170.5 |
| Friction factor | 0.0275 | 0.02480 |

**Reynolds nmber calculation**

$$R_e = \frac{\rho V D}{\mu}$$

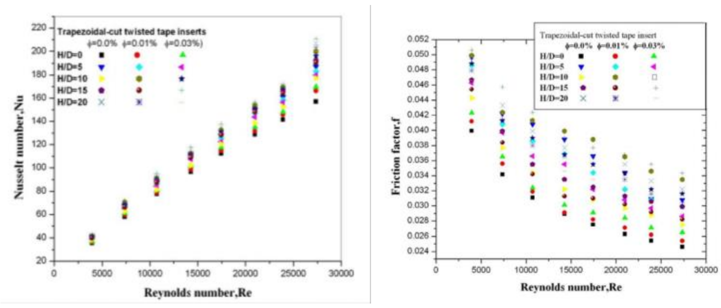
**Nusselt number calculation**

$$Nu = 5 + 0.015 Re^{0.856} Pr^{0.347}$$
$$Nu = 0.021 Re^{0.8} Pr^{0.5}$$

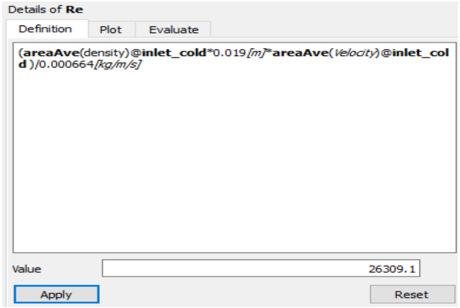
Prandtl number(Pr)= 10.309

**Friction factor calculation**

$$f = \frac{0.317}{Re^{\frac{1}{4}}}$$




(a) (b)




(c)

Figure 6: (a) Nusselt number in base paper (b) friction factor in base paper (c) Reynolds number calculation

Above figures is showing the validation results in which base paper results are matched with same boundary conditions. It can be seen that at Reynolds number 27000, Nusselt number is 175 and in this study Reynolds number is 26309.1 and Nusselt number at this Reynolds number is 170.5 which is almost similar to the base paper results. Friction factor at this Reynolds number is 0.02480 which is almost similar to the base paper results which is 0.0275.

**Hot fluid temperature**

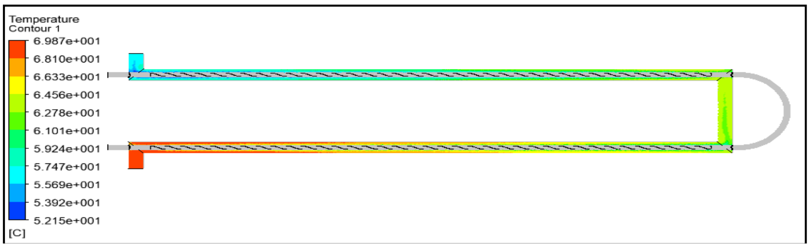



Figure 7: Hot fluid temperature contour

Above figure shows temperature contour of hot fluid and the maximum temperature is obtained as 69.87 ºC which is found at inlet section and the temperature is decreasing throughout length of double pipe u tube heat exchanger, minimum temperature of 52.15 ºC is obtained at outlet section of hot fluid. Temperature decreased because of the heat exchange between both the pipes.

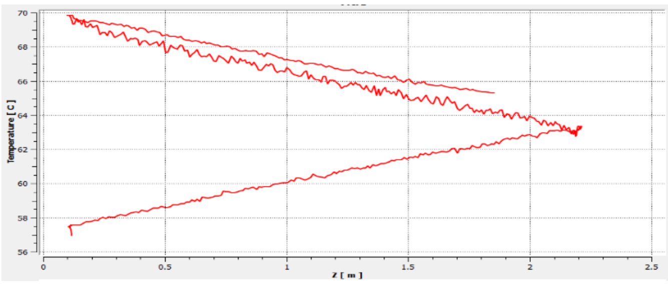



Figure 8: hot fluid variation throughout length of heat exchanger

Above graph is showing the temperature decreasing throughout the length of u-tube heat exchanger. it can observed that hot fluid is releasing heat throughout length because of the contact of cold fluid inside inner tube.

**Cold fluid temperature**

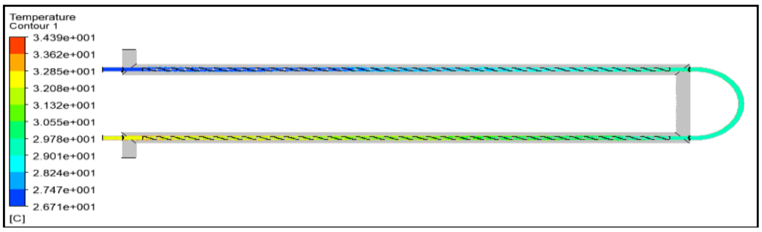



Figure 9: cold fluid temperature contour

Above figure shows temperature contour of cold fluid and the minimum temperature is obtained as 26.71 ºC which is found at inlet section and the temperature is increasing throughout length of double pipe u tube heat exchanger, maximum temperature of 34.39 ºC is obtained at outlet section of cold fluid. Temperature of cold fluid is increased because it absorbed hot fluid temperature throughout the length of double pipe heat exchanger.

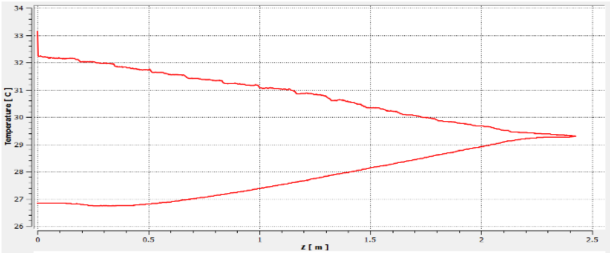


Figure 10: cold fluid variation throughout length of heat exchanger

Above graph is showing that temperature increasing throughout the length of u-tube heat exchanger. It can observed that cold temperature is increasing because it is absorbing hot fluid temperature.

### 4.2. Design-2 results

**Hot fluid temperature**

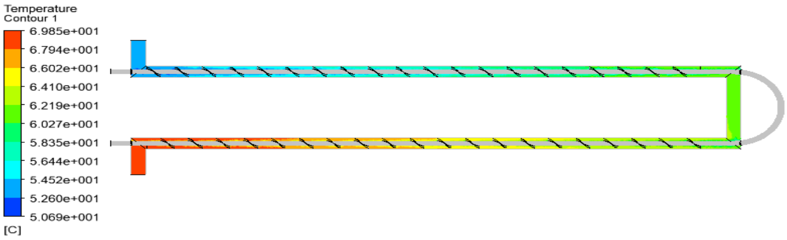



Figure 11: Hot fluid temperature contour

Above figure shows temperature contour of hot fluid in design 2 which have spiral sections at outside of inner tube which will affect flow of hot fluid because of which temperature of hot fluid will decrease more rapidly as compared to without spiral section case. The maximum temperature is obtained as 69.85 ºC which is found at inlet section and the temperature is decreasing throughout length of double pipe u tube heat exchanger, minimum temperature of 50.69 ºC is obtained at outlet section of hot fluid. Temperature decreased because of the heat exchange between both the pipes.

**Cold fluid temperature**

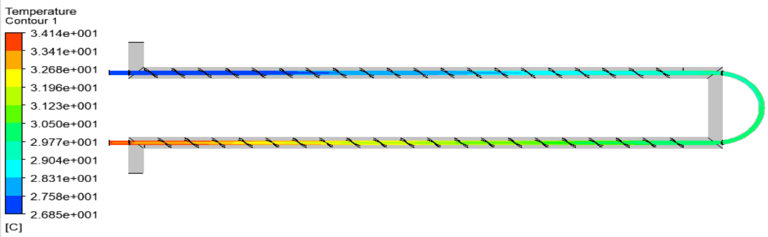



Figure 12: cold fluid temperature contour

Above figure shows temperature contour of cold fluid and the minimum temperature is obtained as 26.85 ºC which is found at inlet section and the temperature is increasing throughout length of double pipe u tube heat exchanger, maximum temperature of 34.14 ºC is obtained at outlet section of cold fluid. Temperature of cold fluid is increased because it absorbed hot fluid temperature throughout the length of double pipe heat exchanger.

### 4.3. Design-3 results

**Hot fluid temperature**

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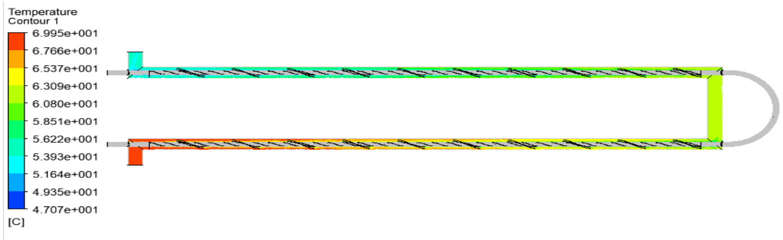


Figure 13: Hot fluid temperature contour

Below figure shows temperature contour of hot fluid in design 3 which have both spiral sections at outside of inner tube and aluminium strip inside inner tube which will affect flow of hot fluid and cold fluid because of which temperature of hot fluid will decrease more rapidly and temperature of cold fluid will increase as compared to above cases. The maximum temperature is obtained as 69.95 ºC which is found at inlet section and the temperature is decreasing throughout length of double pipe u tube heat exchanger, minimum temperature of 47.07 ºC is obtained at outlet section of hot fluid. Temperature decreased because of the heat exchange between both the pipes.

**Cold fluid temperature**

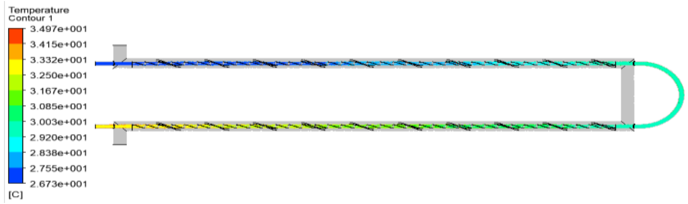


Figure 14: cold fluid temperature contour

Above figure shows temperature contour of cold fluid and the minimum temperature is obtained as 26.73 ºC which is found at inlet section and the temperature is increasing throughout length of double pipe u tube heat exchanger, maximum temperature of 34.97 ºC is obtained at outlet section of cold fluid. Temperature of cold fluid is increased because it absorbed hot fluid temperature throughout the length of double pipe heat exchanger.

### 4.4. Comparison

Table 2 showing temperature at outlet of hot fluid and cold fluid in all 3 cases. In case 1 hot outlet temperature and cold outlet temperature is 52.15 ºC and 34.39 ºC respectively. And in case 2 hot outlet temperature and cold outlet temperature is 50.69 ºC and 34.14 ºC respectively. In case 3 hot outlet temperature and cold outlet temperature is 47.07 ºC and 34.97 ºC respectively. And it can be concluded that design 3 is providing better results as comparison of other 2 designs in comparison to hot outlet temperature.

Table 2 temperature at outlets

| | Hot Temperature | Cold Temperature |
|---|---|---|
| Design 1 | 52.15 | 34.39 |
| Design 2 | 50.69 | 34.14 |
| Design 3 | 47.07 | 34.97 |

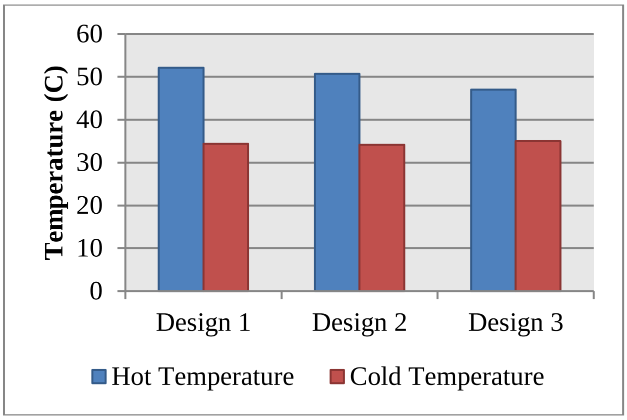


Figure 15: temperature in all 3 designs

Above figure shows chart for outlet temperature of hot and cold fluid in all 3 designs and this is the graphical formations of table 2. It can be seen that design 3 provides less outlet temperature of hot fluid which is the primary requirement of the double pipe heat exchanger.

## 5. Conclusion

In this study double pipe heat exchanger analysed with help of computational fluid dynamics (CFD). In this double pipe heat exchanger water is selected as hot fluid and Nano fluid with 3 % of Al2o3 particles and distilled water mixture is selected as cold fluid which is inserted at atmospheric temperature which flows inside inner tube whereas 70 ºC temperature of hot fluid which is inserted inside annulus tube. And 3 different designs are selected in which aluminum strip inside inner tube and spiral section at outside of inner tube is used for providing turbulence to the fluids. It can be concluded that hot fluid got cooled to 52.15 ºC, 50.69 ºC and 47.07 ºC in design 1, design 2 and design 3 respectively at same boundary conditions whereas temperature of cold fluid increased at almost same level in all 3 cases. By these results it can be concluded that design 3 which have both aluminum strip and spiral section at outside of inner tube provides better results and it can be more effective with same parameters.

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