Experimentation on Fabrication of Double Pipe Heat Exchanger

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Abstract: A heat exchanger is a piece of equipment designed to transfer heat from one medium to another efficiently. It relies on the conduction, convection, and radiation principles with fluids flowing against one another. There are many other forms of heat exchange, but we choose the double pipe heat exchanger since it has two pipes (outer pipe with cold fluid and inner pipe with hot fluid). The goal is to maximize the rate of heat transfer while monitoring the mass flow rates of the two fluids. In order to achieve this, we placed washers between the outer and inner pipes at a certain distance, which would lower the speed of the cold fluid and increase the efficiency of the heat transfer rate. They are extensively utilized in power plants, chemical and petrochemical facilities, oil refineries, sewage treatment facilities, air conditioning, refrigeration, and space heating systems. A heat exchanger is most commonly seen in internal combustion engines, where engine coolant circulates through radiator coils as air passes by, cooling the coolant and heating the incoming air.
Keywords: Double pipe heat exchanger, Inserts, Heat transfer Enhancement, Slots.

I. INTRODUCTION

A heat exchanger is a device that exchanges heat between two fluids that are separated by a solid wall and are at different temperatures. This heat transmission is achieved by the temperature gradient or temperature variations. Radiation, conduction, and convection are the three primary techniques through which heat is transferred. Radiation is involved in the utilization of heat exchangers. Radiation does not have a significant impact compared to conduction and convection, though. As the heat from the hotter fluid goes through the solid wall, conduction takes place. To enhance heat transfer, the wall should be thin and made of a highly conductive material. Convection plays a major role in a heat exchanger's ability to transmit heat.

One of the most basic forms of heat exchangers is the double-pipe heat exchanger. Due to the fact that one fluid runs within one pipe and another fluid flows between that pipe and another pipe that surrounds the first, it is known as a double-pipe exchanger. Concentric tubes are used to make this. There are two flow configurations: co-current and counter-current. Co-current is when the flow of the two streams is in the same direction, and counter-current is when the flow of the two streams is in opposing directions. A double-pipe heat exchanger allows for either co-current or counter-current flow.

Inlet temperatures, flow rates, fluid properties, fluid composition, etc., as well as the quantity of heat transmitted, all vary inside the pipes. The process temperatures shift as a result of this transitory behaviour, eventually causing the temperature distribution to stabilize. The temperature of the fluids varies when heat starts to be conveyed. These temperatures are time-dependent until they reach a stable state.

In this double-pipe heat exchanger, hot fluid flow moving through the inner pipe transfers heat to cooling water moving through the outer pipe.

Until a condition, such as the flow rate or inlet temperature, changes, the system is in a steady state. The temperature distribution varies as a result of these conditions changing over time until a new steady state is reached. Once the process and coolant fluid's inlet and outlet temperatures are stable, the new steady state will be observed. Although the temperatures will never be totally constant in practice, a relatively steady state can be experimentally demonstrated when the inlet temperatures or flow rates are changed sufficiently.

A. Heat Augmentation Techniques

In general, the techniques for heat transfer enhancement can be divided into two categories:

1) Active Method

Active method, it employs additional power from outside sources, which include mechanical aids, surface-fluid vibration, fluid injection and suction, jet impingement, and electrostatic fields.

2) Passive Method

The alternative option is the passive method, which does not require the use of external power. Surface coatings, wavy surfaces, rough and extended surfaces, convoluted (twisted) tubes, liquid and gas additives, turbulators (coil wire, conical ring, and conical nozzle), and swirl/vortex generators (twisted tape, helical screw tape, axial /radial guide vane, tangential inlet nozzle, and snail entrance) are all part of the passive method. Swirl/vortex flow devices are a type of passive enhancement technology. Twisted tape is one of the most important members of this group, and it is widely used in various heat exchange systems, including solar water heaters, heat exchanger systems, refrigeration systems, and the chemical process industry.

3) Compound Method

This approach incorporates both of the previously mentioned methods at the same time, resulting in a higher improvement in heat transmission than either method employed alone. It combines the benefits of passive and active strategies.

B. Problem Definition
1) The problem at hand is to create a heat exchanger that can transfer heat from a higher temperature fluid to a lower temperature fluid.
2) The design should seek to increase heat transmission while minimizing the overall dimensions of the exchanger to create a more compact unit.
3) The heat exchanger must address fouling and corrosion issues, which can affect its efficiency and longevity.
4) The goal is to develop a highly efficient and long-lasting heat exchanger that meets all of these standards while also providing reliable, efficient performance.

C. Objective Of The Project

The enhancement of heat transfer in a heat exchanger is widely applied in industries due to the need for a more compact heat exchanger, a lower operating cost, energy savings, as well as ecological benefits. Inducing washers with different slot configurations can be used as heat transfer enhancement devices in heat exchangers. Effects induced are
1) To increase heat transfer rate.
2) To increase the heat transfer coefficient.
3) To reduce the size of the heat exchanger.
4) To reduce floor area.

D. Scope Of The Work

The main goal of this research is to reduce the thermal resistance and improve the performance of thermal devices. Among various studies, passive heat transfer enhancement using twisted tapes has significantly shown good results. In our study, we developed an experimental facility to observe the heat transfer properties of forced convection heat transfer through a circular tube with washers having different slot geometries used as an insert where the fluid was passed at various flow rates.

II.   LITERATURE REVIEW

Ahire, S., Shelke, P., Shinde, B., & Totala, N. (2014). Fabrication and analysis of counter flow helical coil heat exchanger. International Journal of Engineering Trends and Technology (IJETT)–Volume, 15(5), 229-240. [1] Helical coils are efficient at a low Reynolds number due to secondary flow development, which enhances heat transfer rate. Wilson plot technique was used to determine heat transfer coefficient.

Sivakumar, K., & Rajan, K. (2015). Experimental analysis of heat transfer enhancement in a circular tube with different twist ratio of twisted tape inserts. International Journal of Heat and Technology, 33(3), 158-162. [2] This study measured heat transfer, Reynolds number, and friction factor in a concentric tube with twisted tape inserts. Results showed that the mean temperature of the twisted tube was increased from 2 to 4% compared to plain tube.

Jamra, S., Singh, P. K., & Dubey, P. (2012). Experimental analysis of heat transfer enhancement in circular double tube heat exchanger using inserts. International Journal of Mechanical Engineering & Technology (IJMET), 3(3), 306-314. [3] This study measured heat transfer, Reynolds number, and friction factor in a concentric tube with twisted tape inserts. Results showed that the mean temperature of the twisted tube was increased from 2 to 4% compared to plain tube.

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B K, Anand & Naveena, H.S. & Nagesh, R. & Cg, Prabhakar. (2017). Experimental investigation for the heat transfer of a double pipe heat exchanger. International Journal of Mechanical Engineering and Technology. 8. 203-210. [4] The researchers conducted an experiment to evaluate the performance characteristics of a double-pipe heat exchanger with a high thermal conductivity coating and pure copper pipes. Specific numerical results are not provided.

Mahato, S. K., Rana, S. C., & Barman, R. N. (2021, April). Study of heat transfer enhancement through the non-circular ducts using three dimensional numerical investigations and their comparisons. In IOP Conference Series: Materials Science and Engineering (Vol. 1128, No. 1, p. 012037). IOP Publishing. [5] The study investigated methods for enhancing heat transfer in equilateral triangular ducts. It was found that the twisted hexagonal model enhanced more heat transfer than the twisted square duct for certain Reynolds numbers. Non-circular ducts, such as hexagonally twisted channels, straight square ducts, and CW-CCW twisted square channels, can be effective in enhancing heat transfer for both laminar and turbulent regimes.

### A. Major Findings of Literature Review

The study's main findings indicate that incorporating double counter twisted tape inserts in a circular tube significantly improves heat transfer, friction factor, and thermal enhancement efficiency when compared to plain tubes. The study also reveals that as the twist ratio decreases, the efficiency of heat transfer and thermal enhancement increases, while the friction factor decreases. Furthermore, the use of nanofluids and increasing nanoparticle volume concentration enhances convective transfer of heat and increases the average Nusselt number. In addition, single twisted tape outperforms triple twisted tape and twisted tape with circular rings in terms of thermal performance factor. The study concludes that fluid flow disturbances at both the core and surface of the fluid flow are important for improving thermal performance in a heat exchanger. Finally, the use of nanofluids results in a higher thermal performance factor, indicating improved overall performance in terms of heat transfer and friction.

III. METHODOLOGY OF PROJECT

A. The Basic Approach to Using CFD

Computational Fluid Dynamics (CFD) is used as a tool for the evaluation of solutions to fluid flow problems by means of computer simulation. It involves a set of partial differentiation equations describing conservation laws for the transport of mass, momentum and energy.

Flow chart describing CFD solving step
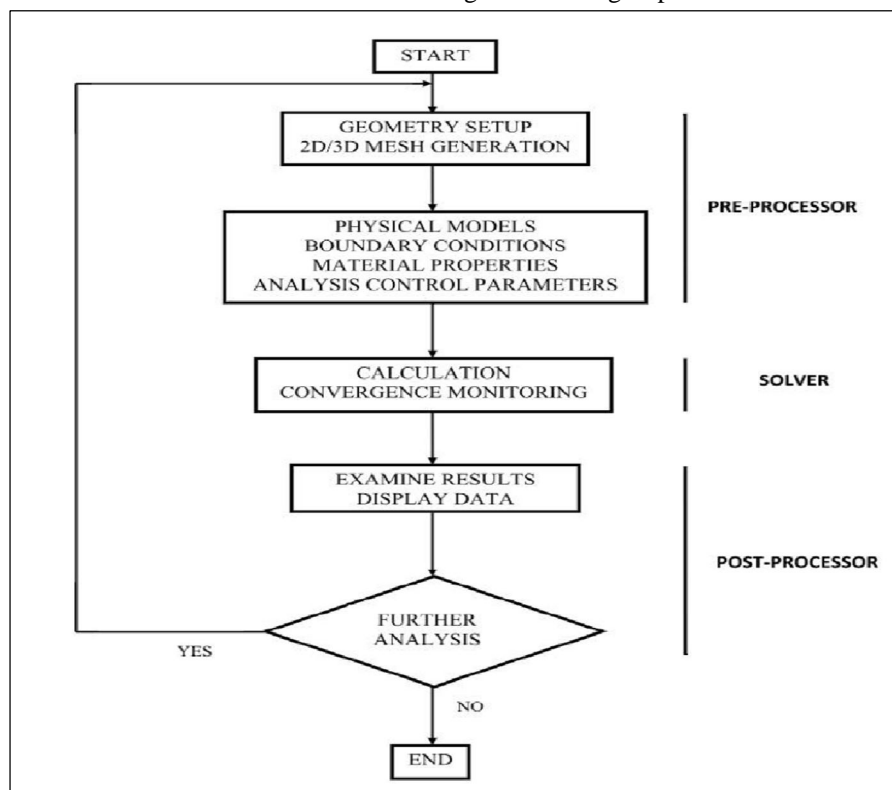
B. Pre-Processor: Establishing the model
1) Identify the process or equipment to be evaluated.
2) Represent the geometry of interest using CAD tools.
3) Use the CAD representation to create a volume flow domain.

C. Create A Computational Mesh In The Flow Domain Solver
1) Identify and apply conditions at the domain boundary.
2) Solve the governing equations on the computational mesh using analysis software.

D. Post Processor
1) Interpreting the results Post-process, the completed solutions to highlight findings.
2) Interpret the prediction to determine design iterations or possible solutions, if needed
3) Analysis and display of results.

E. Mathematical Model
In order to simulate the flow and heat transfer characteristics of Double pipe heat exchanger, k-ε RNG turbulence model with enhanced wall heat treatment is used. Considering some simplifying assumptions, the mechanism that governs fluid flow and heat transfer is due to the conservation of mass, momentum and energy. The energy and turbulence models are considered for capturing the fluid flow and thermal behaviour of the double pipe heat exchanger. These assumptions and equations for incompressible flow are discussed in this section.

F. Assumptions
1) Flow is considered to be steady and incompressible.
2) All the walls have no-slip momentum conditions and adiabatic conditions applied for all other walls being insulated.
3) The pressure force and viscous force alone drive the flow.
4) No source terms are included in the model.
5) No phase change and no heat generation within the heat exchanger.

Table 1: Heat Exchanger Dimensions (in mm)

Sr no	Description	Value
1	Inner pipe ID	18
2	Inner pipe OD	20
3	Outer pipe ID	38
4	Outer pipe OD	36
5	Length of pipes	1000
6	Washer Diameter	35
7	Slots	11

Table 2: Boundary conditions

Material /properties	Hot Water	Cold Water
Mass flow rate (kg/s)	0.02	0.02
Temperature (K)	383	293

IV.   CALCULATIONS

Length of pipe = 1 m

Pipe 1 = Inner dia. 18mm

Pipe 2 = Inner Dia. 38mm

cp for water = 4.18 kJ/kgC

m for water = 0.16 kg/s

1)   By Using Energy Balance Equation

$m \times cp_w \times (T_{hi} - T_{ho}) = m \times cp_w \times (T_{ci} - T_{co})$

$0.75 \times 4.18 \times (110-85) = 0.6 \times 4.18 \times (20 - T_{co})$

$T_{co} = 36.440\ ^\circ C$

2)   To Find Lmtd (Θ_m)

$\theta_1 = T_{hi} - T_{ho}$

$\theta_1 = (110 - 36.44)$

$\theta_1 = 73.56\ ^\circ C$

$\theta_2 = T_{hi} - T_{ce}$

$\theta_2 = (85-20)$

$\theta_2 = 65\ ^\circ C$

$\theta_m = \theta_1 - \theta_2 ln \theta_1 \theta_2$

$\theta_m = 73.56 - 65 ln 73.5665$

$\theta_m = 69.180\ ^\circ C$

3)   Heat Transfer Rate For Water

$Q = cp_w \times (T_{co} - T_{ci)}$

$Q = 4.18 \times (36.44-20)$

$Q = 68.71\ KJ/s$

4)   Heat Transfer Coefficient For Water

$Q = U_w \times A \times \theta_m$

$68.18 = U_w \times (0.030) \times 69.18$

$U_w = 10.53\ W/m^2/k$

5)   Required Mass Flow Rate For Water

$Q = m \times cp_{w \times} \theta_m$

$69.18 = m \times 4.18 \times 69.18$

$m = 0.23\ kg/s$

6)   NTU Of Heat Exchanger

$C_h = m \times cp_o$

$C_h = 0.36 \times 2.20$

$C_h = 0.792\ W/k$

$C_c = m \times cp_w$

$C_c = 0.23 \times 4.18$

$C_c = 0.9614\ W/k$

Capacity ratio = Cmin/Cmax = 0.9614/0.792

C = 1.213

N.T.U. = UoAoCmin

N.T.U. = 72.27 × 0.03455 × 0.9614

N.T.U. = 2.59

7) *Effectiveness Of Heat Exchanger,€*

€= 1-e-NTU(1-C)1-Ce-NTU(1-C)

€= 1-e-2.59(1-1.213)1-1.213e-2.59(1-1.213)

€=0.665

V.   EXPERIMENTAL SETUP

The experimental configuration of the concentric tube, twin pipe heat exchanger is shown in Figure 1. It will comprise a setup of a reducing section, a test section, an overhead tank for cold water supply, a constant temperature reservoir with a 5-liter capacity for hot water supply, a pump, temperature sensors, a thermostat, and a control system. The heat exchanger can operate as a parallel or counter flow exchanger by having cold water flow through the annulus and hot water through the inner pipe, which can be admitted at any one of the ends. In order to reduce heat losses to the surroundings, the exterior pipe is properly insulated with 20 mm diameter asbestos rope. To measure the flow of cold water, two calibrated rotameters with flow ranges of 0.02 to 0.1 kg/sec are employed. The water is drawn by gravity flow from an overhead tank and is at room temperature. The flow rate of hot water from the entrance hot water reservoir is also controlled by a rotameter with a similar capacity. The cold water is kept at 293 K, while the hot water is kept at 383 K. Experiments will be carried out for counter flow arrangements at different mass flow rates of hot water (m_h) ranging from 0.02 to 0.1 kg/sec with an increase of 0.02 kg/sec at each time, while keeping the mass flow rate of cold water (m_c) through the annulus constant at 0.02 kg/sec. 3000 to 24000 was the Reynold's number range in the current investigation. Each time, we recorded the temperature of the hot and cold-water outlets. With the hot water flow rate remaining constant at 0.02 kg/sec, the trials were performed in a similar manner but with different cold-water flow rates. The outcomes were contrasted with outcomes from a CFD model.
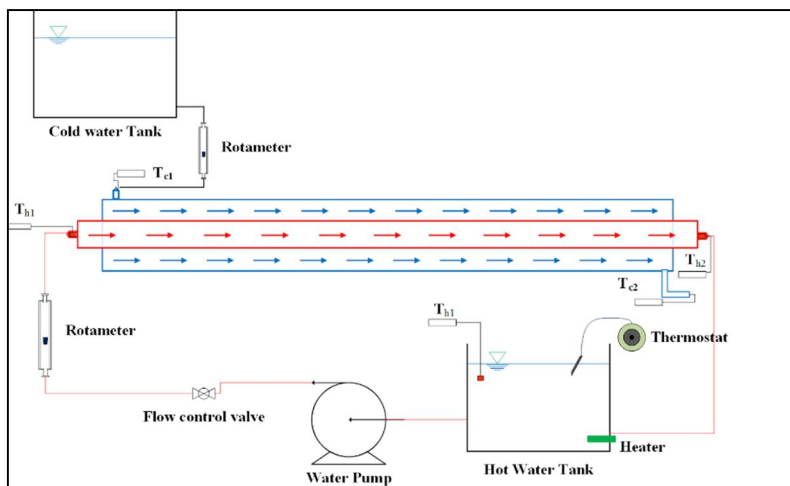

Figure 1

Components For This Experimental Research

1) *Outer Pipe*

The exterior pipe is made of mild steel. This outside pipe is used to pass cold water through. The 1000 mm length of the outer pipe. The outer pipe has a 36 mm inner diameter and a 38 mm outer diameter, respectively. The reason MS has been utilized is due to its excellent weldability, ductility with a high tensile strength, medium thermal conductivity, and excellent electrical conductivity. The resulting results were contrasted with those from the CFD model.
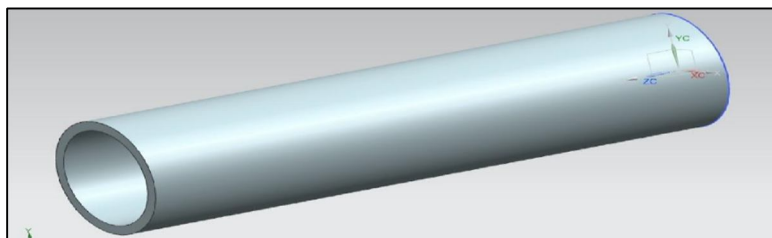

Figure 2

2) Inner Pipe

The inner pipe length being considered for the experiment is 1000 mm. This pipe has an outside diameter of 20 mm and an interior diameter of 18 mm. Aluminium was utilised to make this pipe. This pipe transports hot water.
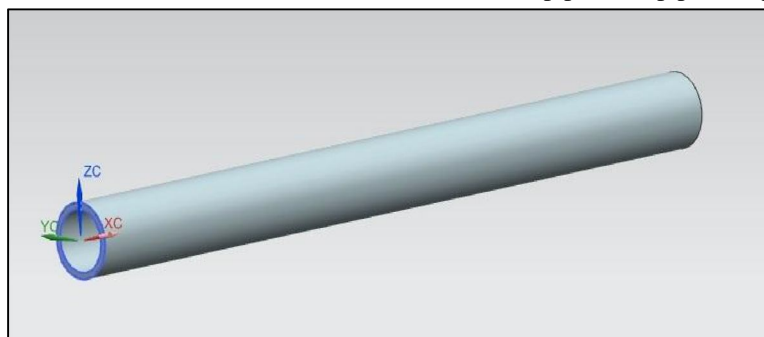

Figure 3

3) Washers

Washers are thin plate discs with holes that are often used to disperse weight. Washers are utilised as inserts in this experiment to improve the surface area for heat transmission. Washers with an outside diameter of 36 mm and an interior diameter of 20 mm were employed in this experiment. Mild steel is used to make washers. The washers with slots used in this experiment were cut with a laser cutting machine. Washers with Rectangular slots are used for this project.

Figure 4(a), (b)

4) Water Pump

A small water pump was used in this experimental setup for maintaining the water flow through the test section while heating. In this case a fountain pump was used. The water pump can sustain temperature up to 60°C of hot water. The specifications of the pump used are given below:

Table 3: Water pump Specifications

Variables	Values
Model	LSP 50
Voltage	165 V
Suction Lift	1.85 M
Power	19W
Frequency	50 Hz

Figure 5

5) Digital Temperature Sensor

The temperature of the fluid is determined using a temperature sensor. Digital temperature sensors are employed in this experiment. This instantly displays the temperature on a digital display. Their range of operation is -30 to 110°C.

Figure 6

6) Rotameter

A rotameter, also known as a variable area metre, is a device used to measure the flow rate of a fluid by allowing a simple float to float in the moving fluid. The mass flow rate calibration for Rotameter is between 0.02 and 0.1 Kg/sec. The acrylic that makes up the Rotameter can withstand water temperatures of up to 900C. In this experiment, the flow rates of hot and cold fluid are measured using two rotameters.
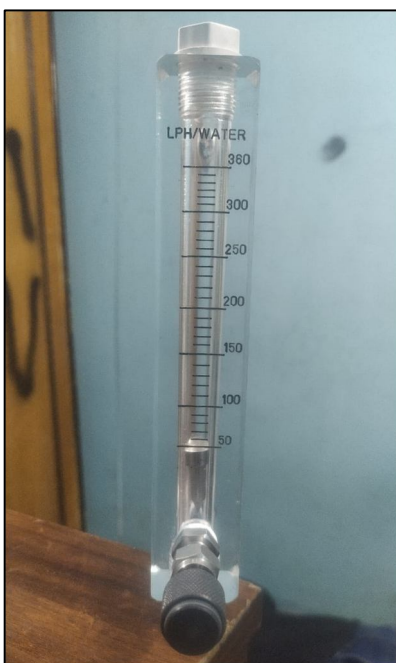

Figure 7

VI.   EXPECTED RESULTS

1) It is expected that as the mass flow rate of cold fluid as well as hot is altered we observe a change in temperature on the temperature sensor.
2) Low mass flow rate/volumetric flow rate: The volumetric flow rate of the water is low which means the volume/mass of water flowing through the pipe section per second is less hence the water molecules will get heated up faster.
3) High mass flow rate/volumetric flow rate: If the number of molecules of water flowing through a point is more then it will take more time to heat them. Hence, we can say that the temperature difference, in this case, will be lesser.

VII. CONCLUSION

In the present study numerical simulation of washer inserted double pipe heat exchanger is done with hot fluid flowing in the inner tube and cold fluid in the annulus. After validating the results for a bare heat exchanger with the experimental results Simulation was done using Rectangular slot configurations inside the washers on the outer body of inner tube. The results indicated washer configurations showed an overall improvement in the thermal characteristics compared with bare one. For better Performance the mass flow rate of the cold fluid should be kept low whereas that of the hot liquid should be high.

For a constant value of m_c of 0.02 kg/s, as m_h was increased, the effectiveness of the washers inserted tube is increased also thermal performance is being increased in counter flow than parallel flow.

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