Design and Finite Element Analysis of a Concentric Tube Heat Exchanger

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Abstract - Heat exchangers are essential in many sectors, such as paper, chemicals, oil, processing, petroleum refining, and power plants. The need for efficient heat exchangers is a result of their high efficiency and environmental concerns. Heat transfer improvement is crucial for increasing efficiency since it enables smaller heat exchanger sizes and a high heat transfer rate with less space needed. Using plain tube and plain twisted tape inserts, counterflow heat exchangers enhance the transfer of heat properties of concentric tube heat exchangers. To improve heat transmission & generate turbulence, twisted tape inserts are used to concentric tube heat exchangers. A variety of techniques, such adding fins or raising fluid velocity, can be tested to see which improves heat transmission in small heat exchangers the most.

Index Terms- Heat transfer, Petroleum refining, Efficiency, Counter flow, Concentric tube, Plain and Twisted tape.

I. INTRODUCTION

The concentric pipe heat exchanger is a method for transferring heat among the two fluids without mixing at different temperatures. It makes use of convection and conduction, with conduction passing through the walls of the heat exchanger and convection happening in each fluid. Chemical facilities and fossil fuel refineries are two examples of industrial domains where tube inserts are utilised to facilitate heat transmission. Heat exchangers frequently experience cross-, parallel-, and counterflow flow patterns. The most efficient technique is counterflow, which has warm fluid entering at one end and cold fluid leaving at the same end. Because of its efficiency, it is the most often used kind of fluid-to-fluid heat exchanger. The literature examines concentric tube heat exchanger design using both an analytical and numerical method.

Pragneshkumar et al. [1] aim to enhance heat transfer surfaces in engineering applications such as air conditioning, heat exchangers, chemical reactors, and refrigeration systems. Passive heat transfer methods, like twisted tape, are important because they improve the effective surface area interaction with fluids. When a quadratic turbulator was linked to a twisted tape insert, the study's double pipe counter flow heat exchanger outperformed a basic twisted tape insert in terms of performance ratio, increasing from 1.13% to 1.16%. In transfer of heat and technical applications, such as heat exchangers, vehicles, & thermal power plants, cylinder pipes are frequently utilised. Heat may be transferred through three different methods: conduction, convection, and radiation. With an emphasis on parallel flow concentric tube heat exchangers, the heat transmission and friction factor in circular tube channels with and without inserts are investigated by Kanika et al. [2]. The primary cause of the heat transfer effect is induced turbulence, which raises the heat transfer rate. With the same shape, various latitudinal spacings, such as y = 15 and y = 45, provide different outcomes under different mass flow rates and heat conditions. The study discovered that the quality of heat transfer characteristics for variables including friction factor, pressure drop, Re, and Nu declines with increasing distance. In comparison to y = 45, the best outcomes were obtained with a linear geometrical spacing of y = 15.

The efficiency of heat exchangers depends on the heat transfer rate, hence new methods for increasing it are required. Techniques for improving passive heat transmission are recommended since they don't impact the system's performance as a whole. Industries employ twisted tape inserts extensively because of their low setup costs, simplicity of maintenance, and affordability. Kalapala et al. [3] look at the effectiveness of a dual pipe heat exchanger system with twisted tape inserts. The study is conducted for different mass flow rates and input temperatures for both parallel and counterflow configurations. The data indicates that the heat exchanger performs better in a counter flow architecture with twisted tapes than in a parallel flow design with twisted plates. The continuous temperature differential across the cross section makes counterflow more effective than parallel flow. Because twisted tape inserts create turbulence in the hot fluid moving zone, they also boost efficacy. Twisted tapes are shown to boost efficacy by 30% at low mass flow rates.

Bandu et al. [4] studied the performance of double pipe heat exchangers (DPHEs) in oil refinery and other large chemical processes. They investigated the flow and temperature field inside the tubes and created DPHEs with various fin orientations. For six distinct fin inclinations, they examined the impacts and heat transmission properties of DPHEs (0, 5, 10, 10).The study used CATIA V5 and hyper mesh for meshing, and ANSYS FLUENT R18.0 for studying the flow and temperature field inside the tubes. The study found that helical fins improved the heat transfer rate and overall coefficient of heat transfer.

Using ZnO nanofluid, Vijaya Sagar et al [5] studied the heat transfer and friction factor of a twin pipe heat exchanger. It was discovered that twisted tape containing 0.4% ZnO nanofluid raised the Nu by 23.56% and the friction factor by 15.32%. Research on the properties of heat transmission in a helically coiled heat exchanger was carried out by Jayakumar et al [6] They discovered that modelling real heat exchangers with constant temperature or heat flow boundary conditions was insufficient. Rather, they used temperature-dependent features of the heat transport medium and conjugate heat transfer to analyse the heat exchanger. A correlation was built to ascertain the interior heat transfer coefficient, and an experimental setup was established to assess heat transfer qualities. According to studies by Yamini et al. [7] helical coil-tube heat exchangers are being looked at for use in a variety of manufacturing due to their more compact design, larger heat transfer area, and improved heat transfer capabilities. According to the study, the intricate flow pattern of helically coiled tubes results in increased heat transfer rates compared to straight tubes. The significance of different curvature ratios and geometry in heat transfer is further highlighted by the research. The optimal fin No for maximum wall temperature and heat transfer was found to be 10. Triangular-shaped fins had the least amount of wall temperature dispersion, according to the study. Technologies for improving heat transmission are critical to industries including electronic components, petrochemicals, industrial processes, and thermal power plants.

Although millimetre or micron-sized particles, which can lead to settling, surface abrasion, and clogging in heat transfer equipment, have received the majority of study attention, energy transmission fluids with suspended solid particles have also been investigated to enhance heat transfer. According to research by Rao et al [8] convective heat transfer in transition flow is greatly enhanced when Al_2O_3 nanoparticles are used as a dispersed phase in water. This improvement increases with Reynolds number and particle concentration.

Deepak et al [9] focuses on employing plain tube, helical fins and plain tube with helical fins with inserts to improve thermal performance in a twin pipe heat exchanger. An insert on the helical fins increases turbulent intensity, which boosts heat transmission. To examine the flow of heat between two liquids via a solid barrier, Joshua [10] created a concentric tube heat exchanger. (LMTD) approach was used, and the apparatus was built for a counter-flow configuration. Water was used in the experiment; hot and cold water were given at 87°C and 27°C, respectively. Hot water came out at 73°C, while chilly water came out at 37°C. With an overall heat transfer coefficient of 711 W/m^2K and a 48 °C log, the heat exchanger was 73.4% efficient. The design of a double pipe heat exchanger in a chemical plant is examined by Karthik et al. [11] With hot water in the outer pipe and hot oil in the inner pipe, the heat exchanger is built to withstand real-world working circumstances. (LMTD) technique and the effectiveness-number of transfer units (ε-NTU) approach were employed in an analytical model. To characterise the heat exchanger's performance in terms of important dimensionless metrics, performance charts were created. For the design study, both counterflow and parallel flow topologies were taken into account. Another option was a numerical model. Based on the criteria and inputs that are available, designers may select an acceptable design process by using the findings, which demonstrate that both analytical and numerical approaches provide the same outcomes.

Pichandi [12] talks about the significance of heat transfer in heat exchangers, emphasising the effect of entropy generation on operating parameters and shape. A MATLAB code is created to solve the mathematical model, which is based on the 1st & 2nd laws of thermodynamics. For the parameters employed in the study, an experimental setup is created, and the model and code are verified with the help of the experimental findings. In addition, a numerical test for grid independence is conducted, and the ideal Re for the specified shape and operating conditions is discovered.

II. DESIGN OF CONCENTRIC TUBE

This project uses SolidWorks software to create a model of this heat exchanger. The model will be used to simulate and optimise the performance of the heat exchanger design. This project includes three distinct types of tubes:

- Normal plain tube
- Plain tape inserted
- Plain Twisted Tape Insert

A. Normal Plain Tube

A concentric tube heat exchanger is a system consisting of two smaller tubes used to exchange heat. It can generate turbulent conditions at low flow rates and withstand high pressure operations, which raises the rate of heat transfer and coefficient of heat transfer.

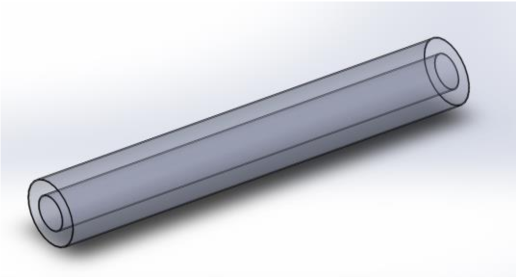


Fig. 1 Normal Plain Tube

B. Plain Tape Inserted Tube

Straight tape inserts have a mean heat transfer gain of 4-24% associated to plain tubes, mainly due to their robust turbulence intensity, which enhances heat transfer. However, this can also result in higher pressure drop and increased energy consumption. The cost of implementing and maintaining these inserts may outweigh the benefits of slightly improved heat transfer.

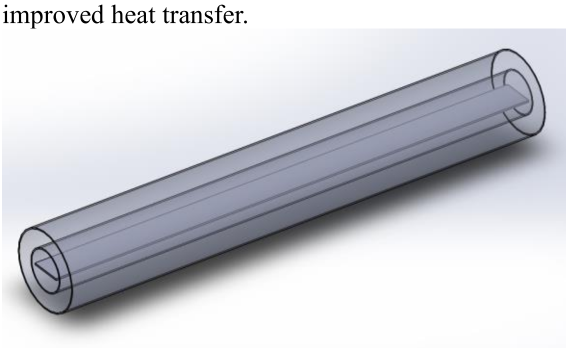


Fig. 2 Plain tape inserted

C. Plain Twisted Tape Insert

Twisted tape and longitudinal tubes are passive equipment that enhance heat transfer rates. Twisted tape generates swirl flow, improving fluid mixing and reducing resistance near the wall. Tubes with longitudinal inserts are also effective for improving heat transfer. Perforated double counter twisted tape inserts in a circular tube increased heat transfer by 80–29% compared to a plain tube, according to a study. This suggests that using twisted tape and longitudinal tubes in tubes can be a practical and efficient method for improving heat transfer in various applications. Overall, the use of these passive equipment options can lead to energy savings and improved overall system performance in a variety of applications.

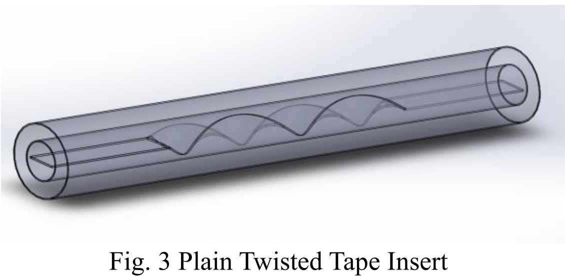


Fig. 3 Plain Twisted Tape Insert

The precise parametric parameters, including length, breadth, thickness, inner diameter, and outer diameter of the chosen concentric tube, are shown in Table 1 below. This data is essential for correctly simulating the fluid flow inside the tube and figuring out the mechanical characteristics of the tube.

Table. 1 Geometry Conditions

PARAMETERS	INNER PIPE	OUTER PIPE	PLAIN TAPE
Length	800mm	800mm	800mm
Inner diameter	66mm	126mm	-
Outer diameter	70mm	130mm	-
Width	-	-	50.8mm
Thickness	2mm	2mm	3mm

III. MATERIAL PROPERTIES

The Concentric tube has selected according to the parameters taken as shown below. The inner pipe, outer pipe and insert are available in market for that material as well as its dimensions. Table 2 represents the mechanical properties of the concentrated pipe, and Table 3 represents the different parametric properties of the cold water and hot water.

Table. 2 Material Property

Material	Aluminum
Thermal Conductivity	202.4 (w^{mK})
Specific Heat	871 (j^{-1kgK})
Density	2719 (kg^{-m3})

Table. 3 Hot & Cold-Water Properties

Description	Cold Water (20 °C)	Hot Water (70 °C)	Symbol
Thermal Conductivity	0.614	0.654	(w^{mK})
Density	995.215	983.2	(kg^{-m3})
Specific Heat	4180.15	4184.3	(j^{-1kg})
Viscosity	0.000827	0.000466	(kg^{-1ms})

IV. ANALYSIS OF CONCENTRIC TUBE HEAT EXCHANGER

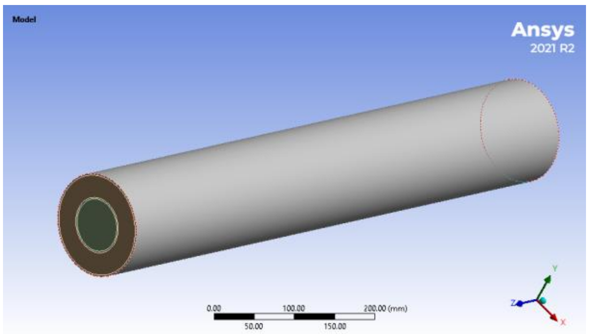


Fig. 4 Normal Tube Model in ANSYS software

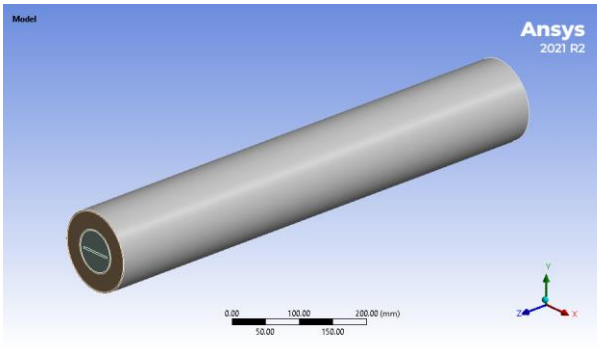


Fig. 5 Plain and Twisted Tape Model in ANSYS software

ANSYS offers the perfect option for everyone from professionals trying to simulate complicated materials and non-linear behaviour to designers and infrequent users seeking quick and reliable results. ANSYS Mechanical's user-friendly interface allows engineers of any level of experience to obtain accurate and timely results. Figure 4 represents a simple concentric tube heat exchanger model in which there are no hidden features, but both the plain tape and the twisted tape inserted in Figure 5 are hidden in the concentric tube. heat exchanger model.

Any model may be effortlessly fitted with the optimal mesh thanks to ANSYS Mechanical's intelligent mesh technology. Astute algorithms generate high-quality models automatically and also simplify the process of adding controls for any last-minute adjustments that may be required.

A. Meshing

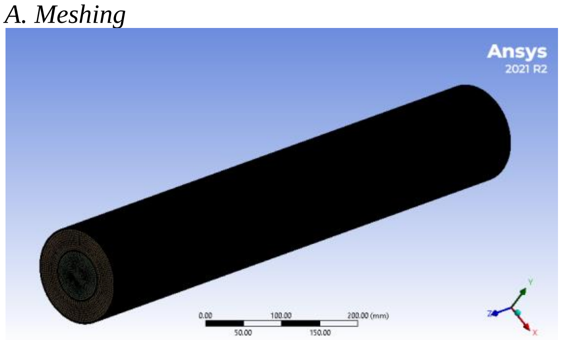


Fig. 6 Mesh Generation of Normal Tube Model

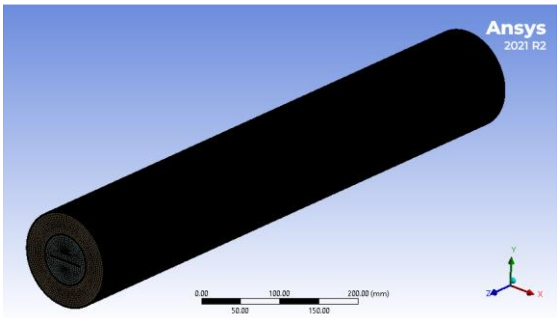


Fig. 7 Mesh Generation of Plain and Twisted Tape Model

Figure 6 shows a simple concentric tube heat exchanger mesh model without hidden features, while Figure 7 shows both plain tape and twisted tape inserted mesh models hidden within the concentric tube heat exchanger model.

V. RESULT & DISCUSSION

A. Normal Tube Model

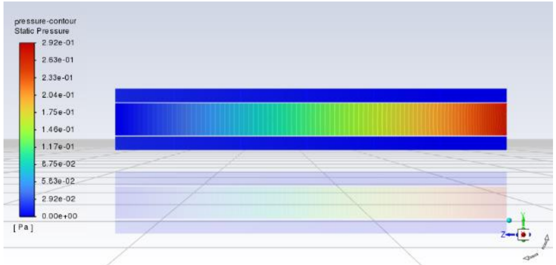


Fig. 8 Pressure Contour Results of Normal Tube

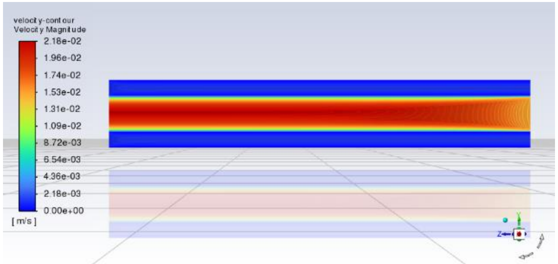


Fig. 9 Velocity Contour Results of Normal Tube

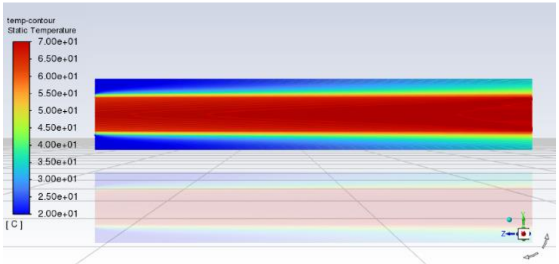
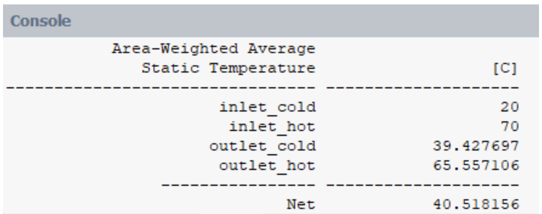


Fig. 10 Temperature Contour Results of Normal Tube



Console

Area-Weighted Average Static Temperature	[C]
inlet_cold	20
inlet_hot	70
outlet_cold	39.427697
outlet_hot	65.557106
Net	40.518156

Fig. 11 Temperature Results of Normal Tube

Figures 8, 9, and 10, respectively, display the pressure, velocity, and temperature contour findings of a conventional tube concentric heat exchanger. Figure 11 reports the temperature results at both the inlet and outlet regions of the heat exchanger, providing a comprehensive overview of the thermal performance. These illustrations are essential for comprehending the exchanger's heat transfer mechanism and can point out possible areas for improvement. Analysing these temperature profiles can help identify any inefficiencies or areas where adjustments may be necessary to optimize heat transfer.

B. Plain Tape Model

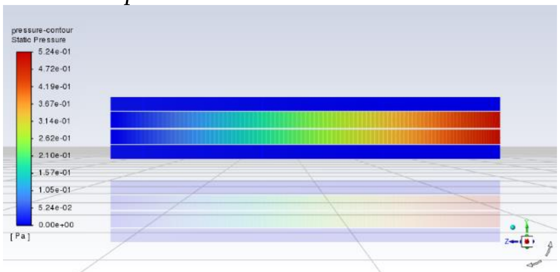


Fig. 12 Pressure Contour Results of Plain Tape Concentric Tube

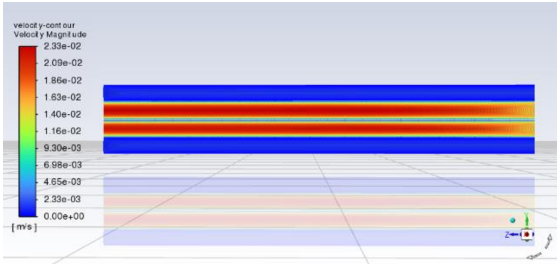


Fig. 13 Velocity Contour Results of Plain Tape Concentric Tube

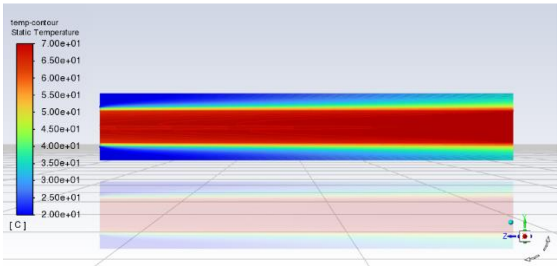


Fig. 14 Temperature Contour Results of Plain Tape Concentric Tube

Console

Area-Weighted Average Static Temperature	[C]
inlet_cold	20
inlet_hot	70
outlet_cold	39.097932
outlet_hot	65.618309
Net	40.057397

Fig. 15 Temperature Results of Plain Tape Concentric Tube

The pressure, velocity, and temperature contour results of a simple tape concentric tube heat exchanger is shown in Figures 12, 13, and 14, respectively. The temperature readings at the heat exchanger's intake and exit areas are shown in Figure 15, which offers a thorough summary of the thermal performance. These diagrams can highlight potential areas for improvement and are crucial for understanding the heat transfer process of the exchanger. These temperature profiles may be analysed to find any inefficiencies or places where changes could be needed to maximize heat transmission.

C. Twisted Tape Model

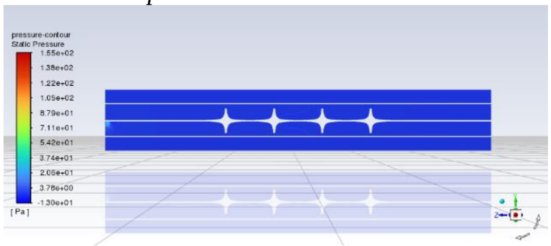


Fig. 16 Pressure Contour Results of Twisted Tape Concentric Tube

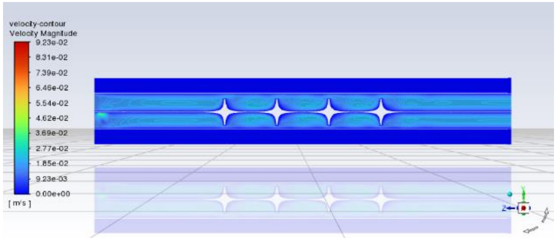


Fig. 17 Velocity Contour Results of Twisted Tape Concentric Tube

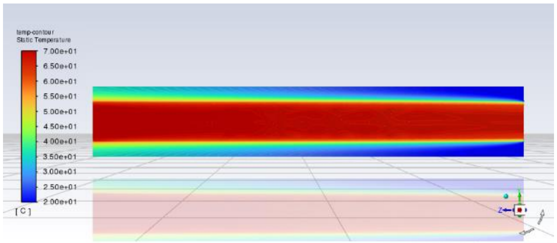


Fig. 18 Temperature Contour Results of Twisted Tape Concentric Tube

Console

Area-Weighted Average Static Temperature	[C]
inlet_cold	20
inlet_hot	70
outlet_cold	42.23774
outlet_hot	65.068361
Net	41.120592

Fig. 19 Temperature Results of Twisted Tape Concentric Tube

The pressure, velocity, and temperature contour results of a simple tape concentric tube heat exchanger is shown in Figures 16, 17, and 18, respectively. The temperature readings at the heat exchanger's intake and exit areas are shown in Figure 19, which offers a thorough summary of the thermal performance. These diagrams can highlight potential areas for improvement and are crucial for understanding the heat transfer process of the exchanger. These temperature profiles may be analysed to find any inefficiencies or places where changes could be needed to maximize heat transmission. The below table 4 represent the comparative results of the parametric temperature of selected tubes.

Table. 4 Comparative temperature reading

PARAMETER	NORMAL TUBE	PLAIN TAPE	TWISTED TAPE
Inlet Temperature (Hot Fluid)	70	70	70
Outlet Temperature (Hot Fluid)	65.557	65.618	65.068
Inlet Temperature (Cold Fluid)	20	20	20
Outlet Temperature (Cold Fluid)	39.427	39.097	42.237

CONCLUSION

Heat transfer in heat exchangers using plain tubes, plain tape, and twisted tape inserts has been well studied. They came to the conclusion that in turbulent flow, the twisted tape inserts work better. The distribution of temperatures between hot and cold fluids serves as its foundation. The model with the twisted tape insert has the largest temperature distribution, indicating that more heat is transported in this model, according to the temperature data (Table 4). The hot and cold fluids in the twisted tape model saw increases of 22.237 °C and decreases of 4.932 °C, respectively. In terms of heat transmission efficiency, the twisted tape model outperforms the standard and plain tape models by 12% to 16%.

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