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Conjugate Heat Analysis on Trapezoidal Heat Exchanger for CO_2 Refrigeration System

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Abstract: ***Present study focus on double pipe trapezoidal helical heat exchanger for CO_2 refrigeration system by numerical analysis. By optimizing the velocity, the mode of study is conjugate heat analysis. Investigation is focussed onto getting desired output of temperature difference between inlet fluid and outlet fluid. When the flow is considered to be parallel, the inlet temperature of the fluid shows a decrement from 30 degree Celsius to 23.5 degree Celsius. Hence as per the analysis and studies, the new design shows a considerable difference in the inlet and outlet temperature and a considerable amount of heat transfer. The outlet temperature can also be varied by making variation in the geometrical design***

Keywords: Conjugate heat analysis, CO_2 refrigeration system, Trapezoidal helical heat exchanger, Effectiveness, Parallel flow

1. Introduction

When you submit your paper print it in two-column format, including figures A refrigerant is a substance or mixture, usually a fluid, used in a heat pump and refrigeration cycle.The using of CFCs as refrigerant are discouraged due to its effect on the ozone depletion; HCFCs are used to decrease the effects. Unfortunately they are targets of the Kyoto Protocol because they have activity in an entirely different realm of greenhouse gases. Carbon dioxide is an alternative refrigerant whose manufacturing is easy, non corrosive and non-ozone depleting.

In **CO_2 Refrigeration System**, the focus of study is towards the heat exchanger and various types of heat exchangers are available for use in refrigeration system. It has been widely reported in literature that heat transfer rates in helical coils are higher as compared to a straight tube. Due to the compact structure and high heat transfer coefficient, helical coil heat exchangers are widely used in industrial applications such as power generation, nuclear industry, process plants, heat recovery systems, refrigeration, and food industry.

Rennie [1] et al. (2006) conducted numerical as well as experimental analysis on double- pipe helical heat exchanger and the flow considered is laminar. The heat transfer characteristics under different flow rates of fluid and tube sizes for both parallel and counter flow heat exchanger were studied. Cooling and dehumidifying conditions were used for analysis. The result obtained is that the outlet temperature of air and water decrease with increase in mass flow rate of water. And with increase in air and water mass flow rates the enthalpy and humidity effectiveness decrease.

Yan Li [2] et al. (2010) conducted study on high pressure shell-and-tube heat exchangers for syngas cooling in an IGCC. The flow field and the heat transfer characteristics of a shell-and-tube heat exchanger for the cooling of syngas were investigated. And it is evident from the result that the heat transfer rate will improve, if the operation pressure is high. The arrangement of the baffle plates inside the exchanger also affects the flow characteristic of fluid.

Jayakumar [3] et al. (2008) had done numerical and experimental work on helical coil heat exchanger considering fluid to fluid heat transfer. From the observation, it is found that constant value of thermal and transport properties of heat transfer medium results inaccurate heat transfer coefficient. Based on the numerical and experimental analysis within certain error limits, a correlation was developed by them to calculate the inner heat transfer coefficient of helical coil.

Lee et al. [4] (2010) numerically studied the heat transfer performance of multi-coil condensers were air flow characteristics are studied for different coil configurations. In their study they had investigated the effects of different included angles between the coils of the condenser. And from the results they concluded that the air flow rate can be improved by the variation of the included angle. The heat transfer rate is increased by 5.29% due to improved flow rate of air. The improvement of heat transfer rate is due to reduction in the stagnant flow regions of the heat exchanger coils, and even distribution of flow throughout the coils.

In contrast to the earlier similar analysis, instead of specifying an arbitrary boundary condition, heat transfer from hot fluid to cold fluid is modeled by considering both inside and outside convective heat transfer and wall conduction. For improved CO_2 refrigeration system performance, here we adapt a new design of **trapezoidal helical tube double pipe heat exchanger** for the numerical study and to find its effectiveness.

2. Numerical Analysis

Many researchers identified that a complex flow pattern exists inside a helical pipe due to which the enhancement in heat transfer is obtained. The curvature of the coil governs the centrifugal force while the pitch (or helix angle) influences the torsion to which the fluid is subjected to. A computational model is a mathematical model in computational science that requires extensive computational resources to study the behavior of a complex system by computer simulation. The computational modeling involves pre-processing, solving and post-processing.

2.1 Geometry of the Model

In the present analysis, we consider trapezoidal helical coils which are vertically oriented, i.e., where the coil axis is vertical. Fig. 1 gives the schematic of the trapezoidal helical coil.

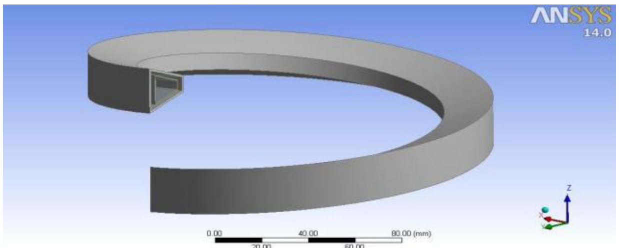

Figure 1: Designed geometry

Table 1: Details of flowing fluid

Details of Body		Details of Body	
Body	outer_fluid	Body	inner_fluid
Volume	55967 mm³	Volume	57055 mm³
Surface Area	57612 mm²	Surface Area	22579 mm²
Faces	10	Faces	6
Edges	24	Edges	12
Vertices	16	Vertices	8
Fluid/Solid	Fluid	Fluid/Solid	Fluid

The trapezoidal heat exchanger geometry is first modelled with the help of ANSYS design modeler (DM) software. The model consists of two trapezoidal tubes placed one inside other. First of all, the outer tube with required solid body of dimensions having a volume of 35062 cubic mm is created. The material is selected as copper and its surface area was considered to be 70249 square mm and the design structure consists of 10 faces, 24 edges and 16 vertices. The inner tube with required solid body of dimensions, having a volume of 11737 cubic mm was created. The material is selected as copper and its surface area was considered to be 46841 square mm and the design structure consists of 10 faces, 24 edges and 16 vertices. Flow volume in inner and outer tube was extracted using ‘Fill’ command. Here fluid is also considered as a design element and table 1 shows the design considerations of flowing fluid.

2.2 Mesh Generation

Hexagonal cells are taken as meshing element because it can fill a volume more efficiently than other mesh shapes and for that sweep method was adopted. Inflation was added to the sweep methods to capture boundary layers. Table 2 shows the details of meshing and the generated high quality mesh is shown in fig. 2.

Table 2: Details of Meshing

Type of Analysis	3D
Type of Element	Tetrahedral (10 Node)
Physical preference	CFD
Solver preference	CFX
Coarse Smoothing	Medium

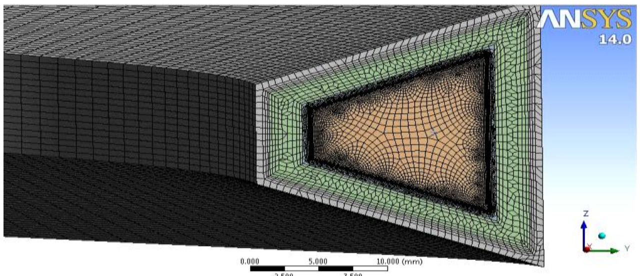

Figure 2: Generated mesh on the design

The number of nodes and elements are 1896033 and 1885600 respectively. The analysis is done using CFX. The physical models that are to be included in the simulation is turbulence model and the materials assigned are copper for both tubes and CO_2 gas flow through both tubes. The boundary conditions applied during the pre-processing stage are given in table 3.

Table 3: Boundary Conditions

	Inlet Velocity (m/s)	Inlet Temperature (°K)	Outlet Pressure (KPa)
Inner fluid	11.8	278	3029
Outer fluid	11.8	303	10000

2.3 Conjugate Heat Transfer Analysis

Conjugate Heat Transfer (CHT) analysis is the coupled solution of conduction through solids and convection in the adjacent fluids. Navier-Stokes equations are solved in the fluid domain and heat conduction equations are solved in the solid domain. Temperature and heat transfer coefficients at the fluid-solid interface are determined by the local energy balance.

Navier Stokes equation

X-Momentum Equation:

$$\rho\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\left(\frac{\partial p}{\partial x}\right)+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)\quad(1)$$

Y-Momentum Equation:

$$\rho\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\left(\frac{\partial p}{\partial y}\right)+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)\quad(2)$$

Z-Momentum Equation:

$$\rho\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\left(\frac{\partial p}{\partial z}\right)+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)\quad(3)$$

Heat conduction equation

$$Q_{cond}=-kA\frac{dT}{dx}\quad(4)$$

Energy Equation

$$\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)=\frac{1}{\alpha}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right)\quad(5)$$

3. Results and Discussion

3.1 Model Validation

Figure 3 shows the results from the study for constant heat flux boundary condition at different mass flow rates. The results from the study fall within the range of the correlations, fitting best with those of Akiyama and Cheng [9, 10]. The difference in the Nusselt numbers for the constant heat flux is negligible for all practical purposes, corresponding to the conclusions of Mori and Nakayama [11].

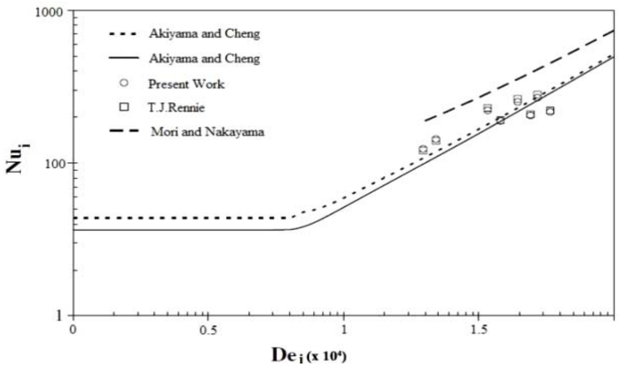

Figure 3: Inner Nusselt number Vs Inner Dean number

3.2 Conjugate Heat Transfer Analysis

Parallel flow of the fluids was considered and by using CFX solver, the convergence of heat transfer and temperature graphs are obtained. The convergence curve shows the region where heat transfer rate becomes a steady rate. The contour output for parallel flow conditions are obtained as results and are shown below. Figure 4 shows the parallel flow configuration and table 4 shows the temperature obtained at outlet of inner tube and outer tube.

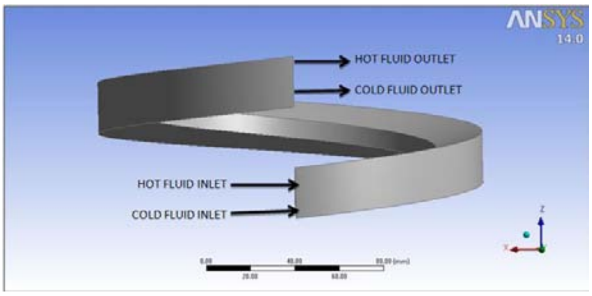

Figure 4: Parallel flow configuration

Table 4: Outlet temperature of parallel flow

Outlet	Temperature (K)
Inner Tube	285
Outer Tube	296.5

The results obtained for the parallel flow through inner pipe are given below.

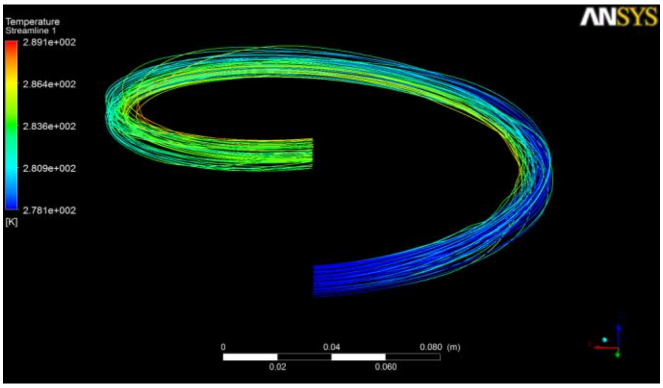

Figure 4: Temperature distribution along the inner pipe

Refrigerant from the evaporator is considered to flow through the inner tube. From fig. 4, the inlet temperature of inner fluid (i.e. CO_2) is taken as 278 K and during simulation it can be seen that the temperature of the refrigerant increases to 285 K at the outlet.

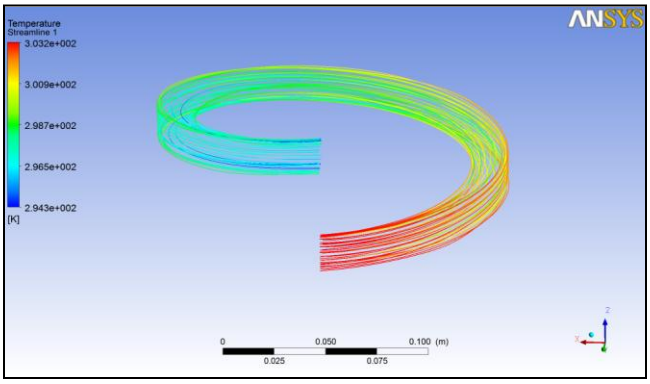

Figure 5: Temperature distribution through the outer tube

The analysis of contour output is done for the outer tube. From fig. 5, the refrigerant (i.e. CO_2) enters at temperature of 303 K and leaves the tube at a temperature of 296.5 K at output. Hence the design can make a decrement of about 6.5 K in the temperature by parallel flow condition. And also same velocities of inner fluid and outer fluid make a significant effect on the temperature difference.

4. Conclusion

Helically coiled Trapezoidal double pipe internal heat exchanger for carbon dioxide refrigeration system has been designed and analyzed using ANSYS 14. Conjugate heat analysis by the optimization of velocity has been done on the trapezoidal helical tube double pipe heat exchanger. Study was focused on getting the desired output of temperature difference between inlet fluid and outlet fluid. When the flow is considered to be parallel, the inlet temperature of the fluid shows a decrement from 30 degree Celsius (303 K) to 23.5 degree Celsius (296.5 K). Hence as per the analysis and studies the new design shows a considerable difference in the inlet and outlet temperature and a considerable amount of heat transfer. The outlet temperature can also be varied by making variation in the design structure. Further research and analysis is possible in the design and carbon dioxide refrigeration system which will be a good replacer for the present systems and for an eco-friendly way of refrigeration

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