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Unveiling Efficiency: Analyzing Shell and Tube Heat Exchangers through Experimentation and CFD

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ABSTRACT

This study investigates the performance of a single-pass shell and tube heat exchanger through a comparative approach. The analysis is conducted in two distinct phases: firstly, an experimental setup is devised for a single-pass shell and tube heat exchanger utilizing brass tubes for hot water and copper tubes for cold water due to the superior thermal conductivity of copper. Water is employed as the fluid medium at varying temperatures. The heat exchanger configuration involves cold water flowing through the shell side and hot water through the tube side. Following the experimental phase, a computational fluid dynamics (CFD) analysis is undertaken by creating a virtual model within a CFD environment. The CFD model is constructed based on the physical parameters of the experimental setup, maintaining identical boundary conditions to assess the heat exchanger's performance. Results are presented in tabular and graphical formats for each combination of input velocities and temperatures. Subsequently, a comparative analysis is conducted to evaluate the heat exchanger's effectiveness.

KEYWORDS: Computational Fluid dynamic (CFD), Heat Exchanger, Ansys.

1.INTRODUCTION

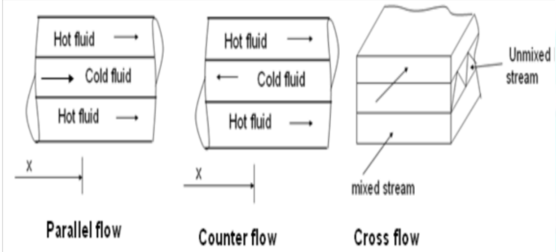
A heat exchanger serves as a mechanism designed to facilitate efficient heat exchange between two different mediums. These mediums can either be kept separate by a solid barrier to prevent mixing or allowed to interact directly. Heat exchangers find extensive applications across various industries including space heating, refrigeration, air conditioning, power generation, chemical processing, petrochemical refining, natural gas treatment, cryogenics, and wastewater treatment [4]. An illustrative instance of a heat exchanger is the radiator in an automobile, where the heat emanating from the engine-cooling fluid, typically water, is transferred to the surrounding air passing through the radiator, acting as the heat transfer medium.

Incorporating two or more streams, heat exchangers can accommodate flow directions that are either parallel or perpendicular to one another. In cases of parallel flow, the streams may move in the same or opposite directions. Consequently, three primary flow arrangements emerge: a)Parallel flow

b) Counter flow

c) Cross flow

From a thermodynamic perspective, the counter flow configuration yields the highest heat (or cold) recovery, whereas parallel flow exhibits the lowest. Cross flow, positioned between the two, demonstrates intermediate thermodynamic performance along with enhanced heat transfer characteristics and simplified mechanical layout. In specific scenarios, a hybrid cross-counter flow configuration delivers increased heat (or cold) recovery coupled with superior heat transfer efficiency. Thus, in general engineering practice, plate fin heat exchangers are deployed in three principal configurations: (a) cross flow, (b) counter flow, and (c) cross-counter flow [7]



Types of flow in Heat Exchangers

2. PROBLEM FORMULATION

Effectiveness of heat exchanger can be increased without significant change in the circuit is possible by only one way i.e. by increasing flow of cold fluid in the inlet valve[2]. However if we increase the flow in cold inlet in the tube type Heat Exchanger, then characteristics goes down which could be balanced by decreasing no. of tube of Heat Exchanger and decreasing the relative velocity of fluids flowing in Tube Type Heat Exchange.

Experimental setup of HE

Property of Material of Heat Exchanger

Property	*Steel*	*Copper*	*Brass*
Density (kg/m3)	*7.87E+03*	*8.96E+03*	*8.60E+03*
Poisson's Ratio	*0.27-0.30*	*0.34*	*0.331*
Thermal Conductivity (W/m-K)	*59.5*	*401*	*115*
Specific Heat (J/kg-K)	*481*	*385*	*375*

3. EXPERIMENTAL ANALYSIS

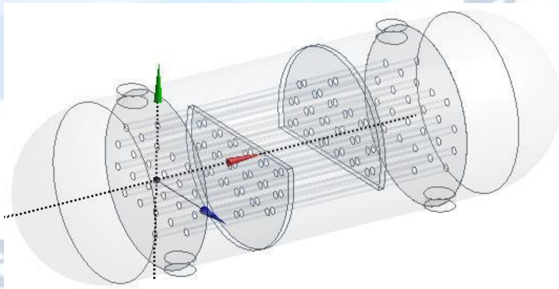
An experimental setup is prepared to perform the research work in laboratory. The setup consists of a single-phase heat exchanging system in which hot water passes through the straight tube and it exchanges heat by cold water flows inside the shell side. The heat exchanger includes an insulated cylindrical shell which is equipped with a copper straight tube.

Specification of Shell and Tube Type Heat Exchanger

S.No.	Parameter Name	Size in mm
1	Total length (mm)	1000
2	Length of shell (mm)	500
3	Diameter of shell (mm)	300
4	Length of tubes (mm)	500
5	Diameter of tubes (mm)	12.7
6	Number of tubes	24
7	Radius of curvature of cover end plates (mm)	390
8	Inlet and outlet port diameter	50.8
9	Distance of inlet and outlet port from the shell end (mm)	50
10	Pitch distance between consecutive tubes (mm)	38.6
11	Baffle thickness (mm)	10
12	No. of baffles	2
13	Distance of baffles from the shell ends (mm)	156.6

4. COMPUTATIONAL FLUID DYNAMIC ANALYSIS

In order to create the solid model of tube geometry we again start with the sketching of the both dome end and maintain the space between them as 500 mm for tube. The curvature of dome is randomly taken as 390 mm to maintain the overall size of heat exchanger. Total 24 tube has been modelled between the both end of dome and each having internal and outer diameter as 10 mm and 12.7 mm[11].Here we assign the different material for tube, shell and outer body of HE. For these analyses we assign copper to the tube and brass for shell inner tube and outer body of HE assign as structure steel. Generally the engineering materials are available in ansys material library but in case if it is not in library then we can also create it by using its mechanical property.

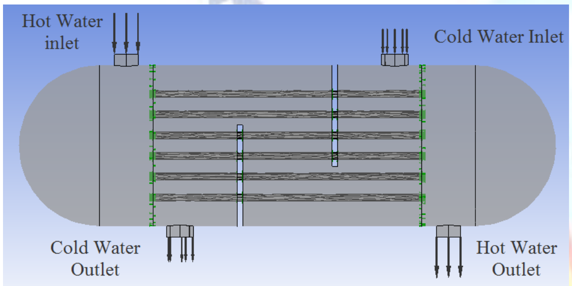


Geometry of heat exchanger

Boundary Condition Heat Exchanger

The term boundary condition deal with the actual condition or environment of working of heat exchanger. Here we are using hot and cold water as a media to flow in shell and tube to transfer the heat from hot to cold fluid. When the hot fluid come into the tube its temperature is 60 °C which is higher and it comes down when it comes in contact with the cold fluid in heat exchanger. The thermal condition of both fluids is given in the table below.

S No	Name Of Fluid	Boundary Condition Type	Value
1	Hot water	Inlet Velocity	0.5 m/s
		Inlet Temperature	65° C
		Initial Pressure	1 atm
2	Cold water	Inlet Velocity	1 m/s
		Inlet Temperature	25° C
		Initial Pressure	1 atm

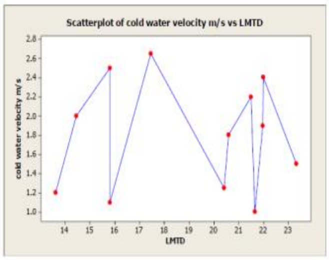


Boundary condition of Helical coil Heat Exchanger

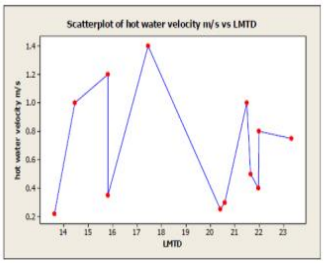
5. RESULT & DISCUSSION

After the experimental procedure we get different set of result in the form of combination of inlet velocity and temperature for cold and hot fluid. The detail of inlet and out let temperature is given in the table below. After the critical analysis of the result we found that the heat transfer rate in increases due to increase the inlet velocity of the cold fluid and when we increase the velocity of hot fluid there is significant change in the temperature of outlet hot fluid. Similarly the value of LMTD is high for first two and last three experiment and for rest of experiment its nature is irregular. For experiment Number 6 and 8th the value of LMTD is almost same for both the combination of inlet velocity and temperature of hot and cold fluid.

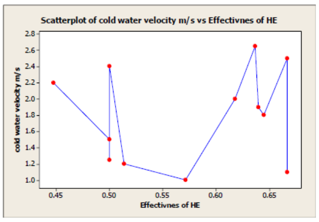
The overall effectiveness of the heat exchanger is lie in between the value of 0.51 to 0.67, which shows the performance of the heat exchanger and effectiveness is also vary according to the combination of velocity and inlet temperature of cold and hot fluid.



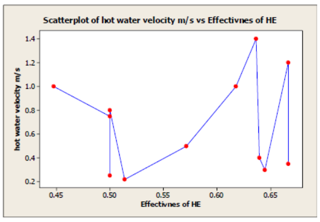
Experimentally Variations in LMTD with respect to hot water inlet velocity



Experimentally Variations in LMTD with respect to cold water inlet velocity



Experimentally Variations in Effectiveness with respect to cold water inlet velocity

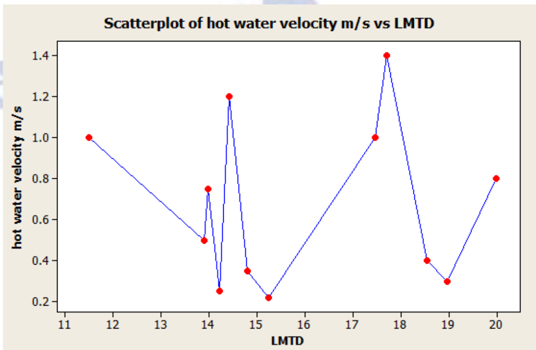


Experimentally Variations in Effectiveness with respect to cold water inlet velocity

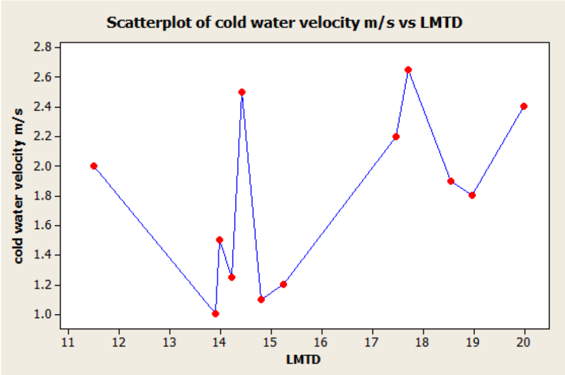
Computational Fluid Dynamic Result of Shell and tube Type Exchanger

According to the experimental result we create the same combination of hot and cold fluid of the heat exchanger and perform each experiment in CFD workbench. There are 12 different separate combinations of inlet and out temperature of hot and cold fluid and different velocity. After the analysis of heat exchanger in CFD work bench we get set of output in the form of cold and hot outlet of both fluids.

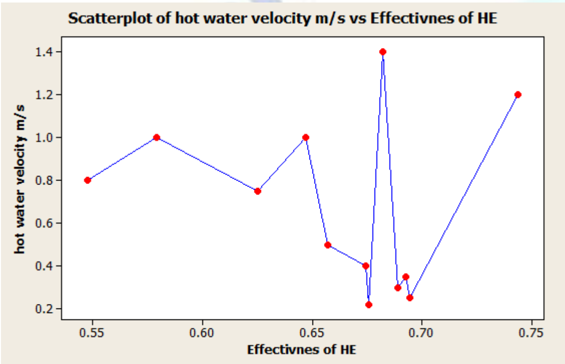
The result obtained from the CFD workbench shows very good agreement between the outlet and inlet temperature of the hot and cold fluid as compare to the experimental result. Here the velocity and inlet temperature of cold and hot is same as the experimental and computed by on least square method. CFD work on ideal condition and no human as well as physical error like leakage, humidity etc considered, so its shown better result under the same boundary condition.



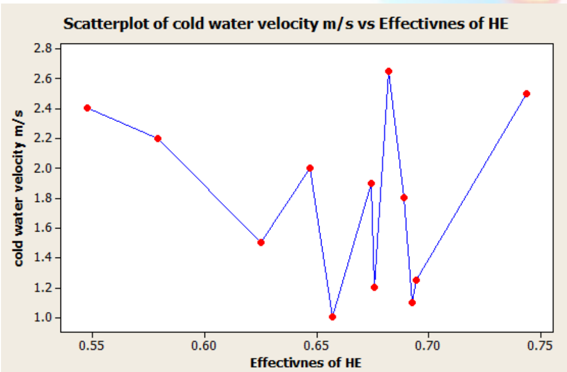
CFD Variations in LMTD with respect to hot water inlet velocity



CFD Variations in LMTD with respect to cold water inlet velocity



CFD Variations in Effectiveness with respect to hot water inlet velocity

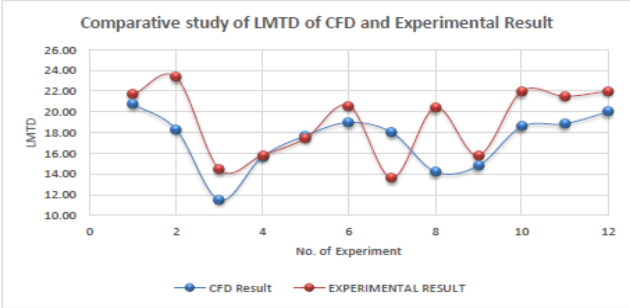


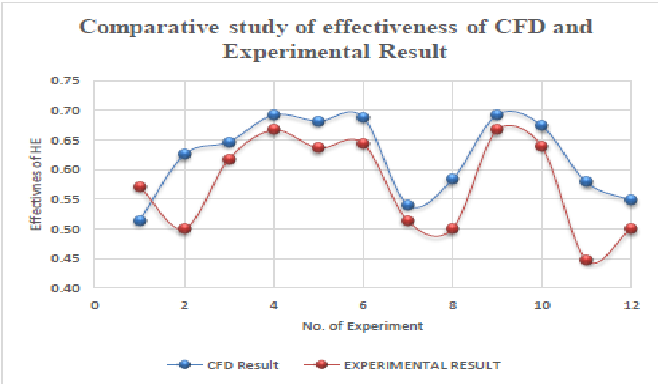
CFD Variations in Effectiveness with respect to cold water inlet velocity

6. CONCLUSION & FUTURE SCOPE

Two different approaches have been performed to know the distribution of temperature and effectiveness of heat exchanger under the same working condition. The phase I we perform the experimental study in shell and tube type heat exchanger and taking 12 different combination of temperature and inlet velocity. Based on the output of experiment result we calculate the effectiveness and LMTD value for each experiment.

Similarly in phase II we are using the same combination of velocity and temperature of hot and cold fluid and performed the CFD analysis. A comparative graph of distribution of LMTD and effectiveness the value of CFD and experimental result of heat exchanger and we found that the effectiveness of CFD result is higher than the experimental result except 1st experiment.





The reason behind that is CFD workbench is work under the ideal condition and experimental study work on physical condition. The nature of graph is almost same for both the study and variation found during the experiment due to the change in velocity of fluid.

The experiment Number nine shows large value of effectiveness both cases while the experiment no 1st shows smallest value of effectiveness for both cases. Based on the analysis of the graph we concluded that the CFD result show better result as compare to the experimental result

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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