STUDY THE EFFECT OF INCLINED BAFFLES ON SHELL SIDE LIQUID FLOW PRESSURE VARIATION FOR A SMALL SHELL AND TUBE HEAT EXCHANGER WITH HOT TUBE SIDE FLUID FLOW USING CFD APPROACH

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ABSTRACT

The present work is embraced to study the cold fluid flow through the shell compartments and its pressure changes between shell inlet and shell outlet nozzle for an STHX which is implemented with an inclined baffle plate. The work focuses on pressure changes on shell side using Flow Vision, commercially available CFD software. A small STHX with 20° inclined baffles having shell side cool liquid flow and tube side hot liquid stream flow conditions. On shell side, four set of constant fluid flow conditions varying from 0.3 kg/sec to 0.6 kg/sec are used, while on tube side a constant fluid flow of 0.3 kg/sec is considered. The inlet temperatures for cold fluid and hot fluid are different for each set of liquid flow conditions. Heat duty, average convective heat transfer coefficients, pressure changes and temperatures at outlet nozzles on the shell side and tube side are studied. Initially, an experimental setup is developed as shown in figure 2 and used to generate the output table 4 for varied flow conditions on shell side as mentioned in the previous section. Later for the same set of inlet temperatures, flow rates, and pressure conditions on the shell side and tube side liquid flow, the results are obtained using CFD technique. The CFD output results are obtained using “Flow Vision”, a commercial code and are compared with experimental output results for validation. Theoretical results are developed for a zero-degree segmental baffle heat exchanger using Bell-Delaware method. The validated output results found through CFD analysis are compared with the theoretical results for same temperature, pressure, and fluid flow conditions. This approach undertaken helps to understand the variations in the temperature, the pressure and fluid flow due to changes in the baffle inclination. Heat transfers, heat transfer coefficient, pressure drop for shell side fluid flow are compared for CFD and theoretical approach. The contour plots generated by the CFD code displays hot temperature regions, high-velocity regions, compartmental temperature, velocity and pressure distributions including the inlet and outlet compartments.

ABBREVIATIONS: STHX-Shell and Tube Heat Exchanger, CFD-Computational Fluid Dynamics

KEYWORDS: Shell and Tube Heat Exchanger, Inclined Baffles, CFD & Pressure Drop

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INTRODUCTION

Globally, the transportation of both light and heavy goods is fulfilled in major percentage of roads. It is essential for any nation to have a strong transportation network to support the economy. Automotive is used as a means to transport the goods for long and short distances through the road network. Automotive for decades have

been supporting the transportation domains which are furnished with internal combustion motors as a source of energy and expected to continue their utility in future also. Fossil fuels are used as a prime source of energy for burning by the internal combustion engines. After the combustion, the waste heat from the automotive exhaust is left unused leading to decreased efficiency of the power source. It also adds to environmental pollution with exhaust gases containing HC, CO, CO₂, etc. This additionally leads to global warming. It is found to be necessary to tap this exhaust waste for some valuable purpose. The innovative technology suggests to use the exhaust heat to preheat the fuel admitted for turbocharging or produce electricity with thermo-electric generators. This may be true from the focus to save some percentage of fossil fuel and to provide our future generation a healthy living. The attenuation of pollution by vehicles and betterment of internal combustion engine efficiency is envisaged. Using STHXs in the exhaust manifold of vehicles is one of the techniques by which heat may be recovered from the exhaust gas. STHX are simple in their construction and used widely in various sectors like automotive, industry, agriculture, environment, fishery, and household. The STHX are constructed for different sizes differing in the number of tubes, number of baffle plates, baffle shapes, tube stacks, tube shapes, types of fluids used, stream patterns so on. They can be cleaned with less effort. The STHX have a better heat duty but large pressure drops for the shell side flow. If pressure drop can be controlled by new designs, STHX can be used for heat recovery of automotive exhaust widely. In this regard, a study is undertaken to use incline baffle in place of straight baffles and understand the effects of baffle inclinations on heat duty and pressure drops for the shell side flow.

EXPERIMENTAL DETAILS

A heat exchanger of about 750 mm length small sized which may be used in the manifold of an automotive exhaust to absorb the exhaust gas heat is considered for experimental study with inclined baffles of 20° inclination. Eight tubes are arranged in a triangular pitch of 45° which are made up of Aluminium is fitted in to shell. Six baffles made of steel are placed with 20° inclined position with equal spacing along the shell liquid flow direction. The detail of specifications for hot tube heat exchanger is given in table-2. The shell and the baffle plates are made up of steel. A hot tube cold shell fluid flow condition is considered for both experimental and CFD analysis. Four shell side fluid flow conditions are considered using cold water with constant flow rate of 0.3 kg/sec, 0.4 kg/sec, 0.5 kg/sec and 0.6 kg/sec. Hot fluid flow in the tubes is kept 0.3 kg /sec constant for all cases of shell side fluid flow. In the beginning, an experimental set up as shown in figure-2 is undertaken for the hot and cold liquid flow conditions as mentioned in the Table-4. To obtain the steady state conditions for temperature, pressure, and discharge in view of more accuracy in the obtained results, sufficient time was allowed for the liquid flow on both hot and cold sides. Temperature and pressure outputs were observed to tabulate the output results. The conditions which have been mentioned above for experimental setup are adhered to define inputs for the CFD analysis using 'Flow Vision', a commercially available CFD software. The outputs result from the CFD and experimental study are compared.

Figure 1: Meaning of Baffle Inclination

Figure 2: Experimental Set up for Inclined Baffle STHX with Hot Tube Flow

The reader is suggested to understand the meaning of inclined baffle going through the figure-1. To assemble the tube bundle through the baffle hole and alignment of baffle plates into the shell, sufficient care is taken during fabrication. The baffles were drilled with holes using plates in inclined position through the drilling spindle axis to ensure proper positioning of the tube bundle through the baffle holes. The peripheral edge of the baffle plate was also generated by cutting the baffles in the inclined position of the plate to ensure proper mating of baffle edge with the shell inner circular surface.

CFD ANALYSIS DETAILS

Table-1 shows the boundary conditions used for the solution of the hot tube and cold shell heat exchanger problem by CFD method.” Flow Vision”, CFD software is used for this purpose. The model is developed in “CATIA V-5”, CAD software and exported to “Flow Vision”. The CFD software is integrated one with meshing and analysis capability. The flow conditions, pressure, and temperature inputs are defined in Flow Vision and analyzed. The numbers of iterations were chosen with a guess in the beginning and were gradually increased for each run till the convergence conditions were satisfied. The shell side and tube side heat duty were ascertained to be equal at convergence. This is necessary to fulfill the energy conservation condition. Table-3 shows the material and fluid properties which were used in the CFD analysis. The material properties were taken from the data records and the average fluid properties used for CFD analysis were found from the water properties tables for the appropriate temperatures used in experimental approach. Only one set of contours for temperature, pressure and velocity are presented here. This is with the view of space limitations, and the reader can visualize the contours going through the results.

Table 1: Boundary Conditions used in CFD Solution 'Flow Vision'

Initial conditions Hot fluid temperature Cold fluid temperature Steel temperature	Boundary Conditions Tube-connected-wall Temperature = L-conjugate Shell External wall Heat flux = 0
Hot inlet / Cold inlet Temperature input Mass velocity input Pressure input	Hot outlet/ Cold outlet Temperature output Pressure output

Table 2: Symbols used, Exchanger Dimensions and Specifications

Symbol	Specification	Dimension
D_s	Inner diameter of shell	0.076m
d_o	Outer diameter of tube	0.015875m
d_i	Inner diameter of tube	0.01448m
r_o	Outer radius of tube	0.0079m
r_i	Inner radius of tube	0.00724m
L_o	Total length of shell with tube end sheets	0.64m
L	Length of Flow	0.604m
B_t	Baffle thickness	0.0015m
B_s	Baffle spacing	0.086m
P_T	Tube pitch	0.02m
N_b	Number of Baffles	06
N	Number of Tubes	08

Table 3: Material and Fluid Properties used for CFD Formulation

Steel: Density(ρ_{st}) – 8030 Kg/m ³ Specific heat (C_{pst}) – 502.5 J/kg °K Conductivity (k_{st}) – 16.27 W/m ⁰ K	Aluminum: Density(ρ_{al}) – 2728 Kg/m ³ Specific heat (C_{pal}) – 895 J/kg °K Conductivity (k_{al}) – 242.3 W/m ⁰ K
Water shell side: Density(ρ_s) – 992.2Kg/m ³ Specific heat (C_{ps}) – 4174 J/kg °K Conductivity (k_s) – 0.63 W/m ⁰ K Viscosity (μ_s) – 0.000654 Kg/m-s	Water Tube side: Density (ρ_t) – 979.7 Kg/m ³ Specific heat (C_{pt}) – 4187 J/kg °K Conductivity (k_t) – 0.66 W/m ⁰ K Viscosity (μ_t) – 0.000421 Kg/m-s

RESULTS AND DISCUSSIONS

The CFD analysis is a help to visualize the flow streams with velocity and pressure variations for both shell-side liquid and tube side liquid. However, the accuracy of results from the CFD software is to be ascertained through alternate approach. For this reason, a comparison of CFD results with the experimental method is made.

To understand the effect of baffle inclination on heat exchanger parameters, the results for heat exchanger with an inclined baffle is compared with segmental baffle heat exchanger of the same size.

Table 4: Experimental Observations for Pressure

Tube Flow in kg/sec	Shell Flow in kg/sec	Shell Pressure Drop in mm of Hg	Pressure Drop in Pascal
0.3	0.3	143	163
0.3	0.4	137	168
0.3	0.5	130	174
0.3	0.6	118	178

Table 5: Comparison of Experimental and CFD/Numerical Results for 20° Inclined Baffles

Shell side flow in kg/sec	Pressure Drop			
	Shell Side		Tube Side	
	Numerical	Experiment	Numerical	Experiment
0.3	2714.15	2667	111.70	---
0.4	4443.84	4133	103.97	---
0.5	6461.89	5866	135.56	---
0.6	10071.1	7999	104.45	---

Figure 3: Shell Side Pressure Drops for 20° Baffles

Figure 4: Shell Side Pressure Drops for 0° and 20° Baffles

Figure 5: Comparison of Shell Side Pressure Drops for 0° and 20° Baffles

Figure 6: Pressure Contour on Shell Side for 0.3 kg/sec Shell Liquid Flow

Figure 7: Velocity Contour on Shell Side for 0.3 kg/sec Shell Liquid Flow

Figure 8: Pressure Contours for 0.3 kg/sec Shell Liquid Flow

CONCLUSIONS

The comparison of results from the 20⁰ numerical and experimental approaches is used to validate the numerical results. The validation of CFD/numerical results is justified through the graphs from the table 4, 5 and figure 3. The results show reasonable agreement between numerical and experimental results for shell outlet pressure variations for shell side liquid.

The results from “Flow Vision” analysis for 20⁰ inclined baffles are compared with zero degrees segmental baffle heat exchanger evaluated using Bell-Delaware approach. The graph from figure 4 and figure 5 are used to conclude the effect of baffle inclination on shell side liquid pressure drop for a heat exchanger. The pressure drops for inclined baffles on the shell side increase as the shell side flow rate increase from 0.3 kg/sec to 0.6 kg/sec. The increase in shell side pressure drop is around 18% between 0.3 kg/sec to 0.4 kg/sec. The increase in shell side pressure drop between 0.4 kg/sec to 0.5 kg/sec and between 0.5 kg/sec to 0.6 kg/sec is less than 3%.

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