STUDY THE EFFECT OF INCLINED BAFFLES ON HEAT DUTY 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 considers on convective coefficients of heat transfer for STHX for an inclined baffle. The work is undertaken using Flow Vision, a commercially available CFD code on a small STHX with inclined baffles having hot tube side liquid flow conditions and cold shell side liquid flow conditions. Four set of constant cold liquid flow conditions with 0.3kg/sec to 0.6 kg/sec are considered through shell compartments and a constant flow of 0.3 kg/sec for hot liquid is considered through the tubes. Heat transfer rate, overall heat transfer coefficients, pressure drops and temperatures at inlet and outlet nozzles on shell-side and tube side are studied.

The results out of the work using CFD strategy is compared with the experimental work which is carried out for the same set of inlet temperatures, flow rates, and pressure conditions through shell compartments and tube side liquid flow. The CFD results are validated using the experimental output results. The validated results from the CFD analysis are compared with the theoretical results computed using the Bell-Delaware method for the same heat exchanger with zero-degree segmental baffles. The process carried out helps to realize the effects of baffle inclination on shell side convective heat transfer coefficient in a shell and tube heat exchanger. The temperature and velocity plots help to study the 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 & Heat Transfer Coefficient

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INTRODUCTION

The transportation sector by roads is mostly fulfilled by Automotive both for light and heavy merchandise at national and global level. Automotive for long have used internal combustion engine as a source of power and continue to use in future. The internal combustion engines have served as a source of drive-by burning fossil fuel. The waste heat from the automotive exhaust is left unused which results in the addition of pollutants to air and polluting it. Also results in reduced efficiency of an internal combustion engine. It also adds to global warming. It is therefore found as prior importance to use the exhaust waste heat either to produce electricity using thermo-electric generators or to preheat the fuel feed for turbocharging. This is envisaged from the perspective of saving fossil fuel for future decades and also preventing environment pollution to some extent for better living of future

generation. STHX may be considered as one of the sources to recover the waste heat from the automotive exhaust manifold. STHX being effective to heat transferring equipment which is easy to construct and convenient to use commonly in various areas like industry, agriculture, fishery, household, environment, and automotive. These may be made available in different sizes with various configurations like a number of tubes, tube arrangements, tube shapes, baffle shapes, liquid flow patterns, and liquid selection soon. They are also relatively easy to dismantle and clean. The STHX have been considered as heat transfer equipment with better heat transfer coefficients and on the other hand have large pressure drops for shell side liquid. Thus, it may be considered as a possibility of utilizing this equipment with appropriate construction which may have a better heat transfer coefficient and lesser pressure drop values. In this regard, a study is undertaken to understand the effects of baffle inclinations on heat duty and pressure drops on the shell side in a tiny STHX.

EXPERIMENTAL METHODOLOGY

A heat exchanger of about 750 mm length, which can be loaded into the manifold of an automotive exhaust is analyzed with inclined baffles of 20° inclination. The tube bundle is made up of Aluminium tubes of eight numbers fitted with a triangular pitch of 45° . Six baffles are fitted with inclination along the shell flow direction with equal spacing. The details of the heat exchanger with specifications can be seen 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. The tube side hot fluid flow is kept 0.3 kg/sec for all cases of shell side fluid flow. Initially, an experimental set up as shown in figure-2 is conducted for the fluid flow conditions mentioned in the Table-4. Sufficient time was allowed for the flow conditions to reach the steady state to have better approximate values of temperature, pressure, and discharge. The output parameters were tabulated which were temperature and pressure. The same conditions as mentioned for experimental setup are used as inputs for the CFD analysis using 'Flow Vision', a commercially available CFD code. The outputs from the two approaches are compared.

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.

Figure 1: Baffle Inclination Representation

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

CFD METHODOLOGY

Table-1 shows the boundary conditions used for the solution of the hot tube and cold shell heat exchanger problem by CFD method. The number of iterations chosen changed for each run till the convergence conditions were satisfied. The shell side and tube side heat duty were ascertained to be equal at convergence. 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.

The comparison of results from the 20⁰ numerical and experimental approach is used to validate the numerical results. The validation of CFD/numerical results is justified through the graphs from the figures 3 to 5 and table 5,6. Also, the results show reasonable agreement between numerical and experimental results for shell outlet and tube outlet temperature with less than 0.5 % variation in temperature in Kelvin as seen from table-5.

Table 1: Boundary Conditions Used in Solution Using 'Flow Vision'

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

Table 2: The Symbols Used, 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	640 mm = 0.64m
L	Length of Flow	604 mm = 0.604m
B_t	Baffle thickness	1.5mm = 0.0015m

Table 2: Contd.,		
B_s	Baffle spacing	86mm = 0.086m
P_T	Tube pitch	20mm = 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

Table 4: Experimental Observations

Tube Flow in kg/sec	Shell Flow in kg/sec	Temperature in °K			
		Tube Input	Tube Output	Shell Input	Shell Output
0.3	0.3	340	335	305	312
0.3	0.4	350	344	312	317
0.3	0.5	348	342	313	318
0.3	0.6	343	337	308	312

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

Shell side Flow in kg/sec	Temperature in °K				Heat Duty in Watts	
	Shell outlet		Tube outlet		Numerical	Experiment
	Numerical	Experiment	Numerical	Experiment		
0.3	311.6	312	333.3	335	8327	10186
0.4	318.3	317	341.3	344	10800	11350
0.5	317.2	318	340.2	342	10423	12076
0.6	312.1	312	334.5	337	10559	12678

Table 6: Comparison of Numerical and Experimental Results for 20°Inclined Baffles

Shell side flow in kg/sec	Coefficient of Heat transfer in W/m ²⁰ K	
	Numerical	Experimental
0.3	1170	1353.6
0.4	1388	1386.2
0.5	1432	1576.8
0.6	1470	1655.4

Figure 3: Heat Duty for 20° Baffles

Figure 4: Heat Transfer Coefficients for 20° Baffles

Figure 5: Heat Duty for 0° and 20° Baffles

Figure 6: Heat Transfer Coefficients for 0° and 20° Baffles

Figure 7: Heat Duty for 0° and 20° Baffles

Figure 8: Heat Transfer Coefficients for 0° and 20° Baffles.

Figure 9: Temperature Contour on Shell Side for 0.3 Kg/Sec Shell Liquid Flow

Figure 10: Temperature Contours for 0.3 kg/sec Shell Flow

Figure 11: Temperature Contours for 0.6 kg/sec Shell Liquid Flow

CONCLUSIONS

The results from “Flow Vision” analysis for 20° inclined baffles are compared with zero degrees segmental baffle heat exchanger evaluated using Bell-Delaware approach. The graphs available from figure 5 to 8 are used to conclude the effect of baffle inclination on pressure drop and heat duty of heat exchanger.

The heat duty for twenty-degree inclined baffle heat exchanger increase from around 19% to 37% when compared to zero-degree segmental baffles as shell side fluid flow increases from 0.3 kg/sec to 0.6 kg/sec with the tube side flow of 0.3 kg/sec is being constant.

The overall heat transfer coefficients increase from around 12% to 20% for twenty-degree inclined baffle heat exchanger when compared to zero-degree segmental baffle heat exchanger as the shell side fluid flow increases from 0.3kg/sec to 0.6 kg/sec.

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