IJRAME

ISSN (ONLINE): 2321-3051

INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

CFD Analysis of Shell and Tube Heat Exchanger to Study the Effect of Baffle Cut on the Pressure Drop

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Abstract

The shell side design of a shell and tube heat exchanger; in particular the baffle spacing, baffle cut and shell diameter dependencies of the heat transfer coefficient and the pressure drop are investigated by numerically modelling a small heat exchanger. The flow and temperature fields inside the shell are resolved using a commercial CFD package. A set of CFD simulations is performed for a single shell and single tube pass heat exchanger with a variable number of baffles and turbulent flow. The results are observed to be sensitive to the turbulence model selection. The best turbulence model among the ones considered is determined by comparing the CFD results of heat transfer coefficient, outlet temperature and pressure drop with the Bell–Delaware method results. For two baffle cut values, the effect of the baffle spacing to shell diameter ratio on the heat exchanger performance is investigated by varying flow rate.

***Keywords**:* CFD, Heat Exchanger, Shell and Tube, Baffle Cut, Turbulence Models.

1. Introduction

Shell and tube heat exchangers are known as the work-horse of the chemical process industry when it comes to transferring heat. These devices are available in a wide range of configurations as defined by the Tubular Exchanger Manufacturers Association. The applications of single-phase shell-and-tube heat exchangers are quite large because these are widely in chemical, petroleum, power generation and process industries. In essence, a shell and tube exchanger is a pressure vessel with many tubes inside of it. One process fluids flows through the tubes of the exchanger while the other flows outside of the tubes within the shell. The tube side and shell side fluids are separated by a tube sheet. In these heat exchangers, one fluid flows through tubes while the other fluid flows in the shell across the tube bundle. The design of a heat exchanger requires a balanced approach between the thermal design and pressure drop. The performance parameters include heat transfer, pressure drop, effectiveness etc.

The determination of pressure drop along with heat transfer in a heat exchanger is essential for many applications for at least two reasons:

(1) The fluid needs to be pumped through the exchanger, which means that fluid pumping power is required. This pumping power is proportional to the exchanger pressure drop.

(2) The heat transfer rate can be influenced significantly by the saturation temperature change for a condensing/evaporating fluid in case of multiphase flow if there is a large pressure drop associated with the flow. Ideally most of the pressure drop available should be utilized in the core and a small fraction in the manifolds, headers, or other flow distribution devices.

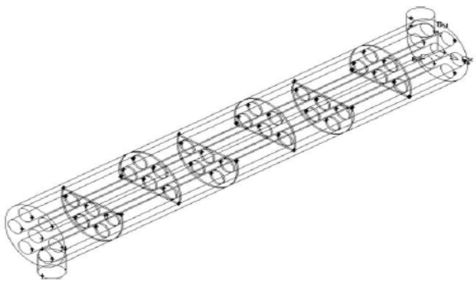

Figure 1: The Model with 6 Baffles

To be able to understand the causes of the shell side design weaknesses, the flow phenomenon inside the shell must be well understood. For that purpose, numerous analytical, experimental and numerical studies have been performed. Most of these studies were concentrated on the certain aspects of the shell-and-tube heat exchanger design. Among others, Gay et al. [4] worked on heat transfer, while Halle et al. [5], Pekdemir et al. [6], Gaddis and Gnielinski [7] investigated pressure drop. Some of the researchers concentrated only on certain parts of the shell-and-tube heat exchanger. It can be particularly useful in the initial design steps, reducing the number of testing of prototypes and providing a good insight in the transport phenomena occurring in the heat exchangers [14]. In all of these simplified approaches, the shell side pressure drop and heat transfer rate results showed good agreement with experimental data.

2. Modelling Details

In this study, a small heat exchanger is selected in order to increase the model detail and to make solid observations about the flow inside the shell. Some of the design parameters and the predetermined geometric parameters are presented here. The geometric model with 6 baffles is shown in Fig. 1. Two different baffle cut values are selected: 25% baffle cut value is very common in shell-and-tube heat exchanger designs; whereas, 36% baffle cut value is selected to place the cut just below or above the central row of tubes. The working fluid of the shell side is water. Since the properties of water are defined as constants in the Fluent database, to improve the accuracy, they are redefined using piecewise-linear functions of temperature by using the ‘‘Thermo-Physical Properties of Saturated Water” tables available in the literature [15].

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2.1 Boundary conditions

The desired mass flow rate and temperature values are assigned to the inlet nozzle of the heat exchanger. The shell inlet temperature is set to 300 K. Zero gauge pressure is assigned to the outlet nozzle, in order to obtain the relative pressure drop between inlet and outlet. The inlet velocity profile is assumed to be

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June 2014.
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uniform. No slip condition is assigned to all surfaces. The zero heat flux boundary condition is assigned to the shell outer wall, assuming the shell is perfectly insulated outside. Since the tube side flow is easy to resolve, the present study is concentrated on the shell side flow. After modelling the tubes as solid cylinders, the constant wall temperature of 450 K is assigned to the tube walls.

The pressure model is selected from the paper published by Kapale U C, Chand S. [16]

Design parameters and fixed geometric parameters.

Shell size (D_s) = 90 mm, Tube outer diameter (d_o) = 20 mm,

Tube bundle geometry and pitch = Triangular, 30 mm

Number of tubes (N_t) = 7, Heat exchanger length (L) = 600 mm,

Shell side inlet temperature (T) = 300 K, Baffle cut (B_c) = 25% & 30% alternate,

Central baffle spacing (B) = 86 mm, Number of baffles (N_b) = 6

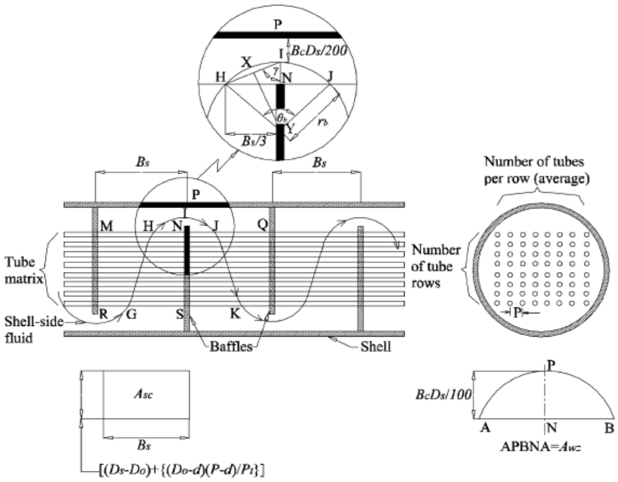

Figure 3: Showing the actual flow pattern in shell-side

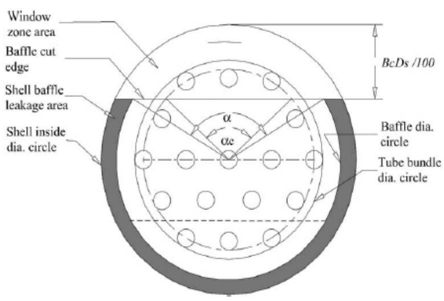

Figure 4: Illustration of baffle cut angles, leakage area.

3. Result and Discussion

3.1. Sensitivity of results to turbulence model and discretization order

In all of the preliminary simulations, the flow inside the shell is observed to be turbulent. Therefore, the viscous model is selected as turbulent. The sensitivity of the results to the turbulence model and the discretization order is investigated using the heat exchanger model with 6 baffles which is shown in Fig. 1. The first and second order discretization schemes and three different turbulence models are tried for two different mesh densities.

Sr.No.	M	G_s	Shell inlet temp	μ_s	ρ_s	Re_s	$\dot{V}$	u_n	ΔP_n	f	u_{sc}	ΔP_c	ΔP_{cdn}	u_{wz}	ΔP_b	ΔP_{wz}	ΔP_{ic}	ΔP_{ec}	ΔP_s
	kg/sec	kg/sec-m^2	^{0}C	kg/m.s	kg/m^3		m^3/sec	m/sec	Pa		m/sec	Pa	Pa	m/sec	Pa	Pa	Pa	Pa	Pa
1	0.5	193.7984	27	0.00083	996.05	1728.776	0.000501983	1.02264	1041.66	0.52	0.17638	28.656	636.442	0.81425	108.153	711.535	4412.49	26.2545	5480.4
2	1	387.5969	27	0.00083	996.05	3457.551	0.001003966	2.04528	4166.64	0.47	0.35275	103.603	2545.77	1.62849	422.547	2836.52	17537.1	94.9199	21798.7
3	2	775.1938	27	0.00083	996.05	6915.102	0.002007931	4.09056	16666.6	0.35	0.7055	308.603	10183.1	3.25699	1593.57	11253.8	69065.6	282.74	86014.9

Figure 5: Analytical Result for baffle cut at 25%

Sr.No.	M	G_s	Shell inlet temp	μ_s	ρ_s	Re_s	$\dot{V}$	u_n	ΔP_n	f	u_{sc}	ΔP_c	ΔP_{cdn}	u_{wz}	ΔP_b	ΔP_{wz}	ΔP_{ic}	ΔP_{ec}	ΔP_s
	kg/sec	kg/sec-m^2	^{0}C	kg/m.s	kg/m^3		m^3/sec	m/sec	Pa		m/sec	Pa	Pa	m/sec	Pa	Pa	Pa	Pa	Pa
1	0.5	167.8416	27	0.00083	996.05	1497.228	0.000501983	1.02264	1041.66	0.52	0.17638	20.5015	27.887	0.35153	44.4994	69.1724	517.542	26.2545	1585.46
2	1	335.6831	27	0.00083	996.05	2994.455	0.001003966	2.04528	4166.64	0.47	0.35275	74.1208	111.548	0.70306	176.595	275.349	2022.7	94.9199	6284.26
3	2	671.3662	27	0.00083	996.05	5988.91	0.002007931	4.09056	16666.6	0.35	0.7055	220.785	446.191	1.40611	692.91	1088.53	7635.08	282.74	24584.4

Figure 6: Analytical Result for baffle cut at 30%

Sr.No.	Mass flow rate	25%	30%	% Decrease
		ΔP_s	ΔP_s	
1	kg/sec	Pa	Pa	
2	0.01666	0.559493	0.539655	3.545710134
3	0.03333	1.98434	1.903972	4.05011238
4	0.05	4.303975	4.11122	4.478534378
5	0.06666	7.500554	7.165568	4.4661501
6	0.08333	11.508868	11.008043	4.351644315
7	0.1	16.518	15.611549	5.487655891
8	0.11666	22.0399	21.101822	4.25627158
9	0.13333	28.646683	27.444256	4.197438845
10	0.15	36.135445	34.566093	4.342971285
11	0.16666	44.467651	42.515915	4.389114235

Figure 7: Comparison of CFD results

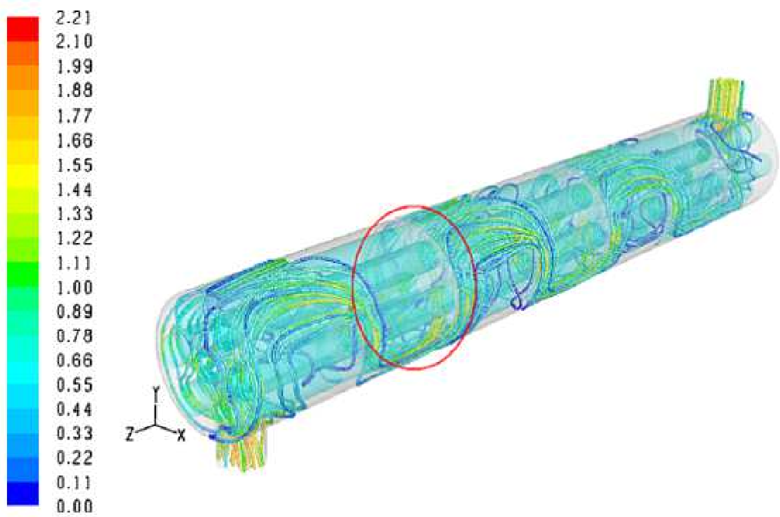

Figure 8: Velocity (m/s) path lines for 6 baffles (1 kg/s mass flow rate)

3.2. Effects of baffle cut on pressure drop

Here, the simulations are repeated for the baffle cut value of 25% and effects of the baffle cut on the heat transfer and the pressure drop are investigated. The percent differences between the analytical calculations and the CFD analysis results are presented in Figure 5. The analytical calculations are taken as the base values for the percent difference calculations.

4. Conclusion

The shell side of a small shell-and-tube heat exchanger is modelled with sufficient detail to resolve the flow and temperature fields. From the CFD simulation results, for fixed tube wall and shell inlet temperatures, shell side heat transfer coefficient, pressure drop and heat transfer rate values are obtained. The sensitivity of the shell side flow and temperature distributions to the mesh density, the order of discretization and the turbulence modelling is observed. By varying baffle cut values of 25% and 30%, for 0.5, 1 and 2 kg/s shell side flow rates, the simulation results are compared with the results from the Kern and Bell–Delaware methods. Using CFD, together with supporting experiments, may speed up the shell-and-tube heat exchanger design process and may improve the quality of the final design. In the near future, improvements in the computer technology will make full CFD simulations of much larger shell-and-tube heat exchangers possible

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A Brief Author Biography

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