A Case Study on Design of Ammonia Condenser: Effect of Independent Variables

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Abstract— **Shell and tube heat exchangers are widely used in process industries for exchange of heat from one fluid to another by indirect means. Design of heat exchanger is lengthy and iterative procedure and overall cost of heat exchanger depends upon various independent variables. Here in present study, we have considered ammonia condenser for study purpose. As ammonia is produced widely in urea manufacturing industries. In present study, we have studied effect of various independent variables like tube outside diameter, tube length and baffle spacing on heat transfer coefficient and pressure drop.**

Keywords— **Ammonia, HTRI, Condenser design, Shell and tube heat exchanger**

I. INTRODUCTION

Heat transfer between process fluids is an inseparable part of most of the chemical processes[1]. Heat exchangers are equipment, which is used in chemical industries for exchange of heat. Several types of heat exchangers are used in industrial processes. These include double pipe heat exchangers, shell-and-tube exchangers, plate-and-frame exchangers and many others[2]. From all of the mentioned heat exchangers, shell-and-tube heat exchangers are widely used in heating and air conditioning, chemical processes, power generation, refrigeration, manufacturing and medical applications. Shell-and-tube heat exchanger provide advantage of high surface area to volume ratio and is adaptable to various operating conditions[3].

Design of shell-and-tube is an iterative procedure, which is constrained by maximum allowable pressure drop. Before starting design, designer have to specify certain independent process variables like outside diameter of tube, geometry of tube pitch, baffle spacing and number of tube side pass partition are independent and can affect design significantly. These independent variables have pronounced effect on heat transfer coefficient and pressure drop. So trial and error procedure is required to find optimum design of shell-and-tube heat exchanger.

Computational tools like HTRI and HTFS are extensively used for rating and thermal design purpose of the heat exchangers however, they do not consist any optimization techniques. These softwares also require input in terms of independent variables, which will govern overall design.

In present study, effect of independent variables are studied in terms of their effect on heat transfer coefficient and pressure drop for ammonia condenser using HTRI. This paper will provide rough estimate to designer for initial selection of independent variables, so that optimum design can be converged with less number of iterations.

II. PROBLEM STATMENT

Ammonia enters into condenser at 7000 Kg/h, 120 °C temperature and 16 bar (a) pressure. At inlet ammonia is in superheated condition. At exit subccoled ammonia liquid is obtained at 26 °C. Cooling water is used as a cooling medium. Water comes from cooling tower so that maximum temperature of water is 20 °C. Discharge head of water pump is 6 kg_f/cm^2. Water temperature is maintained by induced draft fan in cooling tower. Ammonia vapour is allocated on shell side while cooling water is allocated on tube side.

III. RESULTS AND DISCUSSION

Effect of one independent variable is studied while keeping rest of the independent variables constant. Several independent variables like outside diameter of tube, tube length, baffle spacing and number of tube side pass partition are considered for present work. Influence of independent variables are encountered with constant process parameters. Process parameters which are remained constant are tabulated in Table 1. For the given problem, observations are reported in rating mode of HTRI. For rating shell inside diameter was kept 1.1 meter.

Table 1. Constant Process Parameters

Sr. No.	Process Parameter	Value
1	Hot fluid flow rate	1.944 kg/s
2	Cold fluid flow rate	53.7 kg/s
3	Hot fluid inlet temperature	120 °C
4	Hot fluid outlet temperature	26 °C

5	Cold fluid inlet temperature	20 °C
6	Cold fluid outlet temperature	32 °C
7	Hot fluid inlet pressure	1600 kPa
8	Cold fluid inlet pressure	600 kPa

In entire study, units and nomenclature listed (as per Table 2) against their name are used.

Table 2. Nomenclature and units for variables and parameters

Sr. No.	Parameter/Variable	Nomenclature	Unit
1	Tube outside diameter	d_0	mm
2	Tube inside diameter	d_i	mm
3	Tube side heat transfer coefficient	h_i	$W/m^2 °C$
4	Shell side heat transfer coefficient	h_o	$W/m^2 °C$
5	Tube side Pressure drop	Δp_t	kPa
6	Shell side Pressure drop	Δp_s	kPa
7	Tube length	L	m
8	Baffle Spacing	B_S	m

A. *Effect of tube outside diameter*

Effect of tube outside diameter is encountered on tube side and shell side heat transfer coefficient and tube side and shell side pressure drop. For constant wall thickness of tube, with increase in tube outside diameter tube inside diameter is increased. Due to increase in tube inside diameter, tube side velocity decreases for constant volumetric flow rate and number of tubes in given shell decreases. Relation between tube outside diameter and velocity is shown in Figure 1. Decrease in tube side fluid velocity cause reduction in tube side heat transfer coefficient as there will be overall reduction in Reynold’s number. For forced convection heat transfer, heat transfer coefficient is strong function of Reynold’s number. For shell side fluid, velocity increases as the tube OD increases. This increase in shell side fluid velocity is justified as shell side cross flow area decreases with increase in tube OD. But shell side heat transfer coefficient do not vary significantly with the tube OD. Effect of tube OD is more sensitized on tube side heat transfer coefficient than shell side heat transfer coefficient.

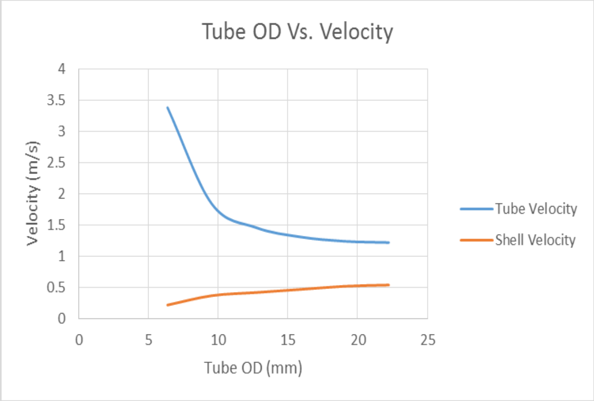

Figure 1. Relation between shell side and tube side fluid velocity and tube OD (Shell ID = 1.1 m, Baffle cut = 25%, Baffle spacing = 0.2 m, Layout angle = 30°, Tube length = 5.486 m)

On the same line results are observed for tube side and shell side pressure drop. Tube side pressure drop decreases as tube OD increases, because tube side velocity decreases with increase in tube OD. For shell side fluid, pressure drop increases slightly as shell side fluid velocity has increased. But effect on tube side pressure drop is more pronounced compared to shell side pressure drop. Observation for shell side and tube side heat transfer coefficients and pressure drops are tabulated in Table 3.

Table 3. Relation between tube OD and shell and tube side heat transfer coefficient and pressure drop.

Sr. No.	Tube OD	Tube side heat transfer coefficient	Shell side heat transfer coefficient	Tube side Pressure drop	Shell side Pressure drop
1	6.35	17694	2906.74	1465.16	4.529
2	9.525	9441.4	2711.92	221.412	4.698
3	12.7	7189.4	2471.27	95.288	4.644
4	15.875	6212.56	2427.53	60.183	4.547
5	19.05	5680.59	2365.46	45.326	4.458
6	22.225	5414.96	2290.73	38.355	4.373

B. *Effect of tube length*

Effect of tube length on tube and shell side heat transfer coefficient and tube and shell side pressure drop is studied. Increase in tube length will not affect tube and shell side heat transfer coefficient and shell and tube side pressure drop much as tube and shell side cross flow area will not change with tube length. There is slight reduction in shell side velocity due to pressure drop along the length of heat exchanger. Obtained results are tabulated in Table 4.

Table 4. Relation between tube length and shell and tube side heat transfer coefficient and pressure drop.

Sr. No.	Tube length	Tube side heat transfer coefficient	Shell side heat transfer coefficient	Tube side Pressure drop	Shell side Pressure drop
1	1.892	4656.86	2381.94	18.068	3.847
2	2.438	4651.09	2417.07	20.293	4.141
3	3.048	4649.47	2373.4	22.515	4.429
4	3.658	4652.98	2451.63	24.746	4.678
5	4.267	4654.13	2368.95	26.958	4.925
6	4.877	4655.31	2449.88	29.187	5.184
7	5.486	4655.66	2423.51	31.413	5.398
8	6.096	4657.41	2401.11	33.638	5.585

C. *Effect of baffle spacing*

Effect of baffle spacing was investigated on shell side heat transfer coefficient and shell side pressure drop. With increase in baffle spacing shell side heat transfer coefficient remains almost constant because for condensation outside tubes and horizontal condenser shell side heat transfer coefficient do not depend upon baffle spacing as per equation 1[4]. Slight decrease in heat transfer coefficient with increase in baffle spacing was observed because de-superheating and sub-cooling heat transfer coefficients depends upon shell side cross flow velocity.

$$(h_c)_b = 0.95 k_L \left[\frac{\rho_l(\rho_l - \rho_v)g}{\mu_L \Gamma_h}\right] * N_r^{-1/6} \quad \text{-----(1)}$$

Where,

$$\Gamma_h = \text{Tube loading} = \frac{W_c}{L N_t}$$

W_c = Total condensate flow in (kg/s)
L = Length of tube
N_t = Tube in bundle
N_r = Average number of tube in vertical tube row.
ρ_v = Density of vapor
ρ_L = Density of liquid
g = Acceleration due to gravity, 9.81 m/s^2

Shell side pressure drop decrease very slightly with increase in baffle spacing as shown in Figure 2. This behavior is justified as increase in baffle spacing increases shell side cross flow area, therefore reducing shell side velocity. Reduction in shell side velocity reduces pressure drop. While tube side pressure drop is not dependent upon baffle spacing therefore tube side pressure drop remains constant (58.296 kPa).

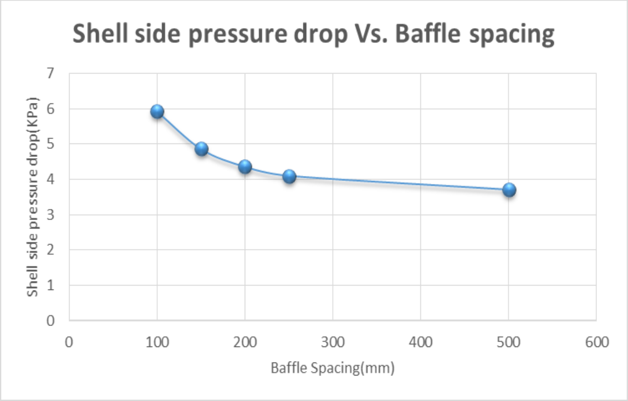

Figure 2. Effect of baffle spacing on shell side pressure drop. (Shell ID = 1.1 m, Baffle cut = 25%, Tube side number of passes = 4, Layout angle = 30°, Tube OD = 19.05 mm, Tube Length = 4.267 m)

D. *Effect of number tube side passes*

Effect of variation in number of tube side passes were studied on tube and shell side heat transfer coefficient and tube and shell side pressure drop. Effect of change in passes on number of tubes, tube and shell side heat transfer coefficient and tube and shell side pressure drop is tabulated in Table 5.

For fixed internal diameter of shell, increase in number of passes decreases number of tubes. Due to reduction in tube side area with increase in tube side passes, tube side velocity increases and tube side turbulence is increased. As tube side heat transfer coefficient is strong function of Reynolds' number, tube side heat transfer coefficient increases. With increase in tube pass from 1 to 16, tube side heat transfer coefficient increases almost 18.5 times. While shell side heat transfer coefficient do not change appreciably with number of tube side passes.

Increase in tube side passes also affects tube side pressure drop considerably. Increase in number of passes from 1 to 16, increases tube side pressure drop almost 165 times. While the same has negligible effect on shell side pressure drop.

Table 5. Relation between numbers of tube passes tube and shell heat transfer coefficient and pressure drop

Pass	No. of tubes	Tube Velocity (m/s)	Shell Velocity (m/s)	Tube side heat transfer coefficient	Shell side heat transfer coefficient	Tube side pressure drop	shell side pressure drop
1	1543	0.18	0.58	740.01	1918	6.93	4.71
2	1498	0.37	0.49	1905.9	2239	9.45	4.57
4	1424	0.77	0.47	3496.9	2210	22.3	4.58
6	1364	1.13	0.43	5604.2	2155	58.2	4.4
8	1324	1.58	0.42	7186.1	2172	129	4.38
10	1282	2.47	0.44	8781.9	2204	252	4.38
12	1244	2.51	0.45	10390	2230	441	4.38
16	1164	4.17	0.43	13665	2211	1148	4.37

IV. CONCLUSIONS

In present work, performance of ammonia condenser is evaluated in terms of tube and shell side heat transfer coefficient and pressure drop. The main findings of the work is as follows:

1. Increase in tube OD and increase in tube side number of passes has pronounced effect on tube side heat transfer coefficient and pressure drop. So, while designing one has carefully select tube OD and number of tube side pass partition plate.
2. Increase in length of tube, makes no significant change in tube and shell side heat transfer coefficient and pressure drop.
3. For condenser, increase in baffle spacing does not make any significant impact on shell side heat transfer coefficient. As condensation coefficient does not depend on baffle spacing. It also does not have any considerable effect on pressure drop as well. So for condensers, purpose of baffles is only to support tube bundle.
4. Increase in number of tube side passes increase tube side heat transfer coefficient significantly but it also suffers from the drawback of high tube side pressure drop. Change in number of tube side passes, do not affect shell side heat transfer coefficient and pressure drop.

REFERENCES

[1] B.V. Babu and S.A. Munawar, “Differential evolution strategies for optimal design of shell-and-tube heat exchangers”, Chemical Engineering Science, 62 (2007) 3720 – 3739.

[2] S. Fettaka, J. Thibault and Y. Gupta, “Design of shell-and-tube heat exchangers using multiobjective optimization”, International Journal of Heat and Mass Transfer, 60 (2013) 343–354.

[3] A. Hadidi, M. Hadidi and Ali Nazari, “A new design approach for shell-and-tube heat exchangers using imperialist competitive algorithm (ICA) from economic point of view”, Energy Conversion and Management, 67 (2013) 66–74.

[4] R.K. Sinnot, “Chemical Engineering Design”, Elsevier Butterworth-Heinemann, Volume 6, Fourth Edition, 634-793.