



Effect of Tube Diameter on Heat Transfer through Staggered Tube Bundles of Shell-and-Tube Heat Exchanger

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Abstract — Cross-flow over tube bundle is generally encountered in practice in heat transfer equipments such as evaporators and condensers of power plants, air conditioners, refrigerators. In such equipment, one fluid moves through the tubes while the other moves over the tubes in a perpendicular direction. Steady state Navier-stokes and the energy equations are applied for cylinders having diameter of tube 0.02, 0.03 and 0.04m having constant p/d ratio for staggered tube layout to obtain the numerical solutions of governing equations using Finite Element Method. The effect of change of diameter of tube on heat transfer and pressure drop has been analyzed using CFD tool. The contours of streamlines, pressure, velocity and temperature are generated to study the effect of change in diameter of tube. The purpose of this study is to investigate the heat transfer and pressure characteristics at various tube diameters for staggered tube bundle layouts in cross-flow. The result shows that as the diameter of tube increases the heat transfer increases with decrease in temperature and pressure drops.

Keywords- U-tube bundle; Triangular pitch, staggered layout; Heat transfer co-efficient; Pressure drop

I. INTRODUCTION

Generally in all chemical processes energy is absorbed in the form of heat. Heat exchanger is device to transfer heat between two or more than two fluids at different temperatures [1]. Particularly in shell-and-tube heat exchanger Circular tube bundles are the most common heat transfer surfaces used in heat exchanger. In U-tube heat exchanger fluid flow normal to the tube cross-sectional area. The most common tube configurations are staggered and inline. The geometric tube arrangements are governed by the geometry of tube bundle and the relative pitches. The variation in temperature and pressure relies upon the number of longitudinal/transverse pitch due to the inlet and outlet effects on pressure drop and heat transfer coefficient, which is mainly directed by mass flow rate of fluid flowing in the tubes. As the bundle is more compact, the temperature difference & pressure drop is larger.

To explore the influence of mass flow rate on heat transfer on a solitary tube or bundle of tube, various researchers carried out hypothetical, exploratory and numerical studies. A. A. Zukauskas (1987) carried out an experimental analysis for the arrangement of tube bundle and different pitches configuration viz. triangular & rotated triangular pitch square, rotated square. He was observed that the tubes are more firmly stuffed in the group with triangular pitch, which transfer more heat to the surface in a shell and slightly higher pressure drop and heat transfer coefficient. However, the clearance between tubes is generally the larger of 0.00635m and 0.025Do [2].

It is generally observed that there is two-phase flow over the bundle of tube in U-tube heat exchangers. Ceong et al. (2000) studied the two-phase structure of cross-sflow in tube bundle by PIV[3]. J. Fillich (1969) brought out analysis on the flow inside a model of heat exchanger under staggered design condition of five lines of tube for the Reynolds number $105 < Re < 107$ [4].

In several positions of the tube bundle the distribution of the skin friction and static pressure around the tubes was determined experimentally. The simulation of the heat transfer in shell and tube heat exchanger model was carried out by Khairun Othma (2009) and validated it in Shell and Tube Heat Exchanger Studies Unit (Model HE 667) using CFD tool within 15% error [5]. A least-squares finite element method was used to study the heat transfer and fluid flow in 3-D heat exchangers with the in-line and staggered both multiple-row tubes configuration by Jyh-Haw Tang (2006). In this study the heat transfer coefficient, pressure drop, pressure coefficient, local and average Nusselt number for different geometric conditions have been examined in detail which shows that the average heat transfer coefficient of staggered configuration is 10%-30% higher than the in-line configuration & the pressure drop distribution is also higher at $Re = 200$ [6].

Vikas Kumar (2003) was carried out 3-D numerical simulation to anticipate the air flow and temperature distribution in the tube heat exchanger connected with large electrical motor. Because of symmetrical geometry, a section of heat exchanger was taken for CFD analysis. To explain the transport equations for turbulent flow energy and the

dissipation rate $k - \epsilon$ turbulence model was utilized. The outlet temperature of both cold & hot air was anticipated by the CFD simulation and it is in close agreement with exploratory results [7].

A numerical investigation was carried out by M. H. Alhajeri (2010) for cross flow pass in a tube bank for an wide variety of Reynolds number running from 380 to 99000 with the inlet velocities ranges from 0.072 m/s to 60 m/s. He was resolved that as the velocity increases, the drag co-efficient abatements until the velocity surpassed 45 m/s, after which it increments. Also, the skin friction drag and pressure drag relies on upon the velocity [8]. For various tube design two-dimensional Navier-stoke mathematical statements written in stream function vorticity variables were independently illuminated along with a species conservation equation. Through Numerical Investigation of hydrodynamics and mass Transfer for in-line tube configuration in laminar cross flow for low Reynold's number, $Re = 10-200$ and $Pe = 10-300$ with p/d ratio of 1.45, 1.50, 1.75, 1.85, and 2.00 are discussed by by T. Lia, b, N.G. Deena, J.A.M. Kuipersa in point of interest [9].

1.1. Equations and correlations used

In cross flow the transfer of heat through tube bundles in staggered condition is represented by A. A. Zukauskas as follows [10]:

$$Nu_b = cRe_b^m Pr_b^n \left(\frac{Pr_b}{Pr_w}\right)^p \tag{1}$$

$$\bar{Nu}_b = 1.04c_n Re_b^{0.4} Pr_e^{0.36} \left(\frac{Pr_b}{Pr_w}\right)^{0.25}, \text{ for } Re_b = 1 - 500 \tag{2}$$

$$\bar{Nu}_b = 0.71c_n Re_b^{0.5} Pr_e^{0.36} \left(\frac{Pr_b}{Pr_w}\right)^{0.25}, \text{ for } Re_b = 500 - 10^3 \tag{3}$$

$$\bar{Nu}_b = 0.35c_n Re_b^{0.6} Pr_e^{0.36} \left(\frac{Pr_b}{Pr_w}\right)^{0.25} \left(\frac{X_t}{X_l}\right)^{0.2}, \text{ for } Re_b = 10^3 - 2 \times 10^5 \tag{4}$$

$$\bar{Nu}_b = 0.031c_n Re_b^{0.8} Pr_e^{0.4} \left(\frac{Pr_b}{Pr_w}\right)^{0.25} \left(\frac{X_t}{X_l}\right)^{0.2}, \text{ for } Re_b = 2 \times 10^5 - 2 \times 10^6 \tag{5}$$

$$Re_b = \frac{u_o d_o \rho}{\mu} \tag{6}$$

Pressure drop for multi row of tube bundle,

$$\Delta p = \left(\frac{Eu}{\chi}\right) \chi \frac{1}{2} \rho u_o^2 \tag{7}$$

For Laminar flow the heat transfer,

$$h_i = \frac{k_i}{d_i} \left\{ 3.65 + \frac{0.0668 Re_i Pr_i (d_i/L)}{1 + 0.04 [Re_i Pr_i (d_i/L)]^{2/3}} \right\} \left(\frac{\mu_i}{\mu_{w,i}}\right)^{0.14} \tag{8}$$

For Turbulent flow the heat transfer,

$$h_f = 0.023 \frac{k_f}{d_f} Re_f^{0.8} Pr_f^{1/3} \left(\frac{\mu_f}{\mu_{f,w}}\right)^{0.14} \tag{9}$$

II. NUMERICAL SIMULATION

ANSYS-CFX 12.1 is utilized to analyse the influence of variation in Tube diameter on pressure drop and heat transfer co-efficient of U-tube type heat exchanger under staggered design and to analyse it by generating the contours of pressure & temperature. Several boundary conditions are apply to conduct the numerical simulation as listed below.

- Temperature of tube wall is steady.
- Periodic inlet and outlet boundaries.
- The same region is repetitive simultaneously.

- Steady Mass flow rate.
- Finite Element method is use.
- Apply Steady state isothermal condition.
- The velocity is 2 m/s at 300C shell side inlet temperature.
- The velocity is 1m/s at 450C tube side inlet temperature.
- In the whole region single fluid is passing.
- Tube wall is stationary (Momentum condition).
- No Slip (Shear condition).
- Across symmetric boundaries fluid does not flow.
- Subsonic flow and it arises at high values of Reynolds number.

III. GEOMETRY

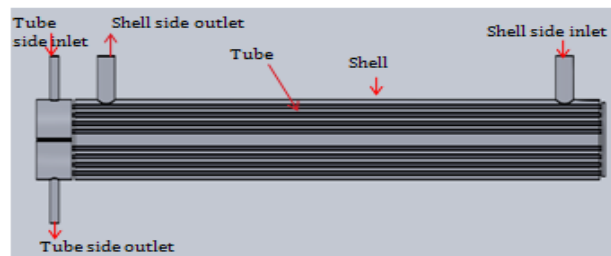


Figure. 1. Model of a Heat Exchanger created in Solid Works

The heat exchanger Cavity model is to be created in Solid Works 2009 X64 edition SPO is appeared in fig. 1. The bundle of tube comprises of consistently separated tubes and the accompanying cases were considered for the investigation. The Heat exchanger has tube diameter of 0.04m and Shell Diameter of 0.55m having length of 1.25m and thickness of 0.005m.

- Case 1 : $d = 0.02\text{m}$
- Case 2 : $d = 0.03\text{m}$
- Case 3 : $d = 0.04\text{m}$

Figure. 2 shows the geometry of third case having p/d ratio is 1.5 for the 0.04m tube diameter & like that there are two other cases having tube diameter are 0.02m & 0.03m. For all the circumstances the both Longitudinal & Transverse pitches are the similar.

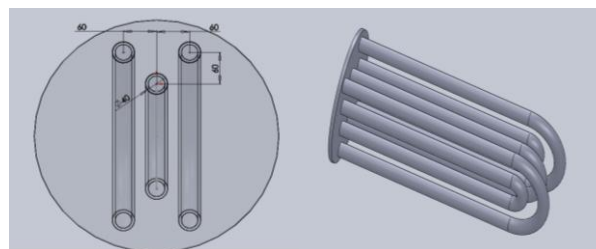


Figure. 2. 3-D tube geometry for Case-3

3-D tube geometry in staggered configuration is shown in figure 2. In ANSYS CFX 12.1 Workbench the cavity model is imported in Mesh module for meshing.

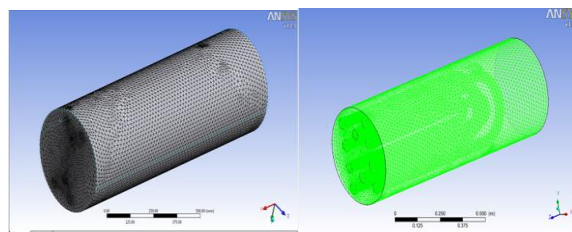


Figure. 3. Mesh generation in Staggered Configuration

The generation of mesh in the control volume is shown in figure 3. 3-D unstructured tetrahedral and hexahedral meshing has been used to get the completely developed dense mesh. The quantities of elements of tetrahedral shape were 695961 and nodes were 162694.

IV. CFD ANALYSIS

Following figure shows the contours of temperature and pressure for the diameter of tube 0.02m, 0.03m and 0.04m.

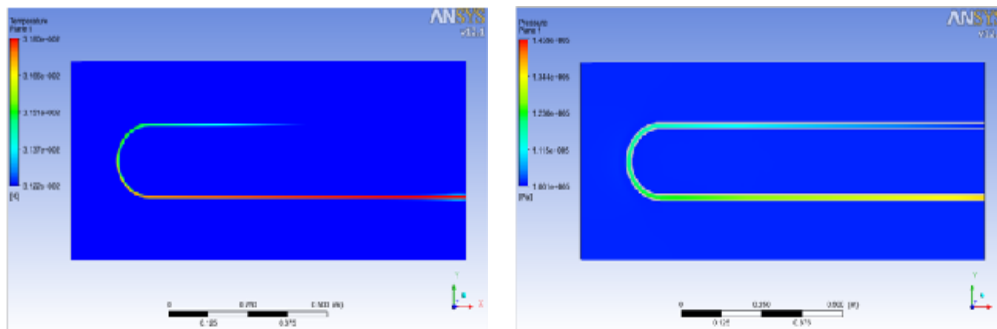


Figure. 4. (a) Temperature & (b) Pressure contours of tube diameter, $d = 0.02m$

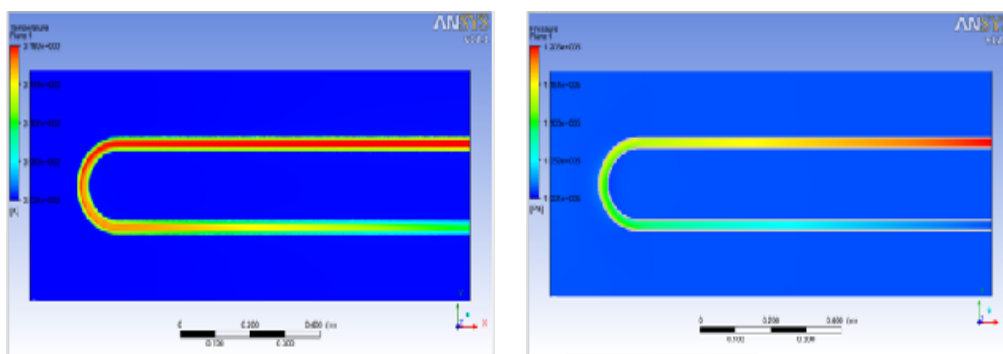


Figure. 5. (a) Temperature & (b) Pressure contours of tube diameter, $d = 0.03m$

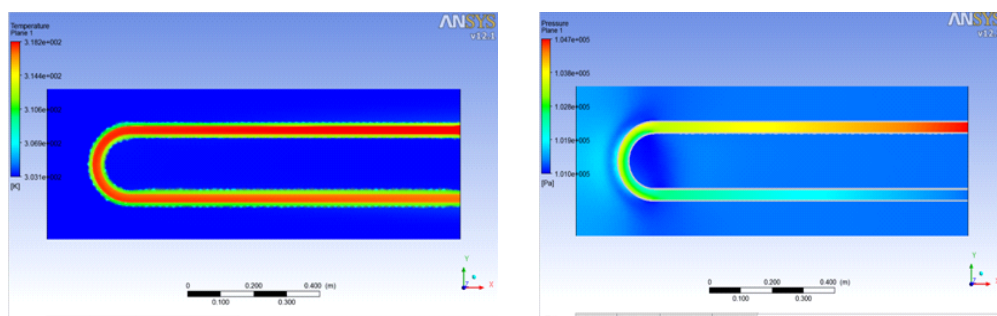


Figure. 6. (a) Temperature & (b) Pressure contours of tube diameter, $d = 0.04m$

IV. RESULTS AND DISCUSSION

Table1. Effect of change in tube diameter on Temperature, Heat Transfer and Pressure Drop at various axial distances along the direction of flow

Sr No.	p/d ratio	Axial Distance	Temperature at different diameter of tube (K)			Heat Transfer at different diameter of tube (W)			Pressure drop at different diameter of tube (Pa)		
			d = 0.02	d = 0.03	d = 0.04	d = 0.02	d = 0.03	d = 0.04	d = 0.02	d = 0.03	d = 0.04
1	1.5	1	318	318	318	0	0	0	145879	120511	105200
2	1.5	2	317.52	317.82	317.2	1246	1051	8309	144526	119452	104898
3	1.5	3	316.6	317.58	316.8	3637	2454	12468	140526	118487	104421
4	1.5	4	315.89	316.58	314.2	5482	8301	39497	138524	116412	104002
5	1.5	5	315.12	315.89	312.5	7492	12349	57247	135987	115102	103495
6	1.5	6	314.54	314.85	312.05	9002	18439	61937	118524	114784	103014
7	1.5	7	313.89	313.15	311.12	10694	28393	71625	116534	112789	102342
8	1.5	8	313.14	312.89	310.95	12648	29921	73417	106897	111457	101545
9	1.5	9	312.23	312.52	310.65	15017	50750	76697	100089	100089	100621

Variation of temperature for p/d = 1.5

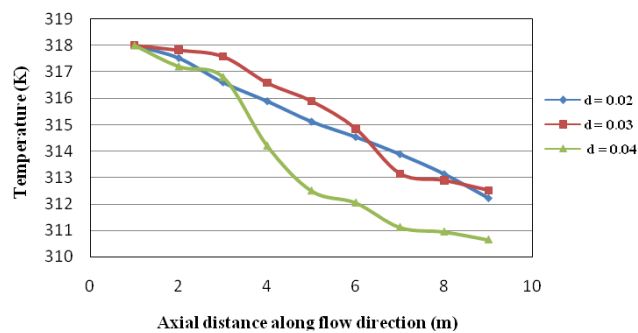


Figure. 7. Effect of tube diameter on temperature at various axial distance

The above result shows that as the fluid travels along with the direction the temperature decreases. And from the graph it can be also suggested that as the diameter of tube increases the temperature of fluid decreases along with the direction of fluid and hence there is maximum drop in temperature for the diameter of tube 0.04m as here taken three different diameter of tube.

Variation of Heat Transfer for p/d = 1.5

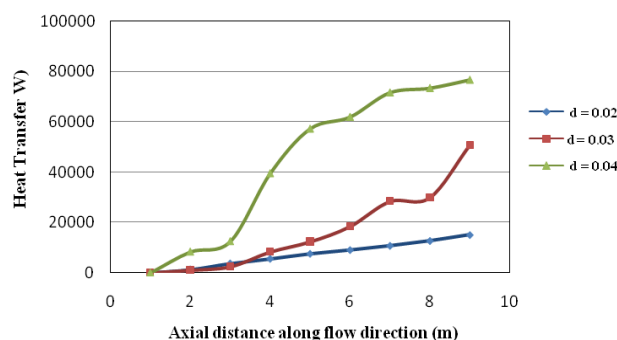


Figure. 8. Effect of tube diameter on Heat Transfer at axial distance

The above result shows that as the fluid travels through the tube along with the direction the heat transfer increases. And from the graph it can be also suggested that as the diameter of tube increases the contact area increases and hence the heat transfer also increases along with the direction of fluid and hence there is maximum increase in heat transfer is for the diameter of tube 0.04m as here taken three different diameter of tube.

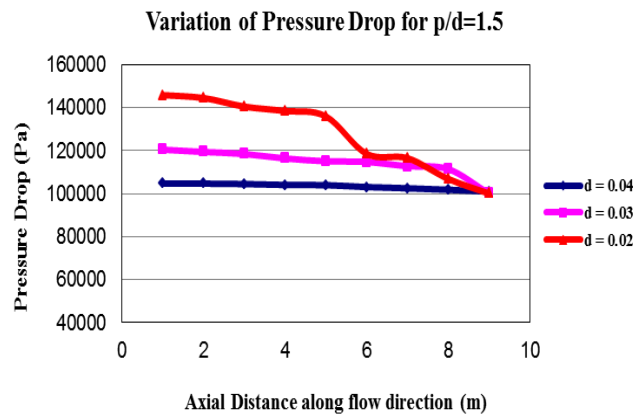


Figure. 9. Effect of tube diameter on pressure drop at various axial distances

The above result shows that as the fluid travels along with the direction there is drop in pressure. And the graph shows that as the diameter of tube increases there is rapid drop in pressure and hence the pressure drop increases with increase in diameter of tube. Hence there is maximum drop in temperature for the diameter of tube 0.04m as here taken three different diameter of tube.

VI. CONCLUSION

The above analysis conclude that as the diameter of tube increases temperature decreases and hence Heat Transfer increases with increase in pressure drop from cold to hot fluid and hot to cold fluid for Shell side and in Tube side both. So, as the area of contact increases the heat transfer increases with decrease in temperature and pressure drop. From the above analysis it can be conclude that for $d = 0.04\text{m}$, it has maximum heat transfer and minimum pressure drop.

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