Design and Fluid Flow Analysis of Helix Heat Exchangers

M.R.Jafari Nasr * [1], M. Rostami[2], A. Salem[3], M.Ahmadlouie[4]

1-Petrochemical Research & Technology Co. (NPC-RT), POBox; 14385, Tehran, Iran
*Email: m.jafarinasr@npc-rt.ir
2 – Chemical Engineering Department Sahand University of Technology, Tabriz, Iran

Abstract
In this article, it was studied how to achieve to a shell-and-tube heat exchanger with an optimum helical baffle of 42 degrees using CFD analysis. The study was followed by considering shell side flow pattern movement and thermal analysis of the exchanger. Finally, a comparison was made between a heat exchanger with segmental baffle and optimal geometry of 25% baffle cut and a helical exchanger. In addition, a modified equation for turbulent flow in shell side of helically baffled exchanger was developed. This study emphasized that the helically baffled exchangers can be removed and be minimized the main limitations of design for the common exchangers with segmental baffle. It was recognized that helix exchangers have a higher thermal performance and a lower fouling tendency.

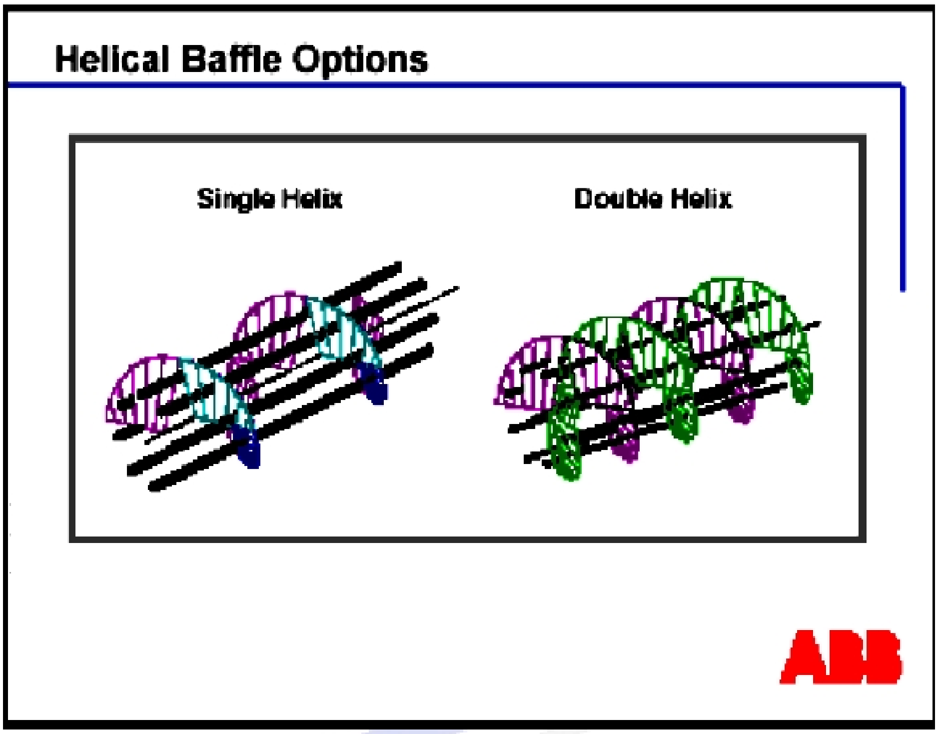
Keywords: Helical baffle, segmental baffle, CFD, rapid design algorithm

Introduction
Since the 1970 with sudden increase in fuel price, there has been a particular attention to reduction of the energy consumption as well as to process optimization. The cost of needed energy for the operation of chemical and petrochemical equipment is identified about sixty percent of the overall cost their usage. So, various industries have been made efforts to reduce the related costs of energy consumption. In this field one of the key equipment which is extensively used in industries and it has important role for possibilities in reduction of the energy consumption are "Heat Exchangers".

Heat exchangers are important apparatus that are used in different fields such as petroleum, gas, petrochemical and food industries. Heat exchangers are compact and none compact from one feature. The most important non compact heat exchangers that are the most useful heat exchangers in the world are shell and tube heat exchangers. These heat exchangers in comparison with compact heat exchangers have lower efficiency and bigger size but shell and tube heat exchangers have been used more than other heat exchangers in industrial units. Technological advancements in making tubes from various kinds of alloys have improved limitations of operational pressure and temperature and fluid types. In addition, invention of new methods in thermal performance causes to have no operational problem. [1] One of the new methods for reaching this goal is using helical baffles that generates spiral flow pattern in shell side.

These heat exchangers have some benefits like:

- Operating time becomes three or four times, with no need to cleaning.[2]
- These heat exchangers decrease economical costs in comparison with segmental baffles.
- Decreasing pressure drop saves a lot of energy since pomp age cost and fuel consumption decreases.
- These baffles make some especial flow that result in lower vibrations while if there is high flow rate in shell side, two row of tubes can be used(double helix)



(Fig 1: various kinds of helixchanger)

- The value of overall saving in energy helical baffles is much more than segmental baffles.

Generalized Governing Equation

The governing equation for turbulent fluid flow and heat transfer in a cylindrical shell and tube heat exchanger are briefly presented; details may be found in Prithiviraj and Andrews [3].The modified two-equation k-ε turbulence model of Prithviraj and Andrew [3] for shell and tube heat exchangers is used to model turbulence transport, where k is the turbulence kinetics energy and ε is the turbulence dissipation rate**.** Blockages in the flow field are presented with volumetric porosities and surface perm abilities. Cell Surface, the volumetric porosity becomes a surface permeability, f_s , defined as the fraction of the projected flow area in the direction of the flow component in the control

Table 1: cylindrical coordinate source terms and diffusion coefficient

Φ	S_Φ	Γ_Φ
V_θ	$-\frac{\rho V_r V_\theta}{r} + 2\frac{\mu_{eff}}{r^2}\frac{\partial V_r}{r} - \frac{\mu_{eff} V_\theta}{r^2} - \frac{\partial \bar{p}}{\partial \theta} + \rho g_\theta - R_\theta$	μ_{eff}
V_r	$\frac{\rho V_\theta^2}{r} - 2\frac{\mu_{eff}}{r^2}\frac{\partial V_\theta}{\partial \theta} - \frac{\mu_{eff} V_r}{r^2} - \frac{\partial \bar{p}}{\partial r} + \rho g_r - R_r$	μ_{eff}
V_z	$-\frac{\partial \bar{p}}{\partial z} + \rho g_z - R_z$	μ_{eff}
H_{shell}	$\frac{U_o A_s}{V_{cell}}\left(\frac{H_{tube}}{C_{p\ tube}} - \frac{H_{shell}}{C_{P\ shell}}\right)$	$\frac{\mu}{Pr} + \frac{\mu_t}{Pr_t}$
H_{tube}	$-\frac{U_o A_s}{V_{cell}}\left(\frac{H_{tube}}{C_{p\ tube}} - \frac{H_{shell}}{C_{P\ shell}}\right)$	—
k	$G - \rho\varepsilon + R_k$	$\frac{\mu_t}{\sigma_k}$
ε	$C_1 G\frac{\varepsilon}{k} - C_2\rho\frac{\varepsilon^2}{k} + R_\varepsilon$	$\frac{\mu_t}{\sigma_\varepsilon}$

volume. The conservative governing partial differentials equation for a general variable, Φ, (See table 1 for a summary of the Φ ' s) may be written as:

$$\frac{(\partial f_v r\Phi)}{\partial t} + \frac{1}{r}\cdot\frac{\partial(f_s r r\Phi V_r)}{\partial r} + \frac{1}{r}\cdot\frac{\partial(f_s r\Phi V_q)}{\partial q} + \frac{\partial(f_s r\Phi V_z)}{\partial z} = S_\Phi \quad (1)$$

If $\Phi = 1$ and $S_\Phi = 0$, then Equation. (1) is the continuity equation. Similarly, equations may be written for momentum (velocity components), enthalpy, and the k-e turbulence model. The source terms for this various Φ ' s are given in table1. In table1 R_r, R_q and R_z are distributed resistance in the radial, tangential and axial direction, respectively. R_k and R_e represent the turbulence kinetic energy generation and dissipation due to the presence of tubes. G is the production of turbulence kinetic energy from shear. And C_1=1.44, C_2=1.92, C_m=0.09, Pr_t=0.9, s_k=1.0, and s_e=1.314. [4]

Simulation of helically baffled exchangers and comparison with segmental baffled

The simulator has a length of 1200mm and the shell diameter of 117.05mm, 3ddp calculator with segregated solution method and turbulent physical model. Inlet fluid to shell is nafta and fluid inside the tube is crude oil. The results of schematic simulations demonstrate velocity distribution in helically and segmentally baffled exchangers.

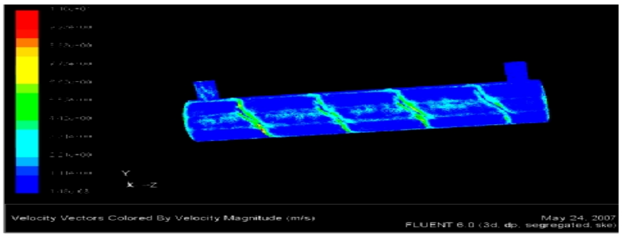


Figure2: helical baffle velocity field

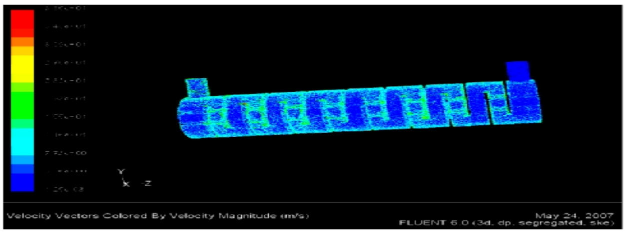


Figure3: segmental baffle velocity field

According to these Figures, velocity distribution is uniform in different points of helixchanger which reduces fouling creation and causes its formation to be uniform. [5]
Another important parameter that has been investigated is pressure drop.

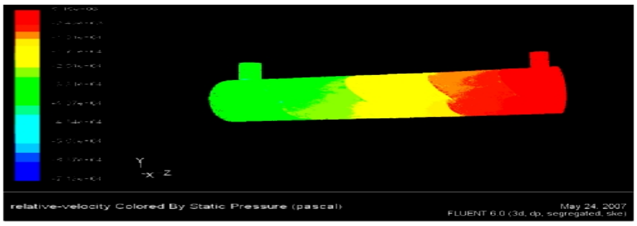


Figure4: helical baffle pressure field

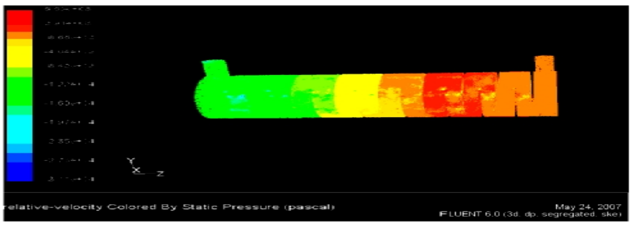


Figure5: segmental baffle pressure field

The pressure drop pattern in helically baffled exchangers has less pressure drop than segmentally baffled exchangers. Heat exchangers with helical baffles because of decreasing tortusity and so decreasing friction effects have lower pressure drop in comparison with segmental baffle heat exchangers.
For the better understanding the advantages of helically baffled, it is necessary to determine

temperature profiles in each case.

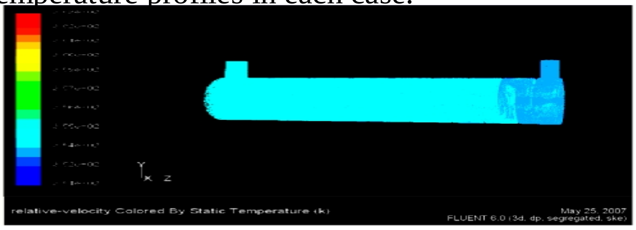


Figure6: helical baffle temperature field

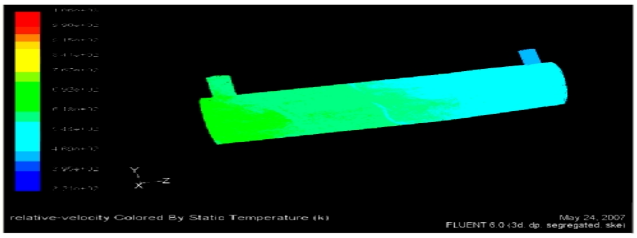


Figure7: segmental baffle temperature field

Helically baffled exchanger contains more thermal potential that leads to a higher thermal driving force and therefore a higher heat transfer coefficient can be achieved. Finally for cost saving, rapid design algorithm is modified by eliminating the velocity terms from current equations which are used for calculation of shell side pressure drop in turbulent flow. In fact especial geometry of baffles eliminates dead regions (or decreasing a lot) and increases turbulence that finally increases heat exchanging between fluid of shell and tube.

Rapid design algorithm

Rapid design algorithm allows utilization of the whole allowable pressure drop which leads to the higher velocity and therefore highest heat transfer coefficient will be available. So a smaller dimensional exchanger can be obtained and the cost of exchangers is decreased. A new relation for shell side velocity is derived from shell side heat transfer coefficient and it is replaced in the pressure drop equation. [6] Thus a direct equation between pressure drop and heat transfer coefficient could be obtained. This is a nonlinear equation based on A, surface area heat exchanger.

There are some equations for shell side turbulent flow in a helically baffled Exchanger, which must be investigated and modified. According to economic advantages of rapid deign algorithm; modified equation for pressure drop of shell side turbulent flow is presented in this work. Total equations for pressure drop and heat transfer coefficient in helically baffled exchanger are presented bellow: [7]

$$\Delta P = (\Delta P_1 + \Delta P_2) . \prod_{i=1}^{4} Z_i \qquad (2)$$

$$\Delta P_1 = 2\ f\ n_r\ \rho u^2\ \frac{l_{t_o}}{H_s} \qquad (3)$$

$$\Delta P2 = 2\ f\ n_r\ \rho u^2\ Z_5 \qquad (4)$$

$$\Delta P = a\ b\ \rho u^2\ (\frac{A}{npd_o L} + Z_5 - 0.5) \qquad (5)$$

$$a = 2\ f\ n_r\ ,\ b = \prod_{i=1}^{4} Z_i\ ,\ c = (\frac{l_{t_o}}{H_s} + Z_5)\ ,\ l_{t_o} = N_b * \frac{H_s}{4},\ n = \frac{A}{npd_o L}$$

$$\Delta P = a\ b\ \rho u^2\ (\frac{A}{npd_o L} + Z_5 - 0.5) \qquad (6)$$

$$h = 0.62\ \frac{k_s}{l}\ [0.3 + \frac{0.037\,\mathrm{Re}^{0.7}\ \mathrm{Pr}}{1 + 2.443\,\mathrm{Re}^{-0.1}(\mathrm{Pr}^{0.67} - 1)}]\ \prod_{i=1}^{8} Y_i \qquad (7)$$

With this relation, the following equation is derived for velocity:

$$u^2 = (\frac{hl}{0.62 k_s p Y_i} - 0.3)^5 . (\frac{E}{F})^{2.5} \qquad (8)$$

Where E, F are:

$$E = 2.443\ (\mathrm{Pr}^{0.67} - 1)$$

$$F = 0.037\ .\mathrm{Pr}\ (\frac{rD_s}{m})^{0.8}$$

Finally the equation (4) can be obtained for pressure drop:

$$\Delta P = (k_1 h_s + k_2)^5\ (k_3 A + k_4) \qquad (9)$$

in which:

$$k_1 = \frac{l}{0.62 k_s p Y_i}$$

$$k_2 = -\ 0.3$$

$$k_3 = \frac{2 f n_r r}{npd_o H_s} . (\frac{E}{F})^{2.5}$$

$$k_4 = 2\ f\ n_r \rho\ (\frac{E}{F})^{2.5} . (Z_5 - 0.5)$$

Nomenclature

A: heat exchanger area [m^2]

f: friction factor

c_p : heat capacity [$\frac{J}{kg \circ c}$]

m : viscosity [$\frac{kg}{m.s}$]

Z_i : pressure drop correction factors

h_s : heat transfer coefficient [$\frac{J}{m^2 .^\circ c}$]

N_b : number of baffle

n_r : number of tube rows

Hs: Helix pitch[m]

Y_i : heat transfer correction factors

l_{to} : baffle length of the tube bundle[m]

L: tube length[m]

Conclusion

This article shows that using helically baffled systems has some improvements in thermal, hydraulic and operational categories. A higher heat transfer coefficient causes higher thermal performance, lower pressure drop and better hydraulic operation of exchangers due to the reduction of rapid pathway change. Also by using these kinds of exchangers, lower vibrations can be attained because of the elimination of dead zone in exchangers. The simulation indicates that the velocity distribution is uniform in helical exchangers and it decreases fouling formation and corrosion in such exchangers. According to these advantages, the proposed method can be applied to design the heat exchanger network of crude oil heating unit in order to reduce total cost of such units in which fouling, corrosion and dimension of exchangers are very important.

Reference

[1]Zhang Zhnegguo, Xu Tao, Fang Xiaoming, Experminental study on heat transfer enhancement of a helically baffled heat exchanger combined with three-dimensional

[2] Basher I. Master, Krishnan, S.Chunangad and Venkateswaran Pushpanthan, "Fouling Mitigation Using Helixchanger Heat Exchangers", ABB Lummus Heat Transfer.

[3]Prithiviraj, M., and Andrews, M.J., Three Dimensional Numerical Simulation of Shell-and-Tube Heat Exchanger, Part A: Applications, vol. 33, no. 8, pp. 799-826, 1998.

[4]Andrews , Malcolm ; Master , Bashir Three-Dimensional Modeling of a Helixchanger® Heat Exchanger Using CFD Volume 26 , Number 6 , Number 6/July-August 2005 , pp. 22-31 (10)

[5]David Butterworth, design of shell-and-tube heat exchangers when the fouling depends on local temperature and velocity, Oxon OX11 0QR, UK, Sep (2001)

[6]M.R.Jafari Nasr, A.Shafeghat; Helical baffles Heat Exchangers as a strong alternative for Energy Saving of Processes; A new Design algorithm (2005)

[7]G.T.Polley,M.H.Panjeshahi, Interfacing heat exchanger network synthesis and detailed exchanger design, Trans IchemeE , Vol.69, part A , pp. 445-457,Dec,(1991)