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A CFD ANALYSIS OF HELICAL BAFFLE VARIATION IN SHELL AND TUBE HEAT EXCHANGER

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Abstract

Heat Exchanger has an important role in industry for successfull processes. The researches of heat exchanger focus on enhancement of heat transfer coefficient. Meanwhile the minimum pressure drop is also required to guarantee the subsequent process. Generally, those to requirements ae satisfied by the configuration of helical baffle. This work considers the helical baffle with different distance variation as well as mass flow rate inlet on the shell side. A CFD analysis is implemented for studying the variiying distance of 0.15m, 0.1m, 0.075m, and 0.06m and with mass flow rate are 0.05kg/s, 0.1kg/s, and 0.2kg/s. The tube of staggered configuration is in triangular arrangement. In this research, turbulence model of k-ε realizable is used as a viscocity model, in parallel-flow configuration. The results show that the heat transfer coefficient is 469.05 W/m².K for 0.06 m distance and 0.2 kg/s inlet mass flow rate, the value of pressure drop is 46.47 Pa. It is concluded that the value between fluid flow and inlet mass flow rate is directly proportional with the value of heat transfer coefficient and pressure drop.

Keywords : Heat exchanger, helical baffle, mass flow rate, heat transfer coefficient, pressure drop.

1. INTRODUCTION

Heat exchanger is the device for heat transfer process between two fluids. It has different temperature and is separated by walls. Heat transfer rate is influenced by many factors such as the fluid velocity, physical characteristics (viscocity, thermal conductivity, specific heat etc), temperature difference between two fluids and heat exchanger surface which separate two fluids. Heat exchanger is implemented in industrial power plant, air conditioning, and waste heat utilization in chemcical processes [1].

In term of fluid flow direction, heat exchanger types are categorized as parallel, counter, cross, and mixing flow [2]. Parallel flow heat exchanger is when the fluids flow from and to the same direction, counter flow is in opposite directions, cross flow is the flow through the other fluid perpendicularly, and for mixing flow is combination from the other type of flow.

Heat exchanger is supported by some integral devices such as baffle to increase effectivity and heat transfer coefficient. Baffle is a flow directing device which is applied for some vessel in industrial processes, such as shell and tube heat exchanger, chemical reactor, and static mixer. Baffle has two functions, i.e. baflle support tubes in right positions for the assembling process and for tubes stability under the operating process. It also prevents the tube vibration by induction current, and it directs the flow across the tube plane, increase the velocity and heat transfer coefficient. Baflle is designed to support the tube bundle to maintain maximum efficiency [3].

Helical baffle has required characteristics to decrease dispersion, pressure drop and increase heat transfer [4]. An experimental study was conducted to analyze the flow pattern in the shell side [5]. The nonlinear correlation was developed for the continuous helical baffle with different shell configurations. Effects of baffle different configurations on heat transfer and pressure drop was investigated [6]. It was found that the heat transfer rate, pressure drop were maximum for single segmental baffle. On the other hand, almost zero stagnation zones were confirmed in helical baffle.

Moreover, a method for designing and rating of Shell and tube heat exchanger with helical baffle was also developed [7]. The comparison revealed that the helical baffles are generally has better performance than segmental baffles. Kern method was also utilized for analyzing helical baffles [8]. It was observed that the flow pattern produced significant increase in heat transfer coefficient and reduced pressure drop.

It is shown that detail and comprehensive analysis of heat exchanger with helical baffles is necessary for the development of heat exchanger design and operation. Thus, this work performs a CFD analysis by varying baffle distance and inlet mass flow rate in order to capture the essential physics of the related flow and heat transfer.

2. MODELLING DETAILS

A. Model Geometry

The geometry is based on the model which was developed by Ozden and Tari [9].

Design Parameters of STHE		
Shell Diameter	Ds (m)	0.09
Shell Length	Ls (m)	0.6
Tube Pitch	Pt (m)	0.03
Tube amount	Nt	7
Tube Outside Diameter	Do (m)	0.02
Tube Inside Diameter	Di (m)	0.019
Baffle Spacing	Lb (m)	0,15; 0,1; 0,075; 0,06
BaffleAamount	Nb	4; 6; 8; 10
Baffle Thickness	ΔBT (m)	0.001

Table 1. Geometry Parameters

Fluid Parameters			
Properties	**Unit**	**cold water (shell)**	**hot water (Tube)**
Input Temparature (T_{in})	K	300	450
Mass Flow Rate (ṁ)	Kg/s	0.05;0.1;0.2	1
Density (ρ)	kg/m³	998	858.2

Table 2. Fluid Parameters

B. Meshing

There are some configurations in meshing process, it uses proximity and curvature as a size function, relevance center is set finely as well as smoothing. The hexahedral mesh is used for shell part and tetrahedral mesh for tube part. Fluid flows inside shell and outside tube will be analysed by their characteristics.

(a) (b)

Figure1.*Meshing (a) Tetrahedral-mesh (b) Hexahedral-mesh*

Moreover, there are inflation properties which are part from boundary layer to increase higher accuration in the transition of geometry.

Distance Variation of Baffle	*Nodes*	*Elements*
150mm	546379	1577249
100mm	554598	1609635
75mm	569965	1716105
60mm	579059	1757381

Table 3.Nodes and Elements Values

C. Solver

The energy equation is activated to support heat transfer and flow compressibility. The k-ε *Realizable* is implemented for turbulent modelling. "*Realizable*" mean that model solves the flow problem with certain Reynolds number, with phsyical consistency for turbulent flows. The turbulence modelling has alternative formula for turbulent viscosity, energy dissipation and properties of vorticity flow with modified equation (spinning fluid) [10].

D. Boundary Conditions

The parameters to determine boundary condition is tabulated as,

Cold Fluids	Water-liquid
Hot Fluids	Water-Liquid
Shell wall	Alumunium
Inlet_cold	mass-flow inlet; T : 300°K; ṁ : 0.05 kg/s
Outlet_cold	Pressure-outlet
Inlet_Hot	mass-flow inlet; T : 450°K ṁ : 1 kg/s
Outlet_Hot	Pressure-outlet

Table 4.Boundary Conditions

The next step is processing, which configures reference values, monitoring, and initialize condition. After all of those processes, the iteration is proceeded to finish the simulation.After the simulation, post processing is performed. It will get some data such as characteristic of external flow from tube (Reynolds number), velocity and temperature distributions along the domain.

3. RESULTS AND DISCUSSION

A. Verifications

Verification of simulation data is conducted based on mass and energy balance equations between hot and cold fluid, which explain heat transfer rate between hot and cold fluid is the same ($q_h = q_c$). The inlet temperature and outlet sides with mass flow rate determine the value of heat transfer.

Total Heat Transfer Rate	(w)
inlet_cold	386.83505
outlet_cold	-17782.137
Net	-17395.302

Total Heat Transfer Rate	(w)
inlet_hot	635037
outlet_hot	-617654.06
Net	17382.938

Figure 2. The values of Q_c and Q_h, L_b=150 mm and $\dot{m}$=0.05 kg/s

Figure 2 explains cold and hot heat transfer rate, which the value of q_c is -17395.302 W. The minus sign means cold fluid receives heat from hot fluid inside the tube. On the other hand, the transfer from hot fluid is q_h= 17382.938 W, which shows is 0.07% deviation. The result means that the balance of energy.

B. Analysis of Temperature Distribution

Figure 3 depicts the outlet temperature for each variation. The highest outlet temperature is on the smallest baffle distance. The same baffle distance (the smallest one) is applied to the segmental baffle, but producing lower temperature distribution as well as outlet temperature. It is due to the increasing of flow resistance in baffle tilt angle and the increasing of high vortex intensity near baffle wall.

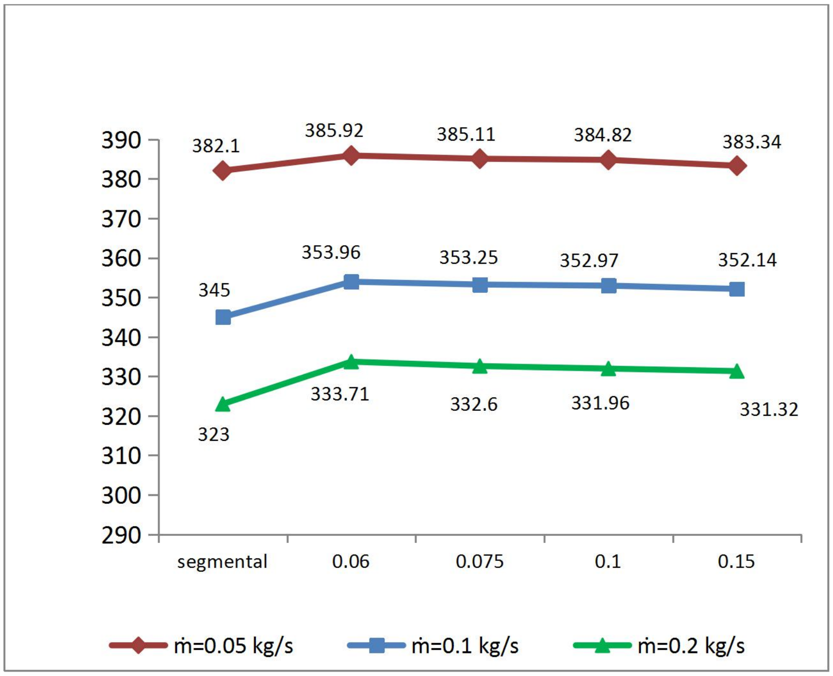
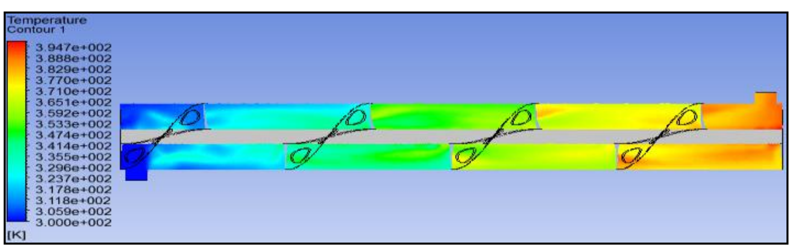


Figure 3. The trends of outlet cold fluid temperature for ṁ = 0.05 kg/s

The results are supported by figure 3 which explains the temperature distribution for several mass flow rate variations. It is shown that the temperature of helical baffle do not have any significant changes. The smaller baffle distance will increase the total flow trajectory along the tube which the transfer is longer and then increase temperature distribution. The highest heat transfer value for 0.06 m distance and mass flow rate of 0.05 kg/s is 385.92 W.



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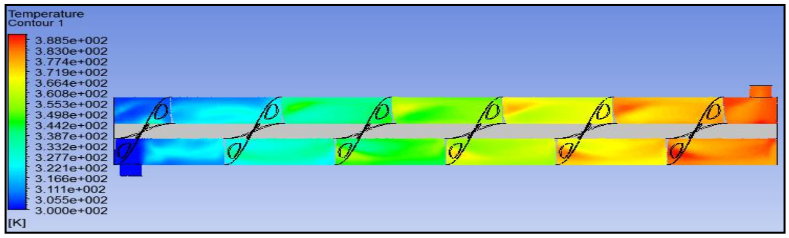

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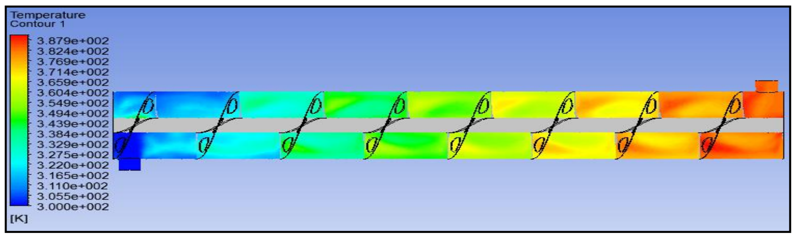

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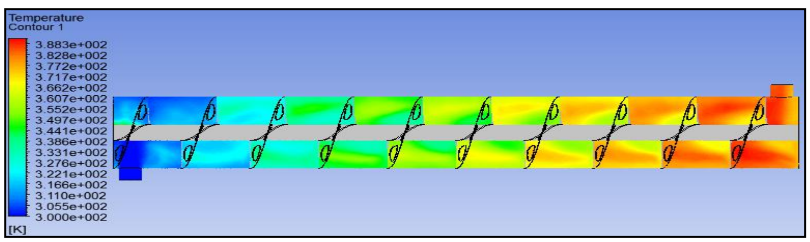

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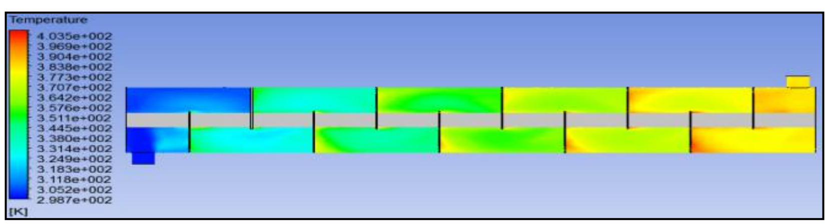
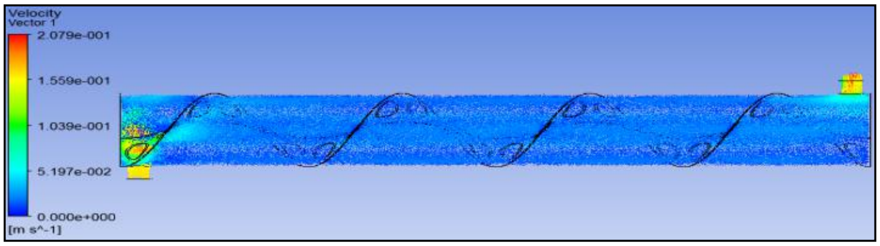


(e)

Figure 4. Contour of temperature distribution for cold fluid for ṁ=0.05 kg/s and variation of baffle distance are (a) 0.15m; (b) 0.1m; (c) 0.075m; (d) 0.06m; (e) segmental.

C. Analysis of Maximum Velocity (Vmax)

The contour of cold fluid velocity distributions are shown by figure 5.



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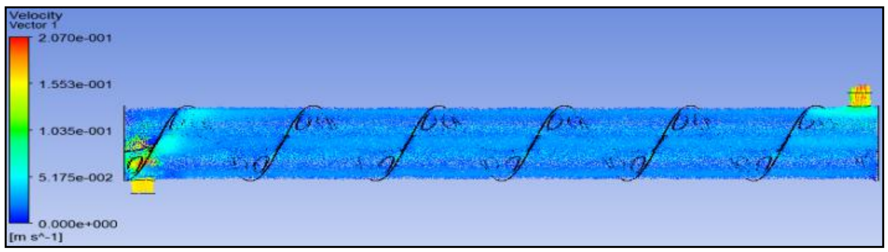

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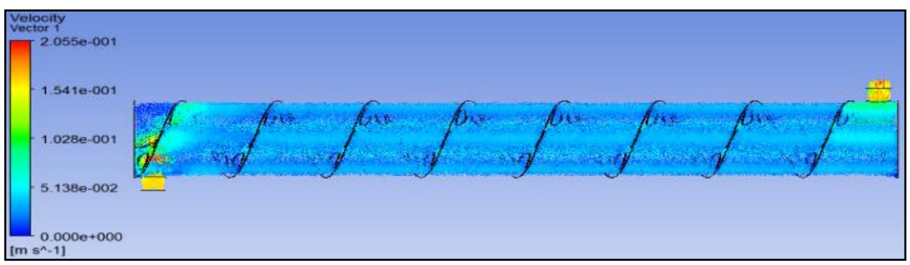

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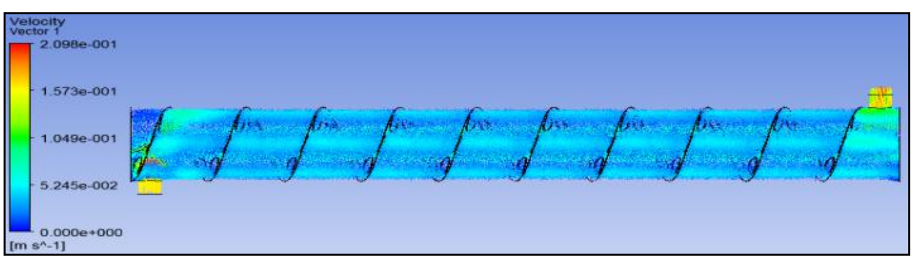

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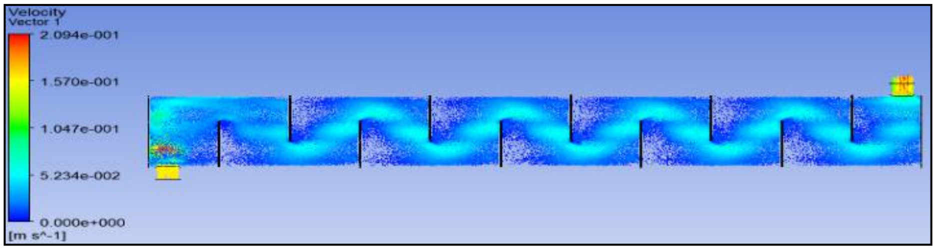

(e)

Figure 5. Contour of cold fluid velocity for ṁ=0.05 kg/s and variation of baffle distance are (a) 0.15m; (b) 0.1m; (c) 0.075m; (d) 0.06m; (e) segmental

The velocity contours show that cold fluid velocity is higher for smaller baffle distance. In this case the cross flow area is smaller and generates higher velocity. The highest maximum velocity is at the 0.06 m distance and 0.2 kg/s inlet mass flow rate.

The same configuration is also applied for the case of segmental baffle and it has lower maximum velocity than the helical baffle types. It is due to the smaller tilt angle, which causes higher flow resistance and recirculation.

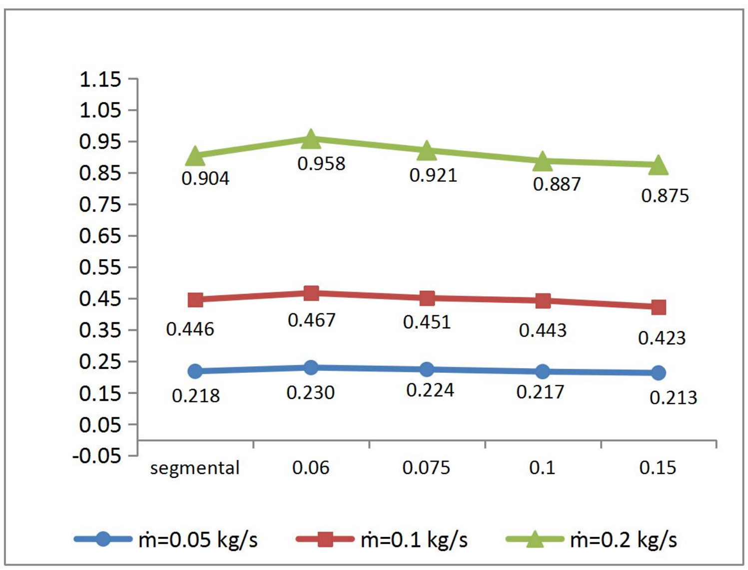

Figure 6. The trends of maximum velocity for cold fluid

D. Analysis of Reynolds Numbers

The results of local Reynolds number also supports the previous exposition. The highest local Reynolds number is on the smallest baffle distance for all inlet mass flow rate. This indicates that higher turbulent level will produce higher heat transfer.

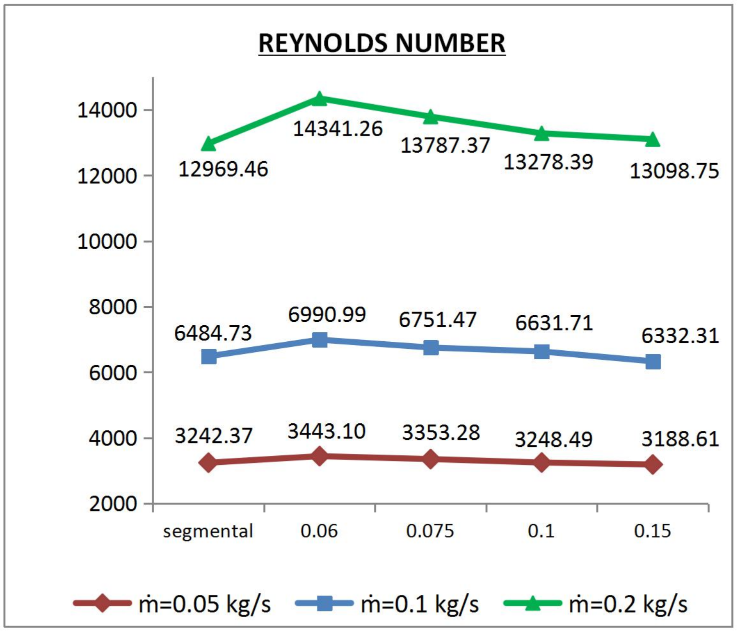

Figure 7. Graph of Reynolds Numbers

It is described that the trends of each inlet mass flow rate for helical baffle type decrease against baffle distance, which relate the helical baffle distance and Reynolds number. Higher distance of helical baffle resulted in lower baffle units, hence the maximum velocity and Reynolds number will be lower. Reynolds number determines the transition of limit layer. For the separated angle θ ≈ 80˚ the turbulent limit layer is lower than laminar limit layer.

E. Analysis of Heat Transfer Coefficient on shell side (ho)

The influence of helical baffle distance and inlet mass flow rate of cold fluid to heat transfer coefficient is explained in figure 8. The calculation example for heat transfer coefficient on the shell side in 0.15 m and 0.05 kg/sbaffle distance and inlet mass flow rate variation is:

$$ho = \frac{(0{,}36\,.\,Ks\,.\,Re^{0.55}\,.Pr^{0.33})}{Ds}$$

$$ho = \frac{(0,36\ .\ 0.613\ .\ 3188,61^{0,55}\ .\ 5,83^{0,33})}{0.09}$$

$$ho = \frac{(33.37)}{0.09}$$

$$ho = 370,83\ ^{W}/_{m^2.K}$$

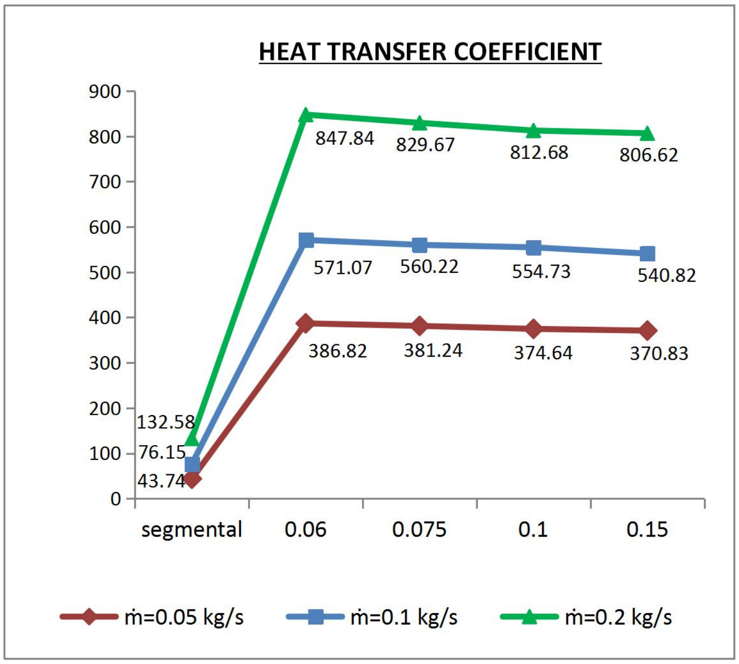

Figure 8. Heat Transfer Coefficient on the Shell Side

Figure 8 explains about heat transfer of cold fluid for each baffle distance and inlet mass flow rate variation. The heat transfer coefficient is proportional to the inleat mass flow rate.

F. Analysis of Overall Heat Transfer Coefficient (Uo)

The most important part for heat exchanger analysis is total heat transfer cofficent (U_o). The result of total heat transfer cofficent calculation is showed in table 5.

ṁ (kg/s)	***Overall Heat Transfer*** **(W/m².K)**				
	Segmental	**0.15 m**	**0.1 m**	**0.075 m**	**0.6 m**
0.05	41,97	274,03	276,11	279,68	282,67
0.1	70,96	356,94	362,95	365,29	369,87
0.2	117,62	456,15	458,08	463,43	469,05

Table 5. The Result of Total Heat Transfer Cofficent

The example of calculation of heat transfer Coefficient on the Tube Side :

$$hi = \frac{Nu}{di} \, . \, kt$$

$$hi = \frac{0.023 \, . \, Re^{0.8} \, . \, Pr^{0.4}}{di} \, . \, kt$$

$$hi = \frac{0.023 \, . \, 3188{,}61^{0.8} \, . \, 5{,}83^{0.4}}{0{,}019} \, . \, 250$$

$$hi = 1107{,}52 \; {}^{W}\!/_{m^2.K}$$

Calculation of Overall Heat Transfer Coefficient:

$$\frac{1}{Uo} = \left[\frac{1}{(ho)}\right] + \left[\frac{1}{(hi)} . \frac{do}{di}\right] + \left[ro.ln\left[\frac{ro}{ri}\right]/Kt\right]$$

$$\frac{1}{Uo} = \left[\frac{1}{370.83}\right] + \left[\frac{1}{1107{,}52} . \frac{0.02}{0.019}\right] + \left[0.01.ln\left[\frac{0.01}{0.0095}\right]/250\right]$$

$$Uo = 274{,}03 \; {}^{W}\!/_{m^2.K}$$

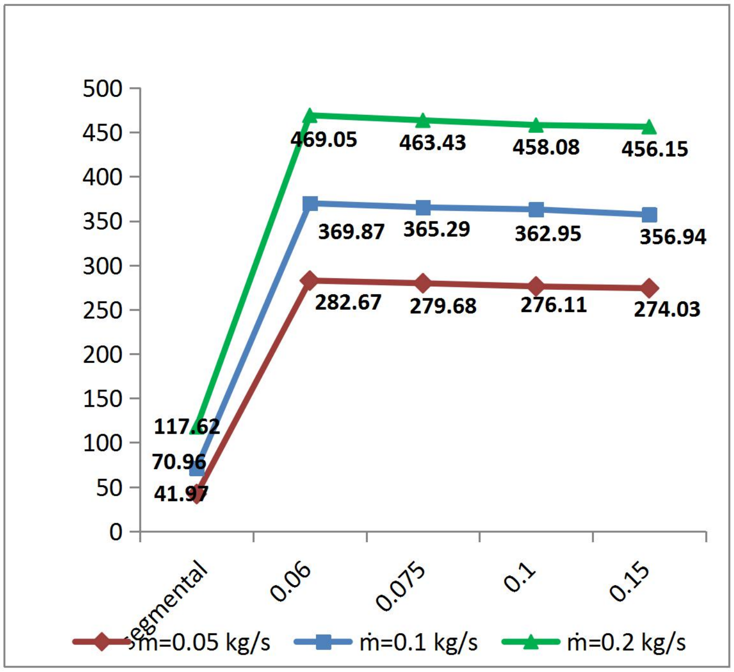

Figure 9. Overall Heat Transfer Coefficient

Figure 9 shows total heat transfer coefficient for baffle distance and inlet mass flow rate inlet variation. It is shown that the highest of total heat transfer coefficient for helical baffle distance is 0.06 m and mass flow rate inlet 0.2 kg/s is 469.05 W/m².K. In this case, the lowest total heat transfer coefficient for 0.06 m baffle distance and inlet mass flow rate 0.05 kg/s is 274.03 W/m².K. for helical baffle type.The influence of total heat transfer coefficient is come from the values of heat transfer coefficient on the side tube and shell. It shows that heat transfer coefficient on the side tube has a constant value. Meanwhile, the more baffle units will influence the increasing of friction factor between fluid and baffle surface and it causes energy dissipation. For mass flow rate inlet, the higher value of inlet mass flow rate will increase velocity and cause bigger vorticity from turbulent between fluid and baffle surface. Hence the value of heat transfer coefficient will increase.

The comparison of heat transfer coefficient between segmental baffle and helical baffle shows that the latter has higher heat transfer coefficient. This phenomenon is caused by difference fluid profil velocity between both baffle that is affected by Reynolds number (Re) and Nusselt Number (Nu). The higher value of maximum velocity will produce higher Reynolds number and nusselt number

G. Pressure Drop

Pressure drop is influenced by several factors such as distance and amount of helical baffle, mass flow rate, maximum fluid velocity that pass through tube, correction and friction factor. Table 6 show the result of calculation.

ṁ (kg/s)	***Pressure Drop* (ΔP)**				
	Segmental	**0.15 m**	**0.1 m**	**0.075 m**	**0.06 m**
0.05	9.74	0.62	1.39	2.45	3.81
0.1	34.16	2.17	4.84	8.58	13.32
0.2	119.77	7.56	16.98	29.96	46.47

Table 6.The Result of Pressure Drop Calculations

The example of pressure drop calculation for helical baffle distance variation 0.15m along mass flow rate inlet 0.05 kg/s :

$$\Delta P = \frac{[fs\,.\,Gs^2.(Nb+1)Ds]}{2\,.\,\rho s\,.\,De\,.\,\varphi s}$$

$$\Delta P = \frac{\left[\exp\left(0.576 - 0.19\ln\left(Re\right)\right).\frac{\dot{m}s^2}{As}.(Nb+1)Ds\right]}{2\,.\,\rho s\,.\,De\,.\frac{\mu s^{0.14}}{\mu t}}$$

$$\Delta P = \frac{[0{,}384\,.\,123{,}456^2.(4+1)0.09]}{2\,.\,998\,.\,0{,}0296\,.\;1{,}28}$$

$$\Delta P = 0{,}62\;Pa$$

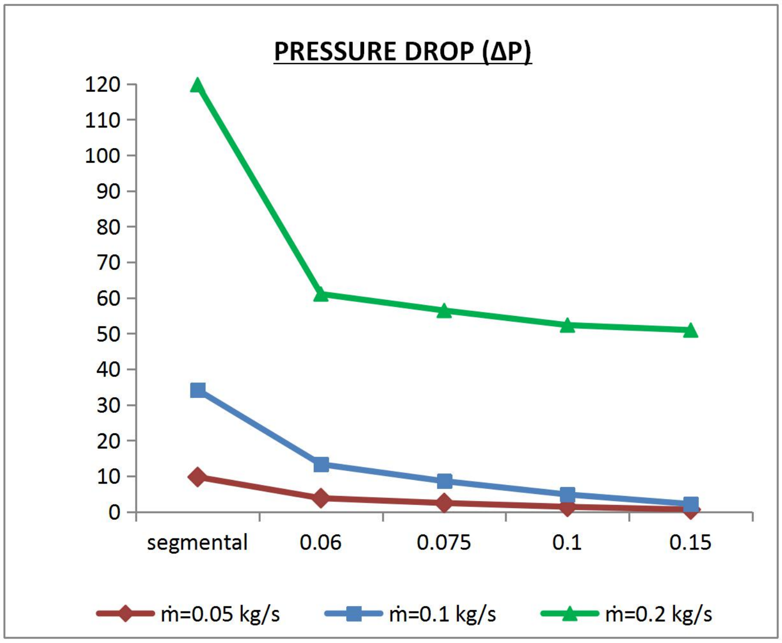

Figure 10. Pressure Drop

Figure 10 shows the trends between pressure drop to baffle distance and inlet mass flow rate inlet variation. It is depicted that the highest of pressure drop value for helical baffle distance 0.06m and inlet mass flow rate 0.2 kg/s is 64.37 Pa. Whereas the lowest pressure drop value for baffle 0.15m and mass flow rate inlet 0.05 kg/s is 3.02 Pa. Pressure drop is influenced by baffle distance and mass flow rate inlet variation. The tube pitch is maintained at a constant value, hence it will not influence to pressure drop value significantly. Baffle distance inversely proportional with amount of baffle. The shorter baffle distance, then amount of baffle will be higher and it cause to cross flow wide that pass through outside tube surface. Beside that the higher baffle amount wil be increased friction factor between fluid and baffle surface and it cause energy dissipation. Moreover, higher inlet mass flow rate will cause increasing pressure drop and vorticity value.

The comparison of pressure drop of segmental baffle, helical baffle with the same baffle units (10 baffles) shows that the latter has a smaller pressure drop value. The phenomenon is caused by more energy dissipation in the segmental baffle.

4. CONCLUSIONS

Shell and tube hat xchanger with helical baffle is analyzed in this research. Different baffle configurations and mass flow rate are investigated. Results show that baffle distance and inlet mass flow rate are proportional to heat transfer coefficient and pressure drop. In this case, the maximum heat transfer coefficient is 469.05 W/m².K for baffle distance of 0.06 m and inlet mass flow rate of 0.2 kg/s. the best pressure drop value is 0.62 Pa for baffle distance of 0.15 m and mass flow rate of 0.05 kg/s.

REFERENCES

[1] F.P. Incropera, D.P. Dewitt, T.L. Bergman, A.S. Lavine, Fundamentals of Heat and Mass Transfer 7th Edition, John Wiley & Sons, 2011, USA.

[2] T. Kuppan, Heat Exchanger Design Boo, 2000, Marcel Dekker.

[3] J.P. Holman, Heat Transfer 10th Edition, Mc-Graw Hill, New York, 2010.

[4] Y. Lei, Y. He, R. Li and Y. Gao, Effects of Baffle Inclination Angle on Flow and Heat Transfer of a Heat Exchanger with Helical Baffles, Chemical Engineering and Processing: Process Intensification, Vol. 47, Issue 12, 2008, pp. 2336–2345.

[5] B. Peng, Q.W. Wang, C. Zhang, G.N. Xie, L.Q. Quo, Q.Y. Chen and M. Zheng, An Experimental Study of Shell and Tube Heat Exchangers with Continuous Helical Baffles, Journal of Heat Transfer, Vol. 129, 2007.

[6] A.S. Ambekar, R. Sivakumar, N. Anantharaman and M. Vivekenandan, CFD simulation study of shell and tube heat exchangers with different Segment Configurations, Applied Thermal Engineering, Vol. 108, 2002, pp. 999–1007.

[7] J. Zhang, Y. He, Y. and W. Tao, A Design and Rating Method for Shell and Tube Heat Exchanger with Helical Baffle, Journal of Heat Transfer 132 (5), 2010.

[8] S.K. Shinde and M.H. Pancha, Comparative Thermal Performance Analysis of Segmental Baffle Heat Exchanger with Continous Helical Baffle Heat Exchanger using Kern Method, Int. J. Eng. Res. Appl., 2012.

[9] E. Ozden, I. Tari, Shell Side CFD Analysis of a Small Shell and Tube Heat Exchanger, Energy Conversion and Management, Vol. 51, Issue 5, 2008, pp. 1004–10014.

[10] T.J. Chung, Computational Fluid Dynamics, Cambridge University Press, 2002.