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Performance Enhancement of Shell and Tube Heat Exchanger on Parallel Flow with Single Segmental Baffle

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ABSTRACT

The shell and tube heat exchanger was a tool to exchange the heat energy between fluids with different temperatures that occurred through direct or indirect contact. The energy exchange in fluids could be occurred with the same phase (liquid to liquid or gas to gas) or two fluids with different phase. To date, the process of heat transfer in the industrial field was crucial in machine work. Therefore, there were studies directed to optimize and develop the function and thermal performance of a heat exchanger by adding Baffles to the side of the shell. Vortex flow that occurs with the addition of baffles will make the area of fluid contact in the shell with the tube wall larger, so the heat transfer between the two fluids will increase. This study aimed to obtain the efficiency of the heat exchanger and its effectiveness when put on parallel flow. The heat exchanger had the dimensions of 54.6 x 10^{-3} m in outer diameter and 22.4 x 10^{-3} m in inner diameter with a tube thickness of 3 mm. The variations on water flow from both fluids were 0.5, 1, 1.5, 2 l/min for hot water and 1, 2, 3, 4 l/min for cold water to obtain the effectiveness of heat exchanger on parallel flow. This research heated the hot fluid in electric heating and used water as the cold fluid. The results showed that heat exchanger with single segmental baffle was more efficient in reducing heat in hot water than heat exchanger without bafe. The flow of fluid affected the average temperature difference; the higher the flow of fluid created a more significant temperature difference. The use of single segmental baffle affected the average temperature difference that was higher than without the baffle. The use of single segmental baffle also influenced the heat transfer greater than without baffle because of the longer distance travelled by the fluid on single segmental baffle with the same flow. Thus, the heat transfer process that occurred was more significant by using a single segmental baffle.

Keywords: *Baffle, heat exchanger, parallel flow, shell and tube*

I. Introduction

Heat transfer is a heat transformation or transfer process from a high-temperature object to a low-temperature object and has critical applications in daily life. The heat exchanger is the device to transform energy. It has a wide range of use, particularly in food and beverage processing industries and other industries [1]–[9]. In usage, there are many types and kinds of heat exchanger. The widely used model, compared to others, is shell and tube type. Li and Kottke [5] suggested that the shell and tube type is customary because of its benefits, such as sturdy construction, easy maintenance, and easy to split apart (not in a single entity) that ease the maintenance. The main components of shell and tube heat exchanger are a tube, baffle, shell, front head, rear head, and nozzle.

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There are researches to optimize the function and performance of the heat exchanger, considering the vital usage. Several previous types of study such as Lei et al. [6] stated that close-installed baffles increase the heat transfer between two fluids; however, it created a significant obstacle to the flow that went through the gap between baffles, and in turn, mainly decrease the pressure. Meanwhile, if the baffles installations were too far in spacing, the pressure drop was small, but the heat transfer was low and could damage the pipes due to bending or vibration. This occurrence shows that the distance between baffles cannot be too close or too far, and that there is a certain optimal distance for a particular heat exchanger. Shrikant et al. [10] observed the effect of baffle type and in-between range on the flow performance and characteristics of STHX in an experiment using Computational Fluid Dynamics (CFD) numerical method to obtain a 3D simulation. Finding the flow condition inside STHX, and correlating it with the experimental results using a single and triple segmental baffle. The results showed that the 5 cm baffle spacing created a higher total heat transfer coefficient compared to the 10 cm baffle spacing. Akbar et al. [11] experimented the turbulent flow using various Reynolds numbers and different baffle heights. The results indicated that the pressure increased along with the baffle heights on a particular flow.

Kumaresan et al. [12] performed an experience to reduce the pressure drop and increase the heat transfer rate from various (25%, 30%, and 35%) shell diameters, then compared the results with the 0˚ segmental baffle. The results exhibited that the 35˚ angle and 30% baffle cut from the inside diameter produced a higher heat transfer and a minimum pressure drop. Eiamsa-ard et al. [13] also carried a similar experiment using CFD from single-pass parallel flow in STHX to design the STHX with segmental and helical baffles and to investigate its characteristics. The best STHX from the research was STHX with 0˚ helical baffle in a segmental partition with 10˚ of baffle angle. Du et al. [14] held an inquiry to observe the effect of various baffle slope angles on the fluid flow in shell and tube with 0˚, 10˚, and 20˚ angles. The conclusion was that the 20˚ corner created a better performance than the 0˚ and 10˚ corners. This research conducted a numerical comparison study between with and without baffle to find the temperature distribution to generate optimal performance. Generally, this research aimed to analyze the effectivity of shell and tube heat exchanger with the baffle.

II. Research Methodology

A. Experimental Apparatus

This research used the shell and tube heat exchanger, with the outer material of stainless steel in 54.6 mm diameter and 900 mm length. The inside pipe material (tube) was copper with 25.4 mm diameter on the outlet and 22.4 mm diameter on the inlet tube as depicted in Figure 1. This research used water as the fluid in the outside and inside pipes. The flow directions in the baffle and without baffle STHXs were parallel flow, disregarding the pipe loss and heat loss, or considered to be steady. The flowmeter for hot water was at maximum 4 l/min, and cold water was at maximum 8 l/min. The inlet and outlet thermometer measurement was 0–100℃. This research used an electrical immersion heater as the water heater with 600 Watt power.

The hot water flowed through the tube while the cold water flowed through the shell. This research used the shell with and without baffle. This research used the open and closed system in the valve from the pump that headed to the cold and hot water channels to control the flow. Table 1 displays the flow in this research. The measurement taken during the process was hot water inlet temperature (T_1), hot water outlet temperature (T_2), cold water inlet temperature (t_1), cold water outlet temperature (t_2), hot water mass flow rate (W), and cold water mass flow rate (w). The output parameters were the heat released by hot water (Q_w), the heat received by cold water (q_w), the difference in average temperature (ΔT_m), the overall heat transfer coefficient (U), and efficiency. Figure 2 shows the used section from shell and tube heat exchanger for this test. The blue pipe represents the cold water flow, and the red pipe represents the hot water flow. Figure 3(a) presents the shell and tube dimensions with baffle, where the red line represents hot water through the tube, and the blue line represents cold water through the baffled shell. Whereas Figure 3(b) illustrates the dimensions and flow direction in the shell without baffle.

Table 1. Hot and cold water fluid flow

Code	Flow (litre/minute)	
	Hot Water	Cold Water
E	0.5	1
F	1	2
G	1.5	3
H	2	4

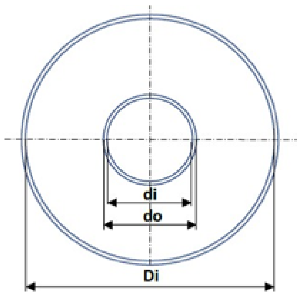

Fig. 1. Heat exchanger area

Fig. 2. Shell and tube heat exchanger (a) Cold water pump, (b) Hot water pump, (c) Cold water tank, (d) Hot water tank, (e) Switch, (f) Flow meter, (g) Thermometer digital, (h) Cold water line, (i) Hot water line, (j) Heat exchanger pipe baffle and no baffle

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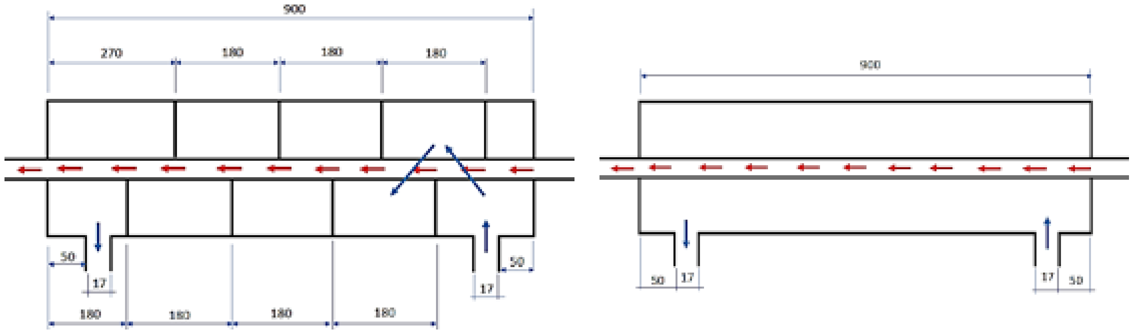

(a) (b)

Fig. 3. Dimensions and water flow direction (a) Heat exchanger with baffle, (b) Heat exchanger pipe without baffle

B. Mathematic Model

Equation (1) formulates the average temperature difference from the parallel flow with and without baffle in cold water channel [15].

$$\Delta t_m = \frac{(T_1 - t_1) - (T_2 - t_2)}{ln\frac{T_1 - t_1}{T_2 - t_2}} \tag{1}$$

Δt_m is the logarithmic average of temperature difference, T_1 is the hot water input temperature, T_2 is the hot water output temperature, t_1 is the cold water input temperature, and t_2 is the cold water output temperature. Equation (2) devises the overall heat transfer coefficient (U) [16].

$$U = \frac{1}{\frac{1}{h_i A_i} + \frac{\ln\left({D_o}/{D_i}\right)}{2\pi k L} + \frac{1}{h_o A_o}} \tag{2}$$

Where A_0 is the total surface area of the outer tube in heat transfer, and A_i is the surface area of the inner tube. Equation (3) and (4) formulate the above factors [16].

$$A_o = \pi\, D_o\, L \tag{3}$$

$$A_i = \pi\, D_i\, L \tag{4}$$

Equation (5) and (6) calculates the heat balance value, of which Q_w is the released heat, q_w is the received heat, T is the high-temperature fluid, t is the low-temperature fluid, and W is the flow rate of high-temperature fluid [15].

$$Qw \cong qw \tag{5}$$

$$WC_p(T_1 - T_2) \cong wC_p(t_2 - t_1) \tag{6}$$

Equation (7) devises the heat transfer convection coefficient. $K_{in,out}$ is the fluid's thermal conductivity, D_H is the hydraulic diameter, and Nu is the Nusselt number [16].

$$h_{in.out} = \frac{k_{in.out}}{D_h} Nu_{in.out} \tag{7}$$

Equation Dittus-Boilter, displayed as equation (8) and (9), formulates the Nusselt numbers from the outer and inner pipes of the shell and tube heat exchanger [16].

$$Nu_o = \frac{h_o.D_h}{k} = 0.023 Re_o^{0.8} Pr_o^{0.33} \tag{8}$$

$$Nu_i = \frac{h_i.D_h}{k} = 0.023 Re_i^{0.8} Pr_i^{0.4} \tag{9}$$

Where $D_h = D_o - D_i$ is the hydraulic diameter influenced by fluid area inside the pipe – heat exchanger pipe. Equation (10) formulates the Reynolds numbers and equation (11) calculates the heat transfer rate between the fluids in the pipe and on the pipe's surface [15].

$$Re_{in.out} = \frac{u.D}{v} = \frac{\rho_{in.out}.u_{in.out}.D_{in.out}}{\mu_{in.out}} \tag{10}$$

$$Q = U\ A_s\ \Delta T_{LMTD} \tag{11}$$

Equation (12) formulates the efficiency of the heat exchanger by comparing the actual quantity of heat transfer and the ideal quantity of heat transfer [16].

$$\eta_H = \frac{actual\ quantity\ of\ heat\ transfer}{ideal\ quantity\ of\ heat\ transfer} = \frac{W.C_p(T_1 - T_2)}{W.C_p(T_1 - t_1)} \tag{12}$$

III. Results and Discussions

Data comparison of two test results are with baffle and without baffle.

A. *The Average Temperature Difference*

The average temperature difference in the heat exchanger with baffle increased because the cold water fluid was still cold. It eventually decreased due to continuous usage of cold water without cooling, and thus, the temperature between cold and hot water was almost balanced without the occurrence of heat transfer. Meanwhile, the test in heat exchanger without baffle underwent increasing average temperature difference because the heat absorption by cold fluid was not maximum due to the cooling process in a short time [7].

The Reynolds number affected the average temperature difference, meaning the higher Reynolds number increased the average temperature difference. This condition was due to the change in the flow type that affecting the temperature, a result of the flow variants. Figure 4 and Table 2 displays that the average temperature in the heat exchanger with baffle had a better performance compared to heat exchanger without baffle; therefore, it absorbed higher heat [5].

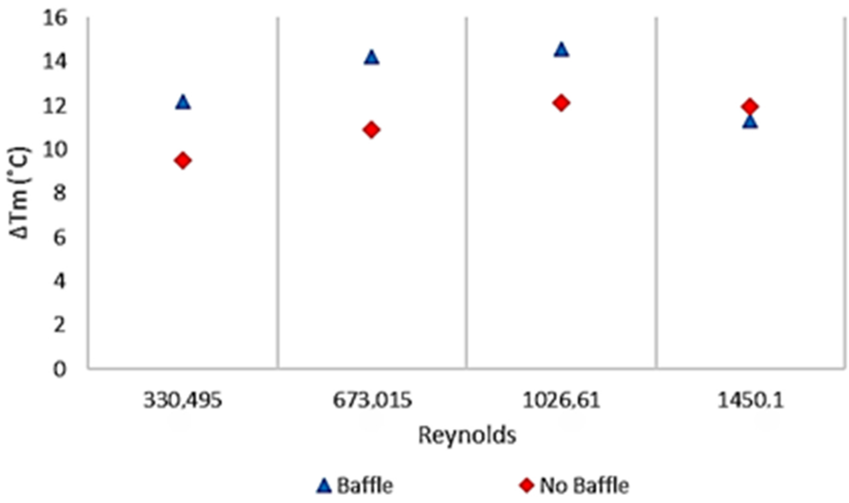

Fig. 4. Correlation graphs between the average temperature difference and the Reynolds number in two tests: with and without baffle

Table 2. Correlation Between Flow Type in Parallel Flow and the Average Temperature with and without Baffle

	Variation	Flow Direction	ΔTm (˚C)
Parallel Flow (baffle)	E	H: Laminar, C: Laminar	12.15
	F	H: Laminar, C: Laminar	14.19
	G	H: Transitional, C: Laminar	14.57
	H	H: Transitional, C: Laminar	11.29
Parallel Flow (no baffle)	E	H: Laminar, C: Laminar	9.47
	F	H: Laminar, C: Laminar	10.92
	G	H: Transitional, C: Laminar	12.14
	H	H: Transitional, C: Laminar	11.94

B. *Heat Transfer*

The heat transfer process from hot water increased along with the increased fluid flow and the average temperatures in inlet and outlet. The received heat in cold water also improved along with the fluid flow and the average temperatures in inlet and outlet. The small gap in the fluid flow affected the heat rate balance closer to the balance rate [4]. Meanwhile, the significant difference in the fluid flow changed the heat rate balance farther from the balance value.

The Reynolds number affected the heat transfer, meaning the higher Reynolds number increased the heat transfer rate. This condition was due to the change in the flow type that affecting the temperature, a result of the flow variants. The laminar flow had a lower heat transfer rate compared to the turbulent flow [1]. Moreover, baffle usage in heat exchanger also affected the heat balance. Figure 5 and Table 3 shows that by using baffle, there was greater heat absorption compared to without baffle with the evidence found in the gap between the released-heat (Q_w) of hot water and the received-heat (q_w) of cold water.

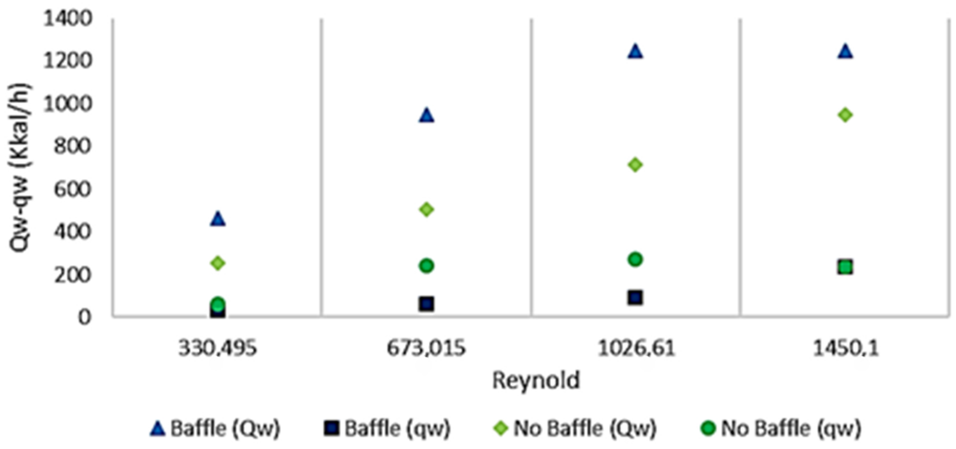

Fig. 5. Correlation Graphs Between Hot and Cold Water Heat Transfer and the Reynolds Number in Two Tests: baffle and no baffle

Table 3. Correlation between flow type in parallel flow and heat transfer with baffle and without baffle

	Variation	Flow Direction	ΔTm (˚C)
Parallel Flow (baffle)	E	H: Laminar, C: Laminar	12.15
	F	H: Laminar, C: Laminar	14.19
	G	H: Transitional, C: Laminar	14.57
	H	H: Transitional, C: Laminar	11.29
Parallel Flow (no baffle)	E	H: Laminar, C: Laminar	9.47
	F	H: Laminar, C: Laminar	10.92
	G	H: Transitional, C: Laminar	12.14
	H	H: Transitional, C: Laminar	11.94

C. *Efficiency*

Heat exchanger efficiency depended on the comparison of the actual heat transfer rate with the ideal heat transfer rate. The real heat was the result of the temperature difference between the hot water inlet and outlet channels. The ideal heat was the result of the temperature difference of the cold water inlet and outlet channels. There was a high efficiency in the initial test and eventually declined in the next test because there was no cooling process for the cold water. It continued to circulate and made it hot (close to the hot water temperature).

The Reynolds number affected the heat exchanger efficiency, meaning the lower Reynolds number resulted in the high efficiency. This condition was due to the change in the flow type that affecting the temperature, a result of the flow variants. The laminar flow had a higher efficiency rate compared to the turbulent flow. Figure 6 and Table 4 shows that the efficiency of the heat exchanger with baffle was higher than heat exchanger without baffle because the cold water ability in absorbing heat was higher using the blocked heat exchanger [11]. Besides, the average temperature difference in the heat exchanger with baffle was larger than without baffle.

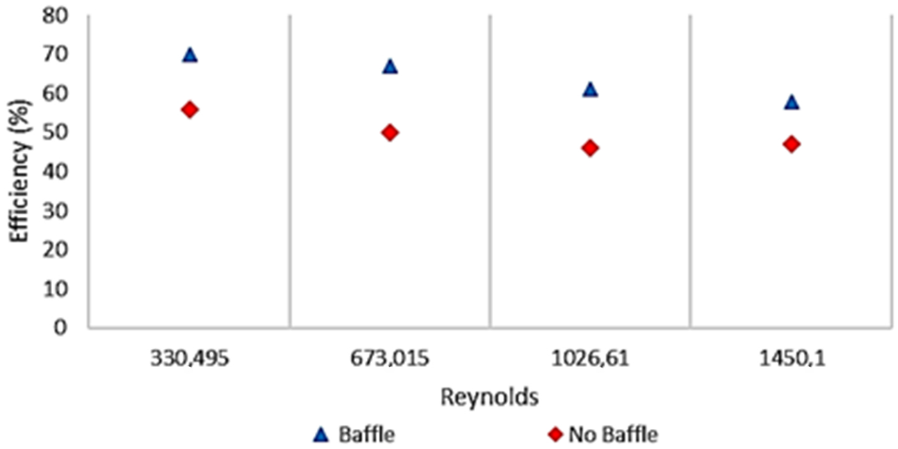

Fig. 6. Correlation graphs between heat exchanger efficiency and the Reynolds number in two tests: with baffle and without

Table 4. Correlation between flow type in parallel flow and efficiency with and without baffle

	Variation	Flow Direction	Ƞ (%)
Parallel Flow (baffle)	E	H: Laminar, C: Laminar	70
	F	H: Laminar, C: Laminar	67
	G	H: Transitional, C: Laminar	61
	H	H: Transitional, C: Laminar	58
Parallel Flow (no baffle)	E	H: Laminar, C: Laminar	56
	F	H: Laminar, C: Laminar	50
	G	H: Transitional, C: Laminar	46
	H	H: Transitional, C: Laminar	47

D. *Overall Heat Transfer Coefficient*

The average temperature influenced the overall heat transfer coefficient, where the fluid flow was also affecting the average temperature differences supported by the test duration. The small fluid flow had a lower ability to transfer the heat, and the high fluid flow had a higher capacity to transfer the heat. The Reynolds number affected the overall heat transfer coefficient, meaning a higher Reynolds number increased the overall heat transfer coefficient. This situation was due to the change in the flow type that affecting the temperature, a result of the various flows. The laminar flow type had a lower heat transfer coefficient compared to the turbulent flow [9]. Overall heat transfer coefficient was the combination of the convection coefficient and the thermal resistance in the pipe's wall of the heat exchanger. Figure 7 and Table 5 presents that the overall heat transfer coefficient in a heat exchanger with baffle was greater than without baffle because the overall heat transfer coefficient was directly proportionated with the heat transfer value.

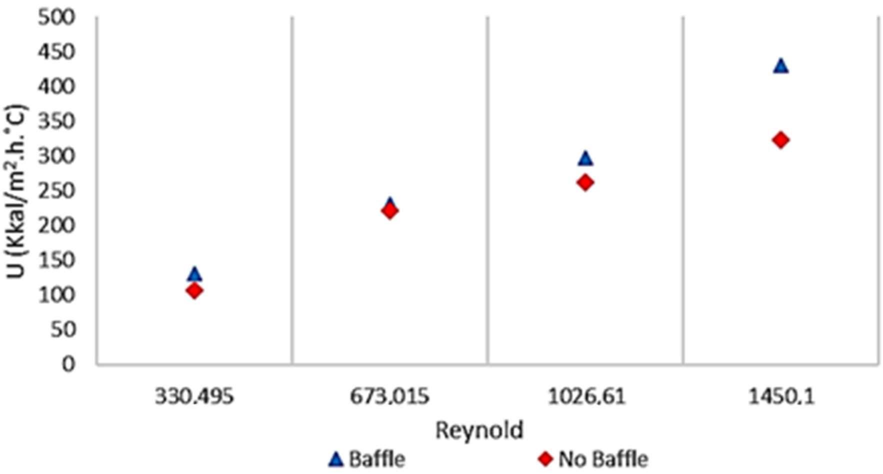

Fig. 7. Correlation graphs between overall heat transfer coefficient and the Reynolds number in two tests: with baffle and without baffle

Table 5. Correlation between flow type in parallel flow and efficiency with and without baffle

	Variation	Flow Direction	U (Kkal/m2.h.˚C)
Parallel Flow (baffle)	E	H: Laminar, C: Laminar	131.13
	F	H: Laminar, C: Laminar	231.05
	G	H: Transitional, C: Laminar	297.71
	H	H: Transitional, C: Laminar	429.82
Parallel Flow (No Baffle)	E	H: Laminar, C: Laminar	107.13
	F	H: Laminar, C: Laminar	221.11
	G	H: Transitional, C: Laminar	262.35
	H	H: Transitional, C: Laminar	322.93

IV. Conclusions

Heat exchanger with baffle was more efficient in reducing heat in hot water compared to heat exchanger without baffle. The more significant difference in heat transfer in exchangers with and without baffle was because of the longer distance travelled by the fluid on single segmental baffle with the same flow. Thus, the heat transfer process that occurred was greater by using a single segmental baffle.

- The efficiency value of a heat exchanger with baffles is 64%, where the efficiency value is greater than the heat exchanger without baffles is 49.75%.
- The overall heat transfer coefficient value of a heat exchanger with baffles is 272.42 $Kcal/m^2.h.^0C$, where the overall heat transfer coefficient value is greater than the heat exchanger without baffles is 228.38 $Kcal/m^2.h.^0C$.

- The average temperature difference of a heat exchanger with baffles is 13.05 ^{0}C, where the average temperature difference value is greater than the heat exchanger without baffles is 11.12 ^{0}C.
- The heat released value of a heat exchanger with baffles is 975.76 Kcal/h, where the heat released value is greater than the heat exchanger without baffles is 604.7 Kcal/h.
- The heat received value of a heat exchanger with baffles is 104.41 Kcal/h, where the heat received value is lower than the heat exchanger without baffles is 201.46 Kcal/h.

References

[1] F. N. Taher, S. Z. Movassag, K. Razmi, and R. T. Azar, “Baffle space impact on the performance of helical baffle shell and tube heat exchangers”, *Applied Thermal Engineering*, vol. 44, pp. 143–149, 2012.

[2] Y. Qiu, M. Li, W. Wang, B. Du, and K. Wang, “An experimental study on the heat transfer performance of a prototype molten-salt rod baffle heat exchanger for concentrated solar power”, *Energy*, 2018.

[3] B. Sciences and T. Nadu, “Shell Side Numerical Analysis Of A Shell And Tube Heat Exchanger Considering The Effects Of Baffle Inclination Angle On Fluid Flow”, *Thermal Science*, vol. 16, no. 4, pp. 1165–1174, 2012.

[4] J. Wen, H. Yang, S. Wang, Y. Xue, and X. Tong, “International Journal of Heat and Mass Transfer Experimental investigation on performance comparison for shell-and-tube heat exchangers with different baffles”, *Heat Mass Transf.*, vol. 84, pp. 990–997, 2015.

[5] H. Li and V. Kottke, “Effect of baffle spacing on pressure drop and local heat transfer in shell-and-tube heat exchangers for staggered tube arrangement”, *Int. J. Heat Mass Transf*, vol. 41, no. 10, pp. 1303-1311, 1998.

[6] Y. Lei, Y. Li, S. Jing, C. Song, and Y. Lyu, “Design and performance analysis of the novel shell-and-tube heat”, *Appl. Therm. Eng.*, 2017.

[7] B. Gao, Q. Bi, Z. Nie, and J. Wu, “Experimental study of effects of baffle helix angle on shell-side performance of shell-and-tube heat exchangers with discontinuous helical baffles”, *Exp. Therm. Fluid Sci.*, vol. 68, pp. 48–57, 2015.

[8] T. V. S. Siva and P. Sai Chaitanya, “Optimization Of Shell And Tube Heat Exchanger Used In A Rankine Cycle Of Exhaust Gas Waste Heat Recovery System Using CFD”, *Int. J. Chem. Sci.*, vol. 14, no. 4, pp. 2247–2258, 2016.

[9] M. Bahiraei, M. Hangi, and M. Saeedan, “A novel application for energy efficiency improvement using nano fluid in shell and tube heat exchanger equipped with helical baffles”, *Energy*, vol. 93, pp. 2229-2240, 2015.

[10] A. A. Shrikant, R. Sivakumar, N. Anantharaman, and M. Vivekenandan, “CFD simulation study of shell and tube heat exchangers with different baffle segment configurations”, *Appl. Therm. Eng.*, 2016.

[11] A. Akbar, A. Arani, and R. Moradi, “Shell and tube heat exchanger optimization using new baffle and tube configuration”, *Appl. Therm. Eng.*, vol. 157, 2019.

[12] G. Kumaresan, R. Santosh, and P. Duraisamy, "Numerical Analysis of Baffle Cut on Shell Side Heat Exchanger Performance with Inclined Baffles", *Heat Transfer Engineering*, vol. 7632, 2017.

[13] S. Eiamsa-ard, K. Ruengpayungsak, C. Thianpong, M. Pimsarn, and V. Chuwattanakul, “International Journal of Thermal Sciences Parametric study on thermal enhancement and flow characteristics in a heat exchanger tube installed with protruded baffle bundles”, *Int. J. Therm. Sci.*, vol. 145, 2019.

[14] B. Du, Y. He, K. Wang, and H. Zhu, "Convective heat transfer of molten salt in the shell-and-tube heat exchanger with segmental baffles", *Int. J. Heat Mass Transf.*, vol. 113, pp. 456–465, 2017.

[15] D.A. Firlianda, A.A. Permanasari, and P. Puspitasari, "Heat transfer enhancement using nanofluids (MnFe2O4-ethylene glycol) in mini heat exchanger shell and tube Heat Transfer Enhancement using Nanofluids (MnFe 2 O 4 - Ethylene Glycol) in Mini Heat Exchanger Shell and Tube", *AIP Conf. Proc.*, vol. 2120, 2019.

[16] A.A. Permanasari, B.S. Kuncara, and P. Puspitasari, "Convective heat transfer characteristics of TiO2-EG nanofluid as coolant fluid in heat exchanger Convective Heat Transfer Characteristics of TiO 2 -EG Nanofluid as Coolant Fluid in Heat Exchanger," *AIP Conf. Proc.*, vol. 2120, 2019.