Effect of Baffle Spacing on Shell Side Heat Transfer Enhancement of a Shell and Tube Heat Exchanger

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Abstract

Baffle is commonly used to improve the performance of the shell and tube heat exchangers. In this research, effect of the baffle spacing to the performance of a shell and tube heat exchanger has been examined experimentally. The length and diameter of the shell of the heat exchanger is 500 mm and 60 mm, respectively. The number of the tube is 4. The inner and outer diameter of the tube is 13.8 mm and 15.8 mm, respectively. The different baffle spacing 71 mm, 55 mm and 45 mm were used and the number of baffles were varied from 6, 8,10 respectively. The hot water mass flow rate was fixed to 4.5 Litres/min and cold-water mass flow rate was varied from 6,9,12,15 Litres/min. Using the experimental data heat transfer coefficient, Nusselt number, effectiveness has been evaluated. The results showed that effectiveness Increased when the baffle spacing decreased. The maximum increment of heat transfer coefficient for 10 no of baffle was 144.02% with respect to without using baffle and 53.13% with respect to 6 no of baffle with volume flow rate of 15 litres/min.

Keywords
Baffle spacing, Heat Exchanger, Shell Tube and Heat Transfer.

1. Introduction
Heat exchangers are used as heat transfer devices in industries, such as nuclear engineering, power systems, and thermal energy storage. STHXs account for the maximum percentage of all heat exchangers because of easy way of manufacture, low cost and high-pressure resistance. The flow-directing or blocking plates needed to accurately guide a fluid flow are known as baffles. Many domestic stoves and power plant vessels, like chemical reactors, STHX include baffles. Baffles have become an important element of the construction of a STHX. A baffle seems to be a device that supports pipe arrangements while also directing flow pattern for peak performance. Baffles were always employed inside a stationary mixer to reduce the radial parts of motion, which induces swirl generation and facilitates blending.Baffles were also frequently added to the internal side of chemical reactors to enhance mixing and therefore boost heat transmission and perhaps chemical reaction. There have many ways to improve the heat transfer of HX devices, but passive and active method are popular among the researchers. On the other hand, compound method is used in critical devices, that's why it is not used in industrial production. To increase heat transfer rate, many techniques require some external power input. Because of the equipment requirements, this approach can only be used in a limited number of situations. These approaches have not demonstrated significant potential in comparison to passive solutions. The single segmental baffle has a high anti-fouling and anti-vibration capability. The pressurized water reactor is the most innovation and widely used reactor, baffle heat exchanger has a direct impact on the PWR's performance.

1.1 Objectives
The following are the research objectives.

- To design and fabricate of a Shell and tube heat exchanger with varying baffle space.
- To analysis experimentally different heat transfer properties by varying baffle spacing and no of baffle.

2. Literature Review
Mohanty and Arora experimented on segmental baffle heat exchanger with different baffle cut configuration and 50% baffle cut gave better result. They used different baffle spacing for 6,8,10,12 number of baffle and

experimented numerically with three different mass flow rates. They found a better heat transfer rate with decreasing the baffle space. Zebua and Ambarita experimented numerically and practically on the effect of baffle spacing of a sthx. They found that efficiency of the heat exchanger kept increasing with baffle space decreasing. Mellal et al. experimented the performance of a STHX for different baffle orientation. 10 baffles inclined by 180^0 has the most thermal performance factor with a maximum value of 3.55 at a Reynolds number of 3000.Many experts are looking at the longitudinal streamlines on the shell side. Wang et al. created a novel construction called double shell-pass HX ,It had a sleeve dividing the shell's inner side in half. The DS-RBHX improves heat transfer characteristics, according to both computational and experimental tests than single shell-pass RBHX. Lei et al. created two unique louver baffles HX. The round orifice plate baffle is a unique form of structural support for generating longitudinal flow, with trefoil-hole & quatrefoil-hole baffles being the most popular due to their excellent anti-vibration as well as anti-fouling dependability. You et al. published a study on STHX's shell side improvement employing trefoil-hole baffles. They discovered that these types of baffles may provide a high-speed flush across pipe walls, which significantly increases heat transfer rate.

3. Methods

For the test section, water was taken as a heat transfer fluid. Cold water was supplied to the Shell side and hot water was supplied to the tube side. The temperature of the hot water inlet and cold-water inlet were kept constant. Four thermometers were placed at hot water inlet and outlet tube and cold-water inlet and outlet tube. Two pressure gauge were set at cold water inlet and outlet section. The volume flowrate of the hot water was kept constant. On the other hand, varying mass flow rate was applied to the shell section of cold water and value of temperature and pressure were measured. Volume flow rate of the cold water was increased by controlling gate valve. Four model were tested with 6,8,10 no baffle and another one is without baffle. The heat exchanger was covered with aluminum foil paper so that no heat loss occurred for radiation from the outer shell. Schematic diagram of the experimental setup is given in Figure 1.

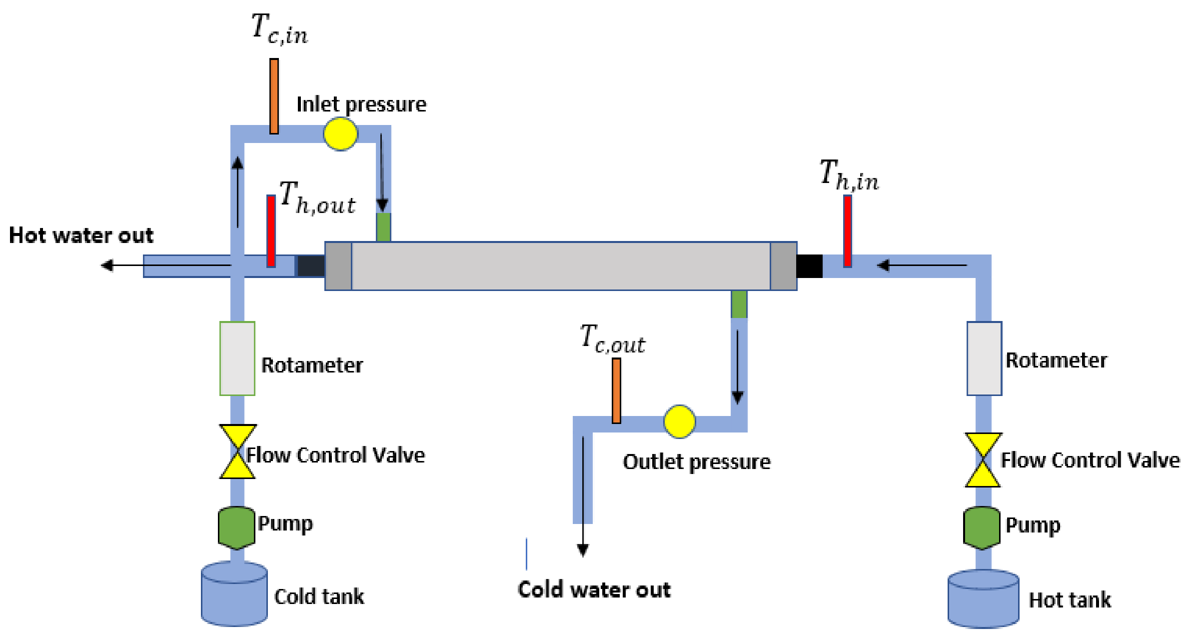

Figure 1. Schematic diagram of experimental setup.

4.Data Collection

4.1 Necessary Data

Shell inside diameter, d_o = 60 mm
Tube outside diameter, d_{o} = 5/8 inch = 15.875 mm
Thickness of the tube = 1 mm
Length of the heat exchanger = 500 mm
Thermal conductivity of copper, k =398 W/m^{2}k
Baffle space for 6 baffle, B = 71 mm

Baffle space for 8 baffle, B = 55 mm
Baffle space for 10 baffle, B = 45 mm
Thermal conductivity of water, k= .654 W/m^2.k
Heat transfer rate of hot water

$$Q_h = \dot{m}_h C_p (T_{h_i} - T_{h_0})$$

Q_h = Heat transfer rate of hot water (J/s)
$\dot{m}_h$= Mass flow rate of hot water (Kg/s)
T_{h_i} = Hot water inlet temp(°C)
T_{h_0} = Hot water outlet temp(°C)
C_p =Coefficient of pressure(J/kg.k)

$$Q_c = \dot{m}_c C_p (T_{ci} - T_{co})$$

Q_c = Heat transfer rate of cold water (J/s)
$\dot{m}_c$= Mass flow rate of cold water (Kg/s)
T_{c_i} = Cold water inlet temp(°C)
T_{c_0} = Cold water outlet temp(°C)
C_p =Coefficient of pressure(J/kg.k)
Shell side heat transfer coefficient [29]:

$$h_s = \frac{Q_c}{A_s \times \Delta T_m}$$

A_s = Total surface area oftube outside(m^2)
ΔT_m = Log mean temperature difference

$$A_s = N_t \pi d_0 L$$

$$\Delta Tm = \frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

LMTD is the log mean temperature difference, based on the inlet temperature difference ΔT_1, and outlet temperature difference ΔT_2.
Tube side heat transfer coefficient [29]:

$$h_t = \frac{Q_h}{A_t \times \Delta T_m}$$

A_t = Total surface area of tube outside
ΔT_m = Log mean temperature difference
Shell side mass velocity is found with:

$$G_s = \frac{\dot{m}_c}{A_s}$$

A_s=Bundle cross flow area(m^2)

$$A_s = \frac{D_s}{P_T} \times (P_T - d_0) \times B$$

D_s=Inner diameter of shell(m)
P_T=Tube pitch(m)
B=Baffle space(m)
$d_0 = Tube$ outer diameter(m)
Equivalent diameter of square layout [29]:

$$D_e = \frac{4\left\{{P_T}^2 - \frac{\pi}{4} \times d_0^2\right\}}{\pi d_0}$$

P_T=Tube pitch(m)
d_0 = Tubeouter diameter(m)
Reynolds number of the shell side [29]:

$$Re_s = \frac{G_s \times D_e}{\mu_s}$$

G_s = Shell side mass velocity(m/s)
D_e = Equivalent diameter(m)
μ_s= Dynamic viscosity (kg/ms)
Prandtl number [29]:

$$Pr = \frac{\mu \times C}{k}$$

μ = Dynamic viscosity (kg/ms)
k= Thermal conductivity (Wm^{-1} k^{-1})
Nusselt Number for shell side:

$$Nu = \frac{h_s \times De}{k}$$

h_s =Shell side heat transfer coefficient
D_e = Equivalent diameter(m)
k=Thermal conductivity of water (Wm^{-1} k^{-1})
Shell side friction factor [29]:

$$f_s = exp(0.576 - 0.19\, ln\, Re_s)$$

Re_s = Reynolds number of the shell side
Effectiveness

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}}$$
$$= \frac{C_h \times (T_{h_i} - T_{ho})}{C_{min} \times (T_{h_i} - T_{ci})}$$

C_h = Coefficient of pressure(J/kg.k)
T_{h_i} = Hot water inlet temp(°C)
T_{h_0} = Hot water outlet temp(°C)

In Tables 1 and 2, heat transfer coefficient, Nusselt number, friction factor, effectiveness have been calculated.

Table 1. Experimental results of heat exchanger with 6 no of baffle for different flow rate

No.	Mass flow rate $\dot{m}_c$ (kg/s)	Hot inlet temperature T_{hi}(°C)	Hot outlet temperature T_{ho}(°C)	Cold inlet temperature T_{ci}(°C)	Cold outlet temperature T_{co}(°C)	Heat transfer coefficient h_s (W/m^2. k)
1	0.10	70	61	30	35	709.21
2	0.15	70	59	30	34.5	980.08
3	0.20	70	58	30	34	1240.72
4	0.25	70	57.3	30	33.7	1466.89

Table 2. Experimental results of heat exchanger with 6 no of baffle for different flow rate

No.	Mass flow rate,$\dot{m}_c$ (kg/s)	Nusselt number Nu	Friction factor f_s	Pressure drops Δp (Pa)	Effectiveness Ɛ	Total heat transfer Q (W)
1	0.10	18.59	0.37	928	0.20	1332
2	0.15	25.7	0.34	1115	0.31	1529
3	0.20	32.63	0.32	1289	0.33	1749
4	0.25	35.40	0.30	1437	0.35	1989

In Tables 3 and 4, heat transfer coefficient, Nusselt number, friction factor, effectiveness have been calculated.

Table 3. Experimental results of heat exchanger with 8 no of baffle for different flow rate

No.	Mass flow rate $\dot{m}_c$ (kg/s)	Hot inlet temperature T_{hi}(°C)	Hot outlet temperature T_{ho}(°C)	Cold inlet temperature T_{ci}(°C)	Cold outlet temperature T_{co}(°C)	Heat transfer coefficient h_s (W/m^2. k)
1	0.10	70	57	30	37	934.40
2	0.15	70	56	30	36.6	1563.98
3	0.20	70	54.5	30	36	1931.70
4	0.25	70	53	30	35	2083.33

Table 4. Experimental results of heat exchanger with 8 no of baffle for different flow rate

No.	Mass flow rate,$\dot{m}_c$ (kg/s)	Nusselt number Nu	Friction factor f_s	Pressure drops Δp (Pa)	Effectiveness Ɛ	Total heat transfer Q (W)
1	0.10	24.57	0.351	1241	0.39	1698
2	0.15	41.13	0.324	1635	0.41	1825
3	0.20	50.80	0.307	1972	0.45	2248
4	0.25	54.79	0.294	2301	0.48	2714

In Tables 5 and 4, heat transfer coefficient, Nusselt number, friction factor, effectiveness have been calculated.

Table 5. Experimental results of heat exchanger with 10 no of baffle for different flow rate

No.	Mass flow rate $\dot{m}_c$ (kg/s)	Hot inlet temperature T_{hi}(°C)	Hot outlet temperature T_{ho}(°C)	Cold inlet temperature T_{ci}(°C)	Cold outlet temperature T_{co}(°C)	Heat transfer coefficient h_s (W/m^2. k)
1	0.10	70	55	30	38	1316.80
2	0.15	70	53	30	37	1568.95
3	0.20	70	52.3	30	36.5	2098.06
4	0.25	70	52	30	36	2245.45

Table 6. Experimental results of heat exchanger with 10 no of baffle for different flow rate

No.	Mass flow rate,$\dot{m}_c$ (kg/s)	Nusselt number Nu	Friction factor f_s	Pressure drops Δp (Pa)	Effectiveness Ɛ	Total heat transfer Q (W)
1	0.10	34.63	0.34	2167	0.46	2002
2	0.15	46.52	0.31	2351	0.51	2289
3	0.20	57.80	0.29	2611	0.53	2775

4	0.25	66.94	0.28	2994	0.55	3060

In Tables 7 and 8, heat transfer coefficient, Nusselt number, friction factor, effectiveness have been calculated.

Table 7. Experimental results for heat exchanger without using baffle for different flow rate

No.	Mass flow rate $\dot{m}_c$ (kg/s)	Hot inlet temperature T_{hi}(°C)	Hot outlet temperature T_{ho}(°C)	Cold inlet temperature T_{ci}(°C)	Cold outlet temperature T_{co}(°C)	Heat transfer coefficient h_s (W/m^2. k)
1	0.10	70	66	30	33	352.25
2	0.15	70	65.5	30	32.7	423.36
3	0.20	70	64.8	30	32.3	639.40
4	0.25	70	64	30	32	920.60

Table 8. Experimental results for heat exchanger without using baffle for different flow rate

No.	Mass flow rate,$\dot{m}_c$ (kg/s)	Nusselt number Nu	Friction factor f_s	Pressure drops Δp (Pa)	Effectiveness Ɛ	Total heat transfer Q (W)
1	0.10	10.51	0.120	311	0.11	827
2	0.15	11.17	0.092	427	0.12	897
3	0.20	13.43	0.085	568	0.14	965
4	0.25	16.02	0.071	732	0.16	1032

5. Results and Discussion

In Figure 2, it was found that when the mass flow rate increased, the heat transfer rate also increased. Heat transfer coefficient increases with increasing the number of baffles. With increasing baffle number fluid turbulence also increased that help to mix up the flow streamline. The Maximum value of heat transfer coefficient is 510.6 w/m^2.k for without baffle heat exchanger. Heat exchanger with 10 baffles has the highest heat transfer coefficient. There is a maximum increase of heat transfer for 10 baffle is 376.12% than the heat transfer coefficient without using baffle at amass flow rate of .25 kg/s and minimum increases heat transfer coefficient for 6 baffle is 216%. In Pressure drop:

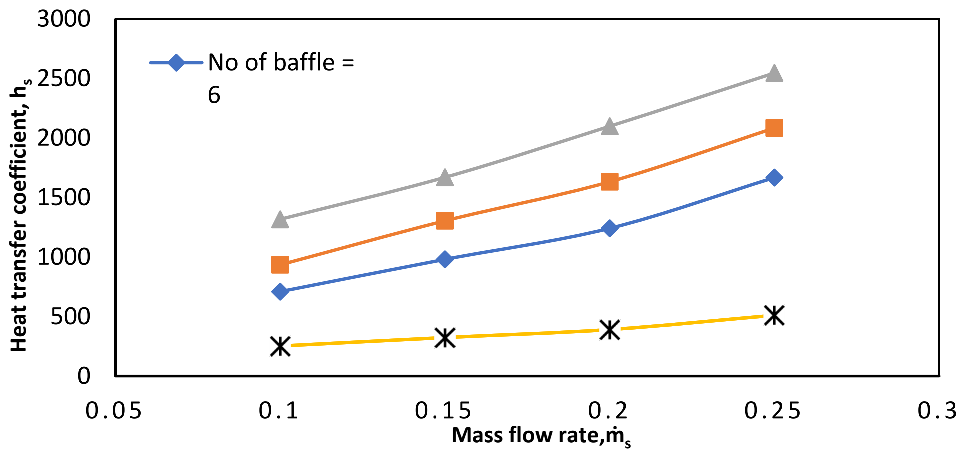

Figure 2. Variation of shell side heat transfer coefficient with mass flow rate.

In Figure 3, the change in pressure drop of cold water in the shell side is shown with the change of mass flow rate. The pressure drop is minimum for without baffle heat exchanger and maximum for 10 baffle heat exchanger. With increasing baffle number pressure drop increases gradually. With increasing pressure drop velocity of the liquid increases and pressure loss also increases Heat exchanger with 6 baffle shows less pressure drop than 8 and 10 baffle heat exchangers. Higher pressure drop creates higher heat transfer with increasing the fluid velocity. Maximum pressure drop occur at .25 kg/s and minimum at .1 kg/s and pressure drop increases with increasing both mass flow rate and baffle number.

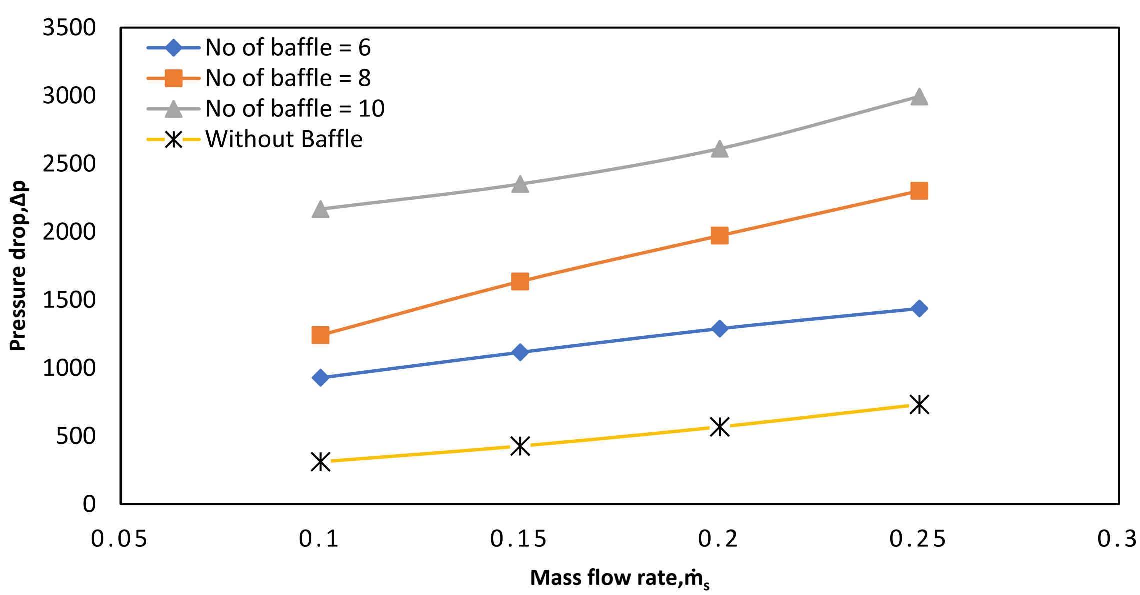

Figure 3. Variation of pressure drop with mass flow rate.

On the other hand, with increasing the pressure drop the shell side pressure loss also increases because the fluid directly strikes baffle surface and shell wall and decreases the pressure of fluid.

Nusselt number:

In Figure 4 change of Nusselt number of the shell side cold water with the change of mass flow rate is shown. Nusselt number is low at plain tube without baffle heat exchanger. Nusselt number increased with decreasing the baffle spacing and increasing the baffle number. The blockage created by the baffle caused turbulence in the test section, which increased the heat transfer rate.

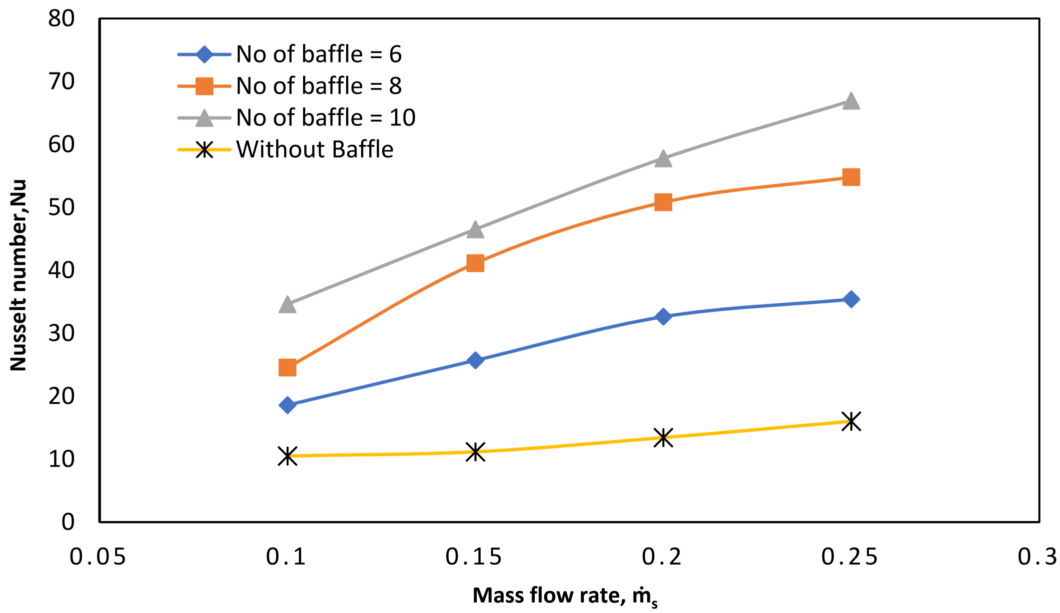

Figure 4. Variation of Nusselt number vs mass flow rate.

Total heat transfer:
Figure 5 shows total heat transfer of the sthx with different number of baffles for the variation of mass flow rate. Heat transfer increases with increasing the baffle number comparing plain tube without using baffle. It was found from the investigation that total heat transfer of 10 baffle sthx was 110%-247% higher than the without baffle heat exchanger.

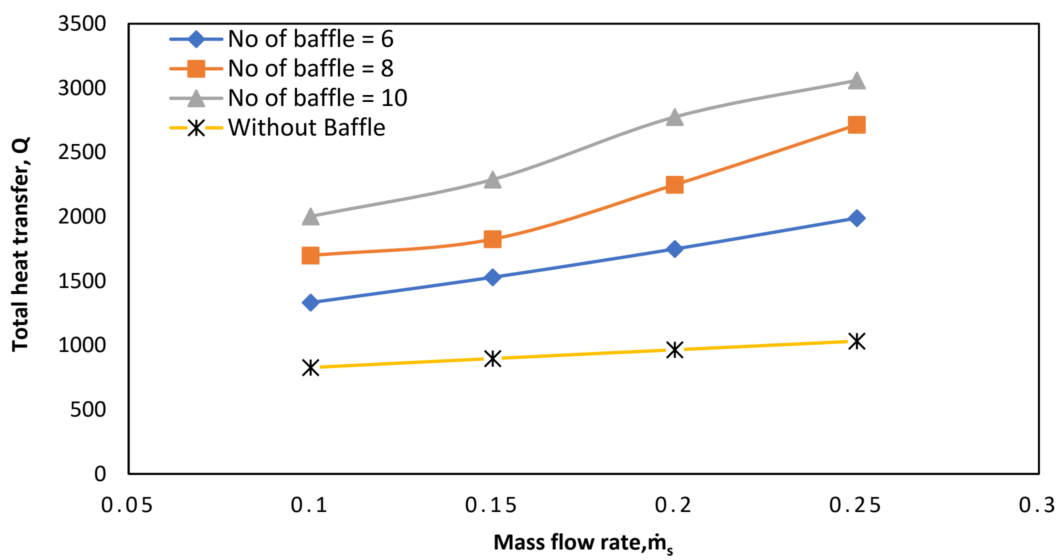

Figure 5. Variation of total heat transfer with mass flow rate.

Effectiveness:

Figure 6 shows the change in effectiveness of sthx for different baffle number with the change in mass flow rate. Effectiveness increases with decreasing the baffle space and increasing mass flow rate. Baffled tube showed better effectiveness than the plain tube without baffles. STHX with 6 baffle shows a rapid increase of effectiveness with mass flow rate. STHX with 10 baffles has a very little increase of effectiveness with respect to 8 baffle STHX.

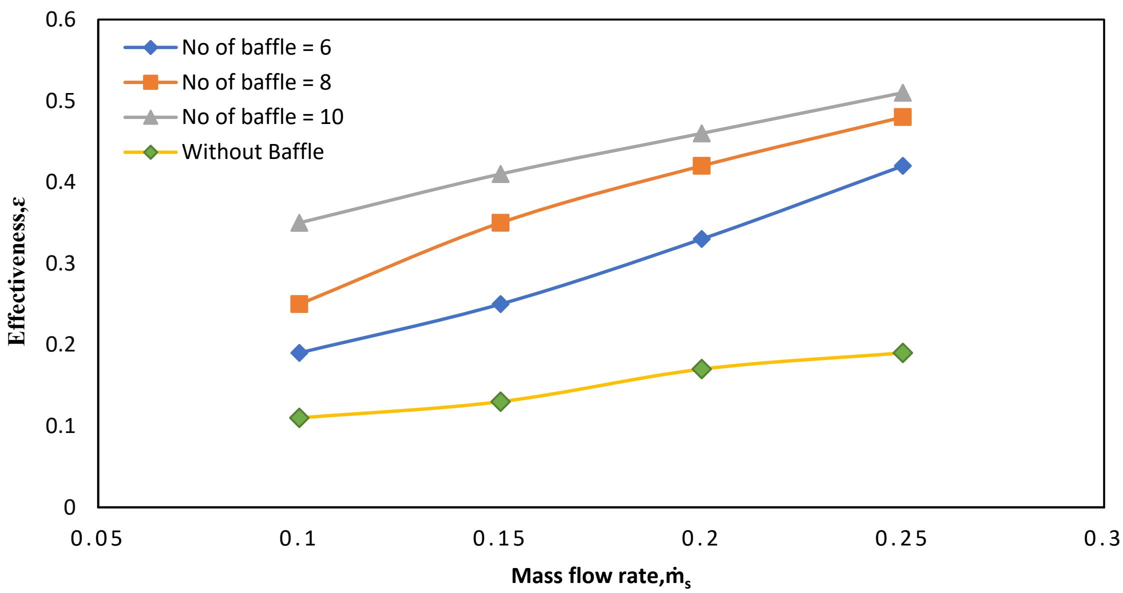

Figure 6. Variation of effectiveness with mass flow rate.

6. Conclusion

An experimental study was carried out to find the heat transfer coefficient, pressure drop, Nusselt number, friction factor and effectiveness of a shell and tube heat exchanger for different number of baffle configuration (6, 8, 10 baffle). From the experiment it was found that decreasing the baffle spacing increases heat transfer coefficient and effectiveness with increasing pressure drop. Increasing the number of baffles increases the effective length of the heat exchanger, increases turbulence that's help the cold water mix properly and increases annulus side heat transfer rate. The maximum increment of heat transfer coefficient for 10 no of baffle is 144.02% with respect to plain tube and 53.13% with respect to 6 no of baffle for mass flow rate of 15 litres/mi. The maximum pressure drop occur for 10 number of baffles which helped to increase the fluid velocity but with increasing pressure drop, pressure loss also increased. Nusselt number increased with decreasing the baffle spacing and increasing the baffle number. The blockage created by the baffle caused turbulence in the test section, which increased the heat transfer rate. The maximum effectiveness with 4 different baffle configurations (6 baffle, 8 baffle, 10 baffle, without baffle) are 35%, 48%, 55% and 16%.

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Biographies

Protap Sarker graduated from Chittagong University of Engineering and Technology with a bachelor's degree in mechanical engineering in 2022. The author is passionate about heat transfer, fluid mechanics, and lithium-ion batteries. As he begins on a new adventure of higher education, he hopes to go deeper and farther into this profession. In his youth, the author was also devoted to extracurricular activities such as business case contests, leadership, and writing, among others.

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Md. Eyasin Hossaincompleted his B.Sc. in mechanical engineering from Chittagong University of Engineering & Technology (CUET) in 2022. The author has a deep interest in thermodynamics, heat transfer, fluid mechanics, lithium-ion batteries etc. He wishes to continue his higher studies to tread further and deeper into this field.

Shantanu Sahahas freshly graduated from Chittagong University of Engineering & Technology in Mechanical Engineering. As a spirited person, he likes to explore different areas of research related to mechanical engineering. His research interest comprises of renewable energy technologies, phase change heat transfer, heat transfer enhancement with nanofluids. He is currently looking for opportunities to work with researchers with similar research interests.