Research Article

Thermohydraulic Analysis of Shell-and-Tube Heat Exchanger with Segmental Baffles

Amarjit Singh¹ and Satbir S. Sehgal²

¹ Department of Mechanical Engineering, RPC, Railmajra 144533, India

² Department of Mechanical Engineering, Chandigarh University, Gharuan 140413, India

Correspondence should be addressed to Amarjit Singh; sandhar88@gmail.com

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In this study, the experimental analysis was performed on the shell-and-tube type heat exchanger containing segmental baffles at different orientations. In the current work, three angular orientations (θ) 0° , 30° , and 60° of the baffles were analyzed for laminar flow having the Reynolds number range 303–1516. It was observed that, with increase of Reynolds number from 303 to 1516, there was a 94.8% increase in Nusselt number and 282.9% increase in pressure drop. Due to increase of Reynolds number from 303 to 1516, there is a decrease in nondimensional temperature factor for cold water (ω) by 57.7% and hot water (ξ) by 57.1%, respectively.

1. Introduction

A heat exchanger is a device built for efficient heat transfer from one medium to another in order to carry and process energy [1]. It is widely used in petroleum refineries, chemical plants, petrochemical plants, natural gas processing, air conditioning, refrigeration, and automotive applications. The most commonly used type of heat exchanger is the shell-and-tube heat exchanger. To increase the heat transfer rate in shell and tube type heat exchanger, the segmental baffles are introduced inside the cover pipe [2–6]. The flow arrangement used in analysis is laminar counter flow as it is more efficient than parallel flow arrangement [7]. The different orientations of baffles in heat exchanger [8–10] are given in Figure 1.

The common focus of publication is to predict the variation of LMTD, heat transfer coefficient, Nusselt number, and pressure drop with change in values of Reynolds number for 0° , 30° , and 60° baffles situated in heat exchanger as shown in Figure 1. The Reynolds number will be varying from 303 to 1516.

The enhancement of Nusselt number with increase in Reynolds number will be presented by Zohir [11], Tandirolu [12], and Promvonge [13]. The heat transfer coefficient values

are calculated using the log-mean-temperature-difference (LMTD) method [14] from the temperature difference and the heat transfer area. Gay et al. [15] and Mehrabian et al. [16] concluded that the heat transfer coefficient increases with inserting baffles. Thundil et al. [17] observed that the pressure drop will decrease with increasing baffle inclination angle and the heat transfer rate increases with increasing baffle inclination angle.

2. Test Specimen

A variety of different strategies are available to improve the performance of shell-and-tube type heat exchanger as discussed by Walde [18]. The present paper mainly attempts to study the different effects in shell-and-tube heat exchanger by increasing Reynolds number with segmental baffles at 0° , 30° , and 60° situated in the cover pipe. The model is situated with four segmental baffles. The various dimensions used in heat exchanger are shown in Figure 2. The working fluid used is deionized water. The material used for the design of model is galvanized iron. The geometric parameters of shell-and-tube heat exchanger are given in Table 1.

FIGURE 1: Shell-and-tube type heat exchanger having (a) 0°, (b) 30°, and (c) 60° baffle angles.

FIGURE 2: Dimensions used in heat exchanger.

3. Results and Discussion

In the present study, different cases were studied to understand the LMTD values, Nusselt number, heat transfer coefficient, and pressure drop of shell-and-tube type heat exchanger having hot water and cold water inlets. Performance comparison and other details are given in Table 2.

The variation of LMTD values with different Reynolds numbers is shown in Figure 3. The variation of heat transfer coefficient with Reynolds number at different inlet temperatures is shown in Figure 4, and the variation of Nusselt number with Reynolds number is shown in Figure 5. Figure 6 shows the variation of ratio of temperature difference (ω) for cold water with increasing Reynolds number, and the variation of ratio of temperature difference (ξ) for hot water with increasing Reynolds number is shown in Figure 7.

Figure 3 shows the variation of LMTD with Reynolds number. It was observed that, with the increase of Reynolds

TABLE 1: Main dimensions and features in heat exchanger.

α	L_a/D_c	1.86
β	L_c/D_c	2.67
γ	L_h/D_h	16.6
δ	L_c/X_c	2.86

θ : 0°, 30°, and 60°.

TABLE 2: Data reduction.

S. no.	Parameters	Data reduction
1.	Heat transfer coefficient	$h = \frac{m \cdot C \cdot \Delta t}{\pi \cdot D \cdot L \cdot \Delta t_m}$
2.	Logarithmic mean temperature difference	$\Delta T_m = \frac{(T_{h(in)} - T_{c(in)}) - (T_{h(out)} - T_{c(out)})}{\ln((T_{h(in)} - T_{c(in)}) / (T_{h(out)} - T_{c(out)}))}$
3.	Nondimensional temperature factor for cold water	$\omega = \frac{t_{c(out)} - t_{c(in)}}{t_{c(out)}}$
4.	Nondimensional temperature factor for hot water	$\xi = \frac{t_{h(in)} - t_{h(out)}}{t_{h(in)}}$
5.	Nusselt number	$Nu = \frac{hL}{K}$
6.	Reynolds number	$Re = \frac{\rho V D}{\mu}$

number from 303 to 1516 there was 23.15 to 38.5% increase in LMTD values. The increase in LMTD value with Reynolds

FIGURE 3: Variation of LMTD with Reynolds number.

FIGURE 4: Variation of heat transfer coefficient versus Reynolds number for different inlet fluid temperatures.

number may be attributed to less retention time within the heat exchanger for the same length of flow.

Figure 4 shows the variation of the heat transfer coefficient with Reynolds number. With increase of Reynolds number from 303 to 1516, the increase of heat transfer coefficient was 95.1%. The increase of heat transfer coefficient is attributed to the increase of mass flow rate due to which the heat transfer rate increases.

Figure 5 shows the variation of Nusselt number with Reynolds number. It was observed, that with the increase of Reynolds number from 303 to 1516, there was a 94.8% increase in Nusselt number. The increase in Nusselt number is attributed to the enhancement in heat transfer rate with increase in velocity of fluid.

FIGURE 5: Variation of Nusselt number with Reynolds number for different inlet fluid temperatures.

FIGURE 6: Variation of ω with Reynolds number (for cold water inlet).

Figure 8 shows the change of pressure drop with variation in Reynolds number. It was observed that the pressure drop increases with the increase in Reynolds number up to 282.9%. The measured pressure drop is in good agreement with the estimated value. A gradual change in the pressure drop with Reynolds number is attributed to the temperature dependence of fluid viscosity and the increasing contraction and expansion pressure losses at the inlet and outlet portion of the heat exchanger, respectively.

Figure 9 shows the variation of the heat transfer coefficient with Reynolds number for three different baffle orientations. It was observed that, with the introduction of the baffles, the heat transfer coefficient increases leading to more heat transfer rate due to introduction of swirl and more convective surface area. It was also observed that, as the angle

FIGURE 7: Variation of ξ with Reynolds number (for hot water inlet).

FIGURE 8: Variation of total pressure drop versus Reynolds number for 0° baffle orientations.

FIGURE 9: Variation of heat transfer coefficient versus Reynolds number for different baffle orientation.

of inclination increases from 0° to 60°, the heat transfer coefficient value increases due to increase in swirl.

4. Conclusion

In this paper, experimental study of shell-and-tube heat exchanger is conducted to calculate the heat transfer coefficient, LMTD, Nusselt number, and pressure drop at different Reynolds numbers (303–1516). It is concluded that the increase in Reynolds number has a significant impact on different parameters of shell-and-tube type heat exchanger. The major findings are summarized as follows.

- The heat transfer coefficient increases with increase in Reynolds number in shell-and-tube heat exchanger for both hot fluid inlet and cold fluid inlet.
- The Nusselt number increases with increase in Reynolds number in shell-and-tube heat exchanger for both hot fluid inlet and cold fluid inlet.
- The value of LMTD increases with increase in Reynolds number from 303 to 1516.
- The value of temperature constants ξ and ω decreased with increase in Reynolds number.
- The value of pressure drop gradually increases with increase in Reynolds number.

Nomenclature

- C : Specific heat of water (J/kg K)
 D_a : Diameter of adapter (m)
 D_c : Diameter of cover pipe (m)
 D_h : Diameter of inner pipe (m)
 h : Heat transfer coefficient (W/m² K)
 K : Thermal conductivity of water (W/m K)
 L_a : Centre distance between two adapters
 L_c : Length of cover pipe (m)
 L_h : Length of inner pipe (m)
 m : Mass flow rate (kg/s)
 Re : Reynolds number
 V : Velocity of water (m/s)
 X_c : Centre distance between two baffles
 ρ : Density of water (kg/m³)
 μ : Viscosity of water (N s/m²)
 ΔP : Pressure drop (N/m²)
 ΔT : Change in temperature (°C)
 ΔT_m : Logarithmic mean temperature difference
 θ : Inclination angle
 α : Ratio of adapter pitch to cover pipe internal diameter
 β : Ratio of length to internal diameter of cover pipe
 γ : Ratio of length to internal diameter of inner pipe
 δ : Ratio of length of cover pipe to baffle pitch.

Subscripts

a: Adapter
c: Cold water
h: Hot water
in: Water inlet
out: Water outlet.

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