RESEARCH PAPER

Different baffle gaps with numerical analysis of multidesigned shell-and-tube heat exchangers

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Abstract

Heat exchangers are broad-spectrum tools used to obtain hot water from cold water. These tools can also be used in heating and cooling processes. Generally preferred types of heat exchangers are used in the production of hot water. The running basis of the dissimilar types of heat exchangers is essentially analogous. It is to gather the heat from a fluid with a forward temperature initially on the heat transfer surface plate or pipe and deliver this heat to another fluid at a lower temperature, which is in contact with the further surface or pipe of the same plate or pipe.

Here, heat exchangers with shell and tube heat exchangers are used. The changes in the fluid behavior resulting from the variation of the space among the baffle plates with the flow rate will be examined. With the computational fluid dynamics method, simulations were carried out through the intermediary program, and the obtained findings were examined.

Keywords: Baffle plate, CFD, Fluid behavior, Heat exchanger

1. Introduction

In shell-and-tube heat exchanger (STGRs) with transverse, longitudinal and spiral flow, the guiding element can tighten the tube bundles and ensure homogeneous distribution of the fluid. The pressure drop (PD) on the shell side and the characteristics of the heat transfer have a great impact on different flow states, causing changes in the performance of STGRs. Therefore, performance-enhancing type deflector plate designs are being developed. For example, it can be determined that the baffle plate heat exchanger manufactured in a discontinuous helical style is better in terms of thermal performance properties and fouling criteria than the conventionally manufactured helical baffle plate heat exchanger.

Fluid behavior and thermal performance effects can be changed by optimizing the design of the heat exchanger. The fact that the thermal performances can be changed thanks to the different designs of the baffle plates has increased the studies on this subject. Therefore, it is possible to improve the thermal performance of the STGR thanks to the designs of transfer plates in different shapes. Designs of transfer plates play an important role in STGRs regarding thermal performance.

2. Materials and methods

In the study where the computational fluid dynamics method was used, analyses were carried out through the computational fluid dynamics (CFD) package programs, Ansys Fluent 2021 R1 with an error rate of ~2%. Three-dimensional analyses were carried out on the newly designed STGR, and limit values were determined. The results obtained with the input of inlet—outlet flow rates and temperatures are given in the results section. Hot inlet—outlet and cold inlet—outlet are given in Fig. 1.

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The flowchart of the analysis process is as follows:

**Flowchart**

1. **Geometry**
2. **Mesh**
3. **Solver**
   - Physical and Solver Setting
4. **Results**
   - Check results
5. **Converge**
   - Define Computational algorithm
   - Discretization methods

**Physical model**

A model with a length of 1250 mm and a diameter of 120 mm by a single body and a single pipe passage was designed as a physical model.

Simulations of the changes between baffle plates, which are among the effective factors of changes in fluid behavior, are shown in Fig. 2 and technical details are given in Table 1. In addition, it causes changes and differences in fluid behavior; baffle plates are given in Fig. 3. In addition, water thermophysical properties of water are as follows: \( q: 976 \text{ kg/m}^3 \), \( c_p: 4191 \text{ J/kgC} \), \( \mu: 0.00039 \text{ kg/ms} \), and \( K: 0.66 \text{ W/mC} \).

2.1. Equations in analytics

A turbulence model selected for the model designed in the study is needed. Choosing the turbulence model correctly allows more accurate information to be obtained. The realizable \( k-\varepsilon \) turbulence model was used in accordance with the model, and the finite volume method was used as the solution method. The equations used are given below:

**Continuity equation**: \( \frac{\partial u_i}{\partial x_i} = 0 \)

**Momentum equation**: \[
A = - \frac{1}{\rho} \frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left( (\nu + \nu_t) \left( \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} \right) \right)
\]

(1)

**Turbulent kinetic energy (k) part**: \[
\frac{\partial u_i k}{\partial x_i} = \frac{\partial}{\partial x_j} \left( (\nu + \nu_t) \frac{\partial k}{\partial x_j} \right) + \Gamma - \varepsilon
\]

(2)

Turbulent energy dissipation (\( \varepsilon \)) part: energy equation:
Production of turbulent kinetic energy \( k \) with \( \Gamma' \) is shown in equation (2) and equation (3) and \( c_m \) is a function of mean strain and rotational speed\(^{30}\):

\[
\frac{\partial \kappa}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ \left( \frac{\nu_t}{\sigma_x} \right) \frac{\partial \kappa}{\partial x_i} \right] + c_1 \Gamma \kappa
\]

\[-c_2 \frac{\varepsilon^2}{k + \sqrt{\varepsilon}} \frac{\partial \kappa}{\partial x_i} = \rho \frac{\partial}{\partial x_i} \left( \frac{\nu_t}{Pr} \right) \frac{\partial \kappa}{\partial x_i} \]  

(3)

Heat transfer rate:

\[
h_i = \frac{\text{Body Heat Transfer} = Q_i = \dot{m} \cdot c_p \cdot s \cdot (T_{s,i} - T_{s,o})}{N \cdot \pi \cdot d \cdot L \left( \frac{T_{s,i} - T_{	ext{wall},i}}{T_{	ext{wall},i} - T_{	ext{wall},o}} \right)}
\]

(5)

2.2. Boundary conditions in analysis

Using the steady-state regime, the influence of pressure and gravity factors comes into consideration. In this case, by ignoring these factors, it becomes easier to get the results more smoothly. In addition, the interaction of the outside atmosphere also plays a role in heat transfer. Heat should not be absorbed by the environmental medium and for the total heat to decrease cumulatively. Therefore, no heat transfer occurred with the external environment and leaks were neglected. In the study, where the temperature of the water entering the system was 350 K and the surface temperature of the pipe was 285 K, the distance between the baffle plates was ensured to be at two different distances. The variations that occur by taking the gap distance as 90 and 110 mm are simulated through comparisons and graphs.

2.3. Mesh independence test

In this study, it was aimed to ensure the correctness of the outcomes by creating mesh grids with different mesh numbers for the designed model. In the designed model, five different mesh systems were created with the number of elements: 902408, 289892, 186743, 138205, and 103089. When the analysis was made between the created grid systems, it was concluded that the 138 205 element numbers model was sufficient for the analysis process, considering that the separation among the latest two network systems was less than 1% and the analyses were carried out accordingly. The results of the analyses were simulated and transferred to the study as in Fig. 4.

3. Results and discussion

In the study, emphasis was placed on the changes in temperature and pressure distributions. Changes in these temperature and pressure distributions were observed as the orientation plate spacing differed. The findings obtained were simulated through figures and transferred to the study.

By choosing the mass flow rate (MFR) ranges of the model STGR as 1.0, 1.4, 1.8, and 2.3 kg/h, different results were obtained at each MFR. These MFRs were analyzed with division intervals of 90 and 110 mm. As the findings are shown in Figs. 5–8, the results obtained in two different MFRs are different from each other.

In the analysis made on the outlet temperature as the plate spacing increased, it was observed that the outlet temperature and pressure drop of the model STGR with a larger spacing of 110 mm were higher than the result values of the model exchanger designed with a partition spacing of 90 mm.
In the model exchanger where the MFR values were selected as 1.0, 1.4, 1.8, and 2.3 kg/h, the effects of the changes observed in two different compartment intervals for each MFR value on the pressure drop and outlet temperature were examined. According to the analysis results, it was observed that at each MFR, if the partition gap was 90 mm at a lower value than the other, the outlet temperature and pressure drop were lower.

In Fig. 5a and b, the changes resulting from temperature and pressure distributions on the fluid behavior when the MFR is 1.0 kg/h and the chamber distance is 90 mm are simulated. However, in Fig. 5c and d, the changes resulting from the temperature and pressure distribution on the fluid behavior when the MFR is 1.0 kg/h and the chamber distance is 110 mm are simulated and transferred to the study. Accordingly, it was determined that the fluid behavior at an MFR of 1.0 kg/h showed various levels of behavior with the change in the gap level of the partition gap. Therefore, according to temperature distributions, it is seen that the temperature distribution of Fig. 5d is higher than that of Fig. 5a. At the same time, when looking at the pressure distributions, it is seen that the pressure distribution in Fig. 5b is higher than in Fig. 5c.

In Fig. 6a and b, the changes created by the temperature and pressure distribution on the fluid behavior when the MFR is 1.4 kg/h and the chamber distance is 90 mm are simulated. However, in Fig. 6c

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**Fig. 4. Mesh independence test.**

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**Fig. 5. (a–b) Model temperature and pressure distribution at gap = 90 mm, flow rate = 1.0 kg/h, (c) model pressure and temperature distribution at gap = 110 mm, flow rate = 1.0 kg/h.**
and d, the changes created by the temperature and pressure distributions on the fluid behavior while the MFR is 1.4 kg/h and the chamber distance is 110 mm are simulated and transferred to the study. Accordingly, it was determined that the fluid behavior at an MFR of 1.4 kg/h showed various levels of behavior with the change in the gap level of the partition gap. Therefore, according to temperature distributions, it is seen that the temperature distribution of Fig. 6d is higher than that of Fig. 6a.

At the same time, when looking at the pressure distributions, it is seen that the pressure distribution in Fig. 6c is higher than in Fig. 6b.

In Fig. 7a and b, the changes created by the temperature and pressure distribution on the fluid behavior when the MFR is 1.8 kg/h and the chamber distance is 90 mm are simulated. However, in Fig. 7c and d, the changes created by the temperature and pressure distribution on the fluid behavior when the MFR is 1.8 kg/h and the chamber distance is 110 mm

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**Fig. 6.** (a–b) Model temperature and pressure distribution at gap = 90 mm, flow rate = 1.4 kg/h, (c) model pressure and temperature distribution at gap = 110 mm, flow rate = 1.4 kg/h.

**Fig. 7.** (a–b) Model temperature and pressure distribution at gap = 90 mm, flow rate = 1.8 kg/h, (c) model pressure and temperature distribution at gap = 110 mm, flow rate = 1.8 kg/h.
are simulated and transferred to the study. Accordingly, it was determined that the fluid behavior at an MFR of 1.8 kg/h showed various levels of behavior with the change in the gap level of the partition gap. Therefore, according to temperature distributions, it is seen that the temperature distribution of Fig. 7d is higher than that of Fig. 7a. At the same time, when looking at the pressure distributions, it is seen that the pressure distribution in Fig. 7c is higher than in Fig. 7b.

In Fig. 8a and b, the changes created by the temperature and pressure distribution on the fluid behavior when the MFR is 2.3 kg/h and the chamber distance is 90 mm are simulated. However, in Fig. 8c and d, the changes created by the temperature and pressure distribution on the fluid behavior when the MFR is 2.3 kg/h and chamber distance is 110 mm are simulated and transferred to the study. Accordingly, it was determined that the fluid behavior at an MFR of 2.3 kg/h showed various levels of behavior with the change in the gap level of the partition gap. Therefore, according to temperature distributions, it is seen that the temperature distribution of Fig. 8d is higher than that of Fig. 8a. At the same time, when looking at the pressure distributions, it is seen that the pressure distribution in Fig. 8c is higher than in Fig. 8b.

According to the results of Fig. 9, changing the splitting spacing affects the heating transference ratio (HTR). It has been observed that the change in all MFR values increases HTR proportionally. In addition, when the mass MFR was 1.0 kg/h and the plate
spacing was 90 mm, HTR increased by ~90% and reached its highest level. In case the plate spacing is 110 mm, HTR, it reached its highest level at a mass MFR of 2.3 kg/h.

According to Fig. 10, the variation of PD in different plate gaps according to MFR was simulated. Accordingly, it is observed that the PD level increases with the increase in mass MFR, but it has been determined that the changes in different plate spacings also increase approximately to each other. It has been observed that the PD is higher with a plate spacing of 110 mm and it seems more logical to choose a model STGR with a plate spacing of 90 mm.

In Fig. 11, the change of mass MFR according to the heat transfer rate per pressure drop criterion, which is the thermohydraulic performance criterion, is simulated, and it is observed that as the mass MFR increases, it decreases regularly in both plate gaps of 90 and 110 mm. As a result, the best performance was observed at 90 mm plate spacing and 1.0 kg/h MFR.

4. Results

In this study, it has been observed that the change in all MFR values increases HTR proportionally. In addition, when MFR was 1.0 kg/h and the plate spacing was 90 mm, HTR increased by ~90% and reached its highest level. In case the plate spacing is 110 mm, HTR reached its highest level at a mass MFR of 2.3 kg/h. Also, it is observed that the PD level increases with the increase in MFR, but it has been determined that the changes in different plate spacings also increase approximately to each other. It has been observed that the PD is higher with a
plate spacing of 110 mm, and it seems more logical to choose a model STGR with a plate spacing of 90 mm.

However, the thermohydraulic performance criterion is simulated, and it is observed that as MFR increases, it decreases regularly in both plate gaps of 90 and 110 mm. As a result, the best performance of criterion is simulated, and it is observed that as MFR increases, it decreases regularly in both plate gaps of 90 mm.

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Author contribution

Lecturer Dr. Mehmet Akif Kartal: Responsible for all processes in the preparation of the article.

Conflicts of interest

There are no conflicts of interest.

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