CFD analysis and comparison of conventional type and perforated plate type shell tube heat exchangers

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Abstract

The baffle plate is the most important elements affecting not only the thermal efficiency but also the hydraulic performance of shell-tube heat exchangers that can be designed in different types today and can be put into the production phase. Different designs of baffle plates are closely related to thermal performance with pressure drop as well. In this investigation, the design geometry of the shell-tube type was carried out by means of the ANSYS Fluent program. In the analyses, it is purposed to examine the consequences on the heat transfer rate per drop of pressure and not only the pressure's drop but also the coefficient parameter of heat transfer of the exchangers in which traditional one-piece type baffle plate and perforated type baffle plate are used where the shell side. Here, water is used as the working fluid; it was examined as 1.2, 1.5, 1.8 and 2.1 kg/h at four varied mass flow rates (m). As a result, the values compared to the traditional one-piece baffle plate and the perforated type baffle plate. It has been monitored that the heat transfer rates per drop of pressure vary.

Keywords: CFD; shell tube heat exchanger; baffle plate; conventional heat exchanger

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1 INTRODUCTION

One of the processes frequently observed in industry and practical applications is heat exchange and the presence of two or more fluids at different temperatures that cause it. Devices where heat exchange takes place between more than one fluid at different temperatures are defined heat exchangers which are used in thermal power plants in our country, pharmaceutical industry, chemical industry, combined cycle facilities, heating–cooling systems and air-conditioning facilities find a place in a very wide range. The step of choosing the type of heat exchanger is the most important step to be taken by the expert who chooses it. Heat exchangers have a wide range of applications. In the selection of heat exchangers, proposal and manufacturing studies should be carried out by considering these areas. In short, when designing and manufacturing different types of heat exchangers, the characteristics of the places of use should be taken into account and produced.

Accurate definition of movement mechanisms and behavior of fluids has an important place in engineering applications and design calculations. Before a product reaches its final stage, it has to go through a number of steps. In the design phase, which is one of them, the use of numerical methods provides much more advantages than analytical methods, as it provides significant advantages in terms of time and cost to the manufacturer in determining some data, such as pressure losses, heat transfer mechanisms and flow rates. In complex models, this need increases much more [1].

In the realization of numerical analysis, data are obtained as a result of solving the problems that occur as a result of fluid motion with computational fluid dynamics that is called 'CFD', which is a ramification of fluid mechanics, using numerical methods and

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algorithms in the background, and utilities on the computer. Thus, it provides an incredible benefit to both the manufacturer and the sector, by saving the manufacturing budget and time to be spent on creating models in places that are dangerous to observe or difficult to reach [2]. With these analyses and the use of computers, important data are obtained in terms of determining the stable regime, determining the fluid behavior depending on time, temperature and pressure diagrams, heat transfers and examining the fluid behavior in dangerous or inaccessible areas to provide detailed information flow. With the progressive development of advanced technology and software, it has become possible to use it in the analysis of turbulent, supersonic flows and multiphase complex flows [3].

Additionally, the hydraulic efficiency of shell and tube heat exchanger (STHE), one of the significant factors affecting their thermal efficiency is the baffle plates. Its effect may vary with its structure and material type. The baffle plates are used in STHE to decrease very important negative effects. For example, it is inevitable to use baffle plates in order to minimize the dead zones, turn the laminar flow into turbulent and direct the fluid movements. However, baffle plates are to prevent imbalance and vibration that may occur during the flow of water.

At the point of changes caused by different baffle plate combinations investigated numerically in STHE. The changes in the heat transfer coefficient (HTC) parameter and their effects on the pressure drop were observed. Six varied types of baffle plates (single piece and double piece, three piece, helical, flower A–B) were used in the study. As a result of the study, it was determined that the one-piece baffle plate used had a negative effect as well as a benefit. It has been observed that although it brings about improvements in the total HTC parameter, it causes high pressure loss, which is an undesirable situation. In addition, the model that significantly reduced the pressure loss was the model in which helical baffle plates were used. In models using two different flower type baffle plates, it was observed that the flower B model raised the thermal efficiency compared to the flower A model [4]. In another numerical study, pressure drops and heat transfer mechanisms caused by varied types of baffle plates in STHE were investigated. It's been observed that model with the helical type baffle plate reduces the dead zones and pressure loss; therefore, it has more advantages than the others, although the model with the one-piece baffle plate causes dead zones and the model with the double-piece baffle plate reduces the vibration [5].

The heat differentiation phenomenon between two or more fluids with varied temperatures is one of the situations frequently encountered in industrial applications and places where the hot–cold relationship is intense. Devices where heat exchange occurs are often called heat exchangers [6]. One of the most used heat exchangers in practice is STHE. These heat exchangers, which make significant contributions to the reduction of energy consumption, energy recycling, transfer and use, take attention with their structural simplicity, high reliability and low production costs [7]. Frequently used in the industry, heat exchangers are manufactured in shell and tube type, which is one of the heat exchangers frequently used in the chemical industry and power plants, increasing energy efficiency in oil refineries. It consists of a geometrically cylindrical body and parallel pipes passing through the body, which may be of different numbers and types [8].

In another study conducted numerically on a STHE, three varied baffle plate types were used. The first of these is the helical type. It was observed that the thermohydraulic efficiency increased compared to the one-piece baffle plate. Also, they observed that STHE with three-leaf-hole baffle plates rehabilitate and improve heat transfer compared to the one-piece type, but also had an increasing effect on pressure drop [9].

In a small-sized body-and-tube type heat exchanger, a single body-tube transition is provided. Leakage effects are neglected and only the body side is concentrated. Body side heat convection coefficient and flow properties were compared in the results obtained from the KERN analytical method as a result of CFD analyses for body side pressure drops and heat convection coefficients according to different flow rates, turbulence models, baffle plate models and baffle plate shear rates, and different results were brought to the literature [10].

Flow performance and heat transfer effects in a STHE were numerically investigated using a one-way ladder type helical baffle plate. According to the outcomes of the analysis, it can be stated that if the ladder type helical baffle plate, which is another type compared to the one-piece baffle plate, is used, the result of increasing HTC per existing data pressure drop is observed [11].

Particle image velocimetry is called PIV method is used to obtain instantaneous velocity measurements and related properties in fluids. According to a research conducted as a result of examining the flow characteristics with the CFD and PIV method, data were obtained by using the experimental setup PIV method, in which the flow structure between the two wings was designed to be examined. Thus, it was determined that the difference between the outcomes of HAD and experimental studies and the outcomes of the experimental studies varied between 0.01 and 0.09 [12].

When the bar baffle plate STHEs are compared numerically with large small hole and one piece baffle plate heat exchangers, it's concluded that the difference in pressure loss ratio varies. While it was seen that the pressure loss ratio was higher in large, small-hole and one-piece baffle plate heat exchangers, the difference was found to be 58% [13].

Due to the high pressure loss and dead zones caused by the use of one-piece baffle plates, the design and production works continue until todays. Research continues to minimize these negative effects in STHE [14].

In the experimental setup created for performance analysis with CFD method, performance characteristic parameters were analysed using ANSYS CFX. In the simulations, the flow is assumed to be stable, turbulent and incompressible. From the simulation results using Reynolds mean Navier–Stokes equations and shear stress transport turbulence model in the numerical solution, it was determined that the highest performance was observed at 90% of the design value of the cross-sectional area of the spiral body perpendicular to the flow, and it has been observed that the impeller rotation speed is realized at 4200 rpm, which is the design input value [15].

According to a numerical study, it was found that HTC per pressure drop in the heat exchanger with three and four leaf and also baffle plates were designed as perforated. It has been determined that the HTC per pressure drop in the heat exchanger with a low number of leaves is higher than the heat exchanger with a higher number of blades [16].

Observations were made on the thermal performances of the heat exchangers, which were investigated numerically in STHE and designed in the style of segmented baffle plate and continuous helical baffle plate. It has been stated that the heat exchangers designed in the style of continuous helical baffle plate have higher thermal efficiency compared to the others and it can be observed that the maximum number of revolutions and the baffle plate spacing are equivalent [17].

Simulating the temperature, pressure and velocity distribution graphs on the baffle plates with the computational fluid dynamics method and numerical expressions for the Nusselt number and the friction coefficient are provided according to another research conducted at the university. When compared with the experimentally obtained data, it was observed that the mutual data were compatible with each other, and it could be determined that the decreases in the thermal characteristics of the heat exchanger were due to the absence of curved areas. However, as a plus effect of the flattening plates, it has been observed that the pressure drops are at lower levels compared to the curved plates [18].

It is important to consider the pressure loss and heat transfer in the selection of the baffle plates. When we do a literature research, the effects of baffle plates, which are one of the factors that affect the working efficiency of STHE, are encountered. The effects of using baffle plates that do not continue at regular intervals were examined and the effects of these angles were followed in terms of their effect on pressure drop and HTC. It has been understood that the small helix angles have a much greater pressure drop than the large ones, and likewise, the HTC is higher. It was also concluded that the best efficiency is in STHE with the highest helix angle of forty degrees [19].

As a result of the numerical examination of the performance of the heat exchanger using different types of baffle plates (one-piece, helical and flower type baffle), in the double-pipe-through-body-tube heat exchanger, not only the lowest HTC but also the pressure drop, as well as the highest heat transfer rate per pumping, could be determined with the flower type baffle plates used in STHE in the pumping part [20].

In this study, data on pressure drop, temperature and pressure distributions were obtained by using different types of designed baffle plates by performing 3D flow analysis via CFD of a STHE. The aim of the study is to test the effects of two different types of baffle plates of which are designed in different types on the pressure drop on the body side and heat transfer in STHE. The effects of four different flow rates, 1.2, 1.5, 1.8 and 2.1 kg/h, on the pressure drop on the body side and heat transfer, were observed in the traditional one-piece and perforated type baffle plate STHE. The results are visualized and interpreted through graphs and figures.

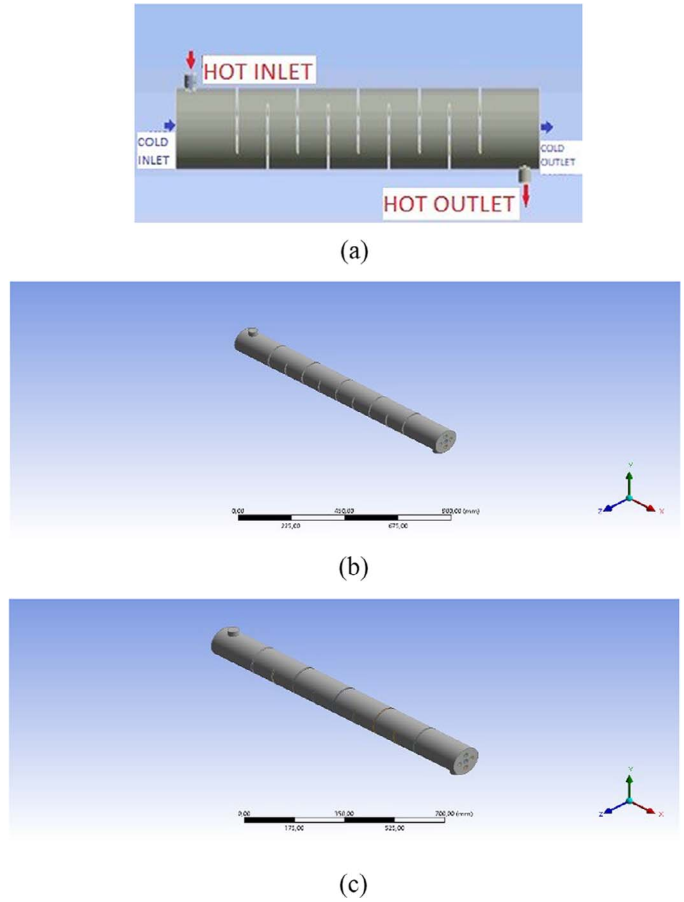


Figure 1. *(a) Inlet and outlet of working fluid.*

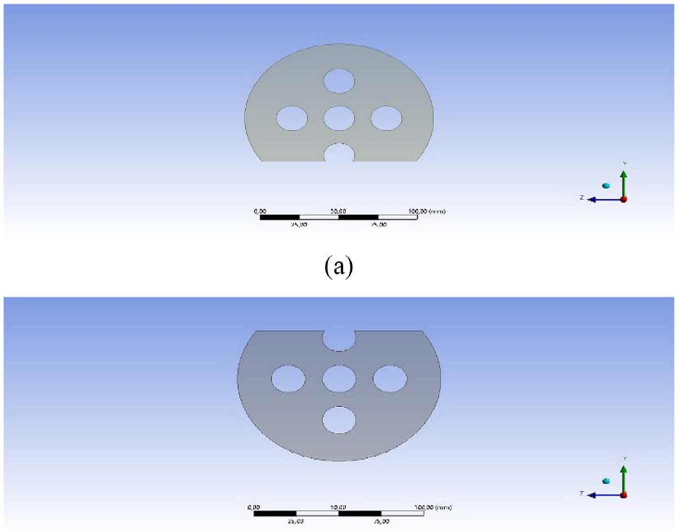
2 MATERIALS AND METHOD

In this study, three-dimensional flow analyses of STHE, in which the conventional one-piece type baffle plate is designed, and STHE with the perforated type baffle plate, in steady state, were made by means of a CFD software, ANSYS Fluent.

2.1 Model description

2.1.1 *Physical model*

A STHE is designed as a physical model to be used in analyses with a length of 1200 mm and a diameter of 120 mm with a single body and single pipe passage. The physical model of the designed STHE is given in Figure 1. The effects of the designed baffle plates on the heat convection coefficient occurring on the body side as well as the pressure drop that may occur were investigated, together with the design and testing of the traditional one-piece type baffle plate and the perforated type baffle plate in this STHE. The ones given in Figure 2 and Figure 3 are the visuals of the baffle plates, water is used as the working fluid in the analysis and its thermophysical properties are given in the next Table 1. The section containing the detailed geometrical properties of the designed STHE is given in Table 2.



(a)

(b)

Figure 2. *(a, b) Conventional one-piece type baffle plate.*

2.1.2 *Governing equations*

Realizable k-ε turbulence model is applied in the analysis parts for STHE, which is solved by using the finite volume method. Also, the expansion of momentum, k-ε, energy and continuity equations is given below:

Continuity equation:

$$\frac{\partial \mathrm{u_i}}{\partial \mathrm{x_i}} = 0 \tag{1}$$

Momentum equation:

$$\left(\frac{\partial \mathrm{u_i}\, \mathrm{u}_j}{\partial \mathrm{x_i}} = A\right) \tag{2}$$

$$A = -\frac{1}{\rho}\frac{\partial \mathrm{p}}{\partial \mathrm{x_i}} + \frac{\partial}{\partial \mathrm{x}_j}\left((\upsilon + \upsilon_\mathrm{t})\left(\frac{\partial \mathrm{u}_j}{\partial \mathrm{x_i}} + \frac{\partial \mathrm{u}_i}{\partial \mathrm{x_j}}\right)\right)$$

Energy equation:

$$\frac{\partial \mathrm{u_i}\, T}{\partial \mathrm{x_i}} = \rho\frac{\partial}{\partial \mathrm{x}_i}\left(\left(\frac{\upsilon}{\mathrm{Pr}} + \frac{\upsilon\mathrm{t}}{\mathrm{Pr}}\right)\frac{\partial T}{\partial \mathrm{x_i}}\right) \tag{3}$$

Turbulent kinetic energy (k) part:

$$\frac{\partial \mathrm{u_i}\, k}{\partial \mathrm{x_i}} = \frac{\partial}{\partial \mathrm{x}_i}\left[\left(\upsilon + \frac{\upsilon\mathrm{t}}{\sigma_k}\right)\frac{\partial k}{\partial \mathrm{x_i}}\right] + \Gamma - \varepsilon \tag{4}$$

Turbulent energy dissipation (ε) part:

$$\frac{\partial \mathrm{u_i}\, \varepsilon}{\partial \mathrm{x_i}} = \frac{\partial}{\partial \mathrm{x}_i}\left[\left(\upsilon + \frac{\upsilon\mathrm{t}}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial \mathrm{x_i}}\right] + \mathrm{c_1}\Gamma\varepsilon - \mathrm{c_2}\frac{\varepsilon^2}{k + \sqrt{\upsilon\varepsilon}} \tag{5}$$

Production of turbulent kinetic energy k; with 'Γ' is shown in equation 4 and equation 5.

$$\Gamma = -\overline{\mathrm{u_i}\, \mathrm{u}_j}\frac{\partial \mathrm{u_i}}{\partial \mathrm{x_i}} = \upsilon_\mathrm{t}\left(\left(\frac{\partial \mathrm{u}_i}{\partial \mathrm{x}_j} + \frac{\partial \mathrm{u}_j}{\partial \mathrm{x}_i}\right)\frac{\partial \mathrm{u}_i}{\partial \mathrm{x_i}}\right) \tag{6}$$

$$\upsilon_\mathrm{t} = \mathrm{c}_\mu\, \frac{k^2}{\varepsilon} \tag{7}$$

The details of the empirical constants for the $k{-}\varepsilon$ turbulence model used are given Table 3 below:

Empirical constants of the $k{-}\varepsilon$ turbulence model and c_μ are a function of average strain and rotational speed [12].

2.1.3 *Determination of boundary conditions in analysis*

In addition to the use of the standard wall functions method in the near-surface areas in the analyses performed, the non-slip boundary condition was also applied to all the surfaces. In addition, it is ensured that the analyses are carried out in the steady regime and based on pressure by ignoring the gravity. Any leaks that may exist between the inner surface of the body and the baffle plates are neglected to simplify the flow analysis. It is also among the assumptions that there is no heat transfer between the surrounding environment and the outer surface of the heat exchanger. The fluid used in analysis processes is water; in four different mass flow rates, 1.2, 1.5, 1.8 and 2.1 kg/h were examined. Finally, it is assumed that the water entering the system is at a temperature of 345 K and the pipe surface temperature is 300 K.

2.1.4 *Grid independence analysis*

The reason for performing the grid independence analysis; It was carried out to ensure the accuracy of the results obtained from CFD analyzes. Four different grid systems with 5 130 026, 5 801 362, 6 639 436, 6 188 502, 6 739 564, 7 285 007 and 7 705 237 elements have been created for STHE designed with a perforated type baffle plate. As a result of the comparison of the difference between the last two network systems at maximum mass flow in terms of pressure drop, it was determined that the difference was around 1%. Therefore, the analysis was carried out by accepting that the grid structure, which has 6 739 564 elements, is sufficient for the flow analysis process. The results generated from the grid independence analysis, where what has been done are visualized, are given in Figure 3(d) Grid Independence Analysis Results at page 5.

2.1.5 *Basic equations in analysis and data reduction*

The following basic equations were used to prepare the data obtained from the analyses [21]:

Body side heat transfer rate (Qs):

$$Q_s = m\,s\ \cdot\ cp,\ \cdot\ (Ts, -Ts, ut) \tag{8}$$

The HTC (hs) at body side is defined as:

$$h_s = \frac{Q_s}{A_s.\Delta \mathrm{T}_m} \tag{9}$$

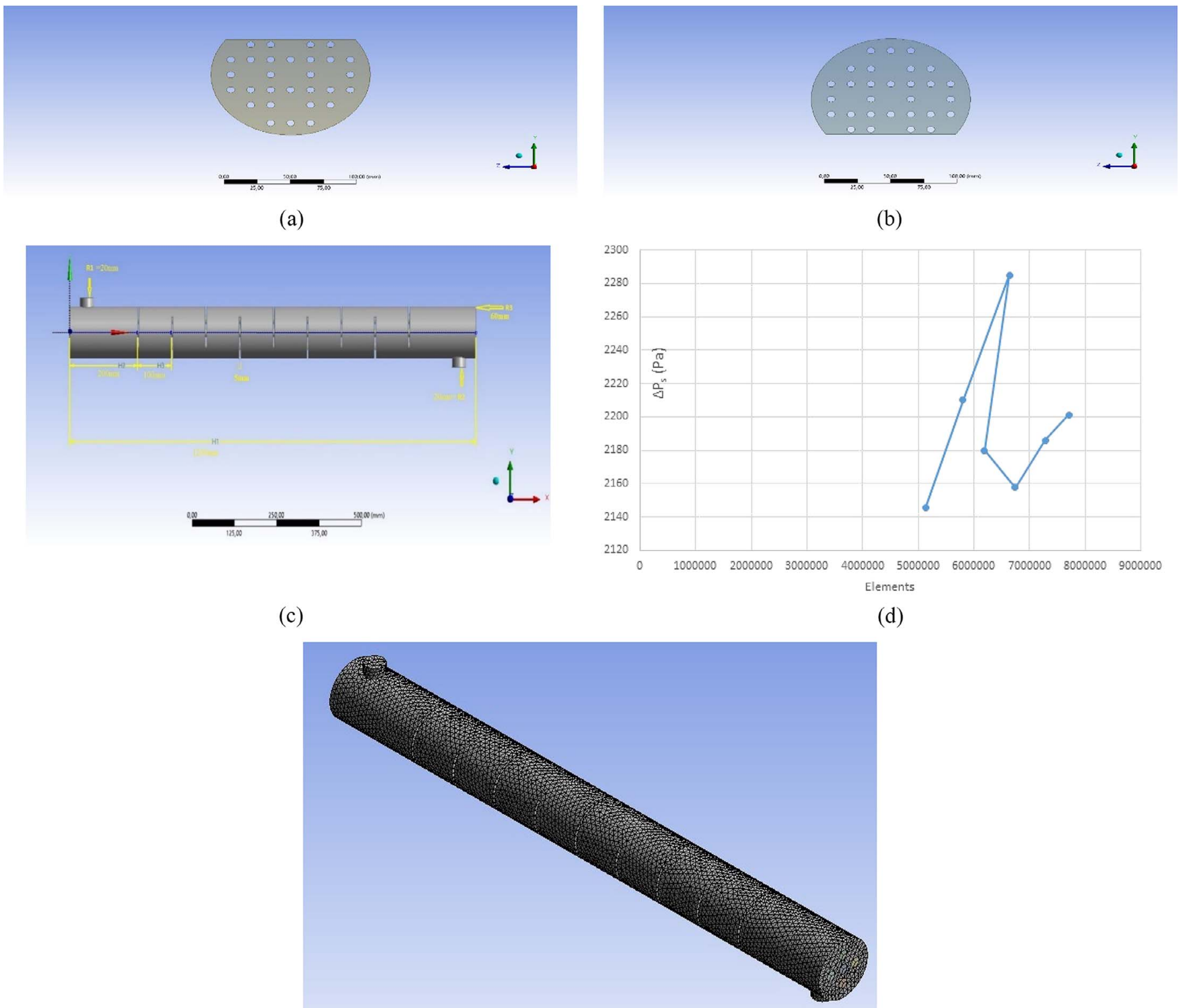


Figure 3. (a, b) Perforated type baffle plate, (c) computational geometry, (d) grid independence analysis results, (e) whole body mesh view.

Table 1. *Thermophysical properties of the working fluid.*

Water (345°K)	
ρ: 976.1 **(kg/m^3)**	c_p: 4191.5 **(J/kg°C)**
μ: 0.000391 **(kg/m s)**	**K:** 0,665 **(W/m°C)**

Table 2. *Detailed geometrical dimensioning of the shell and tube heat exchanger.*

A	B	A	B	A	B
Body		**Pipe**		**Baffle plate**	
C	120	**C**	20	**J**	9
E	1200	**J**	5	**Type**	K
D	1	**D**	1	**H**	5
F		**G**	30	**G**	100
C	40	**O**	Square		
E	20				

Table 3. *Empirical constants of the k−ε turbulence model.*

$\sigma_\varepsilon = 1.2$	$\sigma_k = 1.0$
$c_{1=}$ max$[43{*}10^{-2}, \mu{*}(\mu_t + 5.0)^{-1}]$	$c_{2=}1.9$

The heat transfer area (As):

$$A_s = N \cdot \pi \cdot d0 \cdot L \tag{10}$$

The logarithmic mean temperature difference (ΔTm) between the fluid and tube walls can be expressed by the following equation:

$$\Delta T_m = \frac{\Delta T_{max} - \Delta T_{min}}{\ln \frac{\Delta T_{max}}{\Delta T_{min}}} \tag{11}$$

The maximum temperature difference ($\Delta Tmax$):

$$\Delta Tmax = Ts, -Tw \tag{12}$$

The minimum temperature difference ($\Delta Tmin$):

$$\Delta Tmin = Ts, -Tw \tag{13}$$

3 RESULTS AND DISCUSSIONS

In the results of flow analysis using figures and graphics, temperature and pressure distributions are shown on a plane drawn along the center of STHE. As a first analysis, the temperature distributions of the heat exchanger with a conventional one-piece type baffle plate and the heat exchanger designed with a perforated type baffle plate were examined at maximum mass flow rate. Figure 4 and Figure 5 show the variation of these temperature distributions.

Table 4. *Mesh properties of the selected grid structure.*

Nodes	13 220 346
Elements	6 739 564
Element size	0.01
Growth rate	1.2
Mesh defeaturing	Yes
Defeature size	Default
Inflation option	Smooth transition
Target skewness	0.9
Smoothing	High

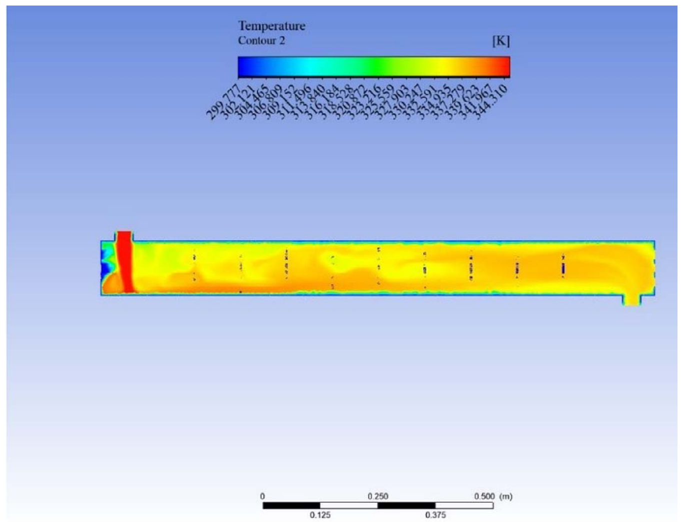


Figure 4. *Temperature distribution of perforated type baffle plate heat exchanger at maximum mass flow rate = 2.1.*

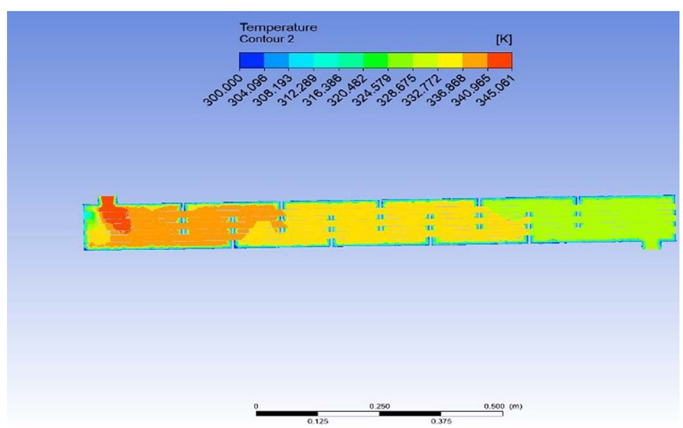


Figure 5. *Temperature distribution of conventional type baffle plate heat exchanger at maximum mass flow rate = 2.1.*

In the next analysis, an examination was made on the outlet temperature. It has been observed that the outlet temperature of the heat exchanger designed with a perforated type baffle plate is at a higher point than the outlet temperature obtained in the heat exchanger with a conventional one-piece type baffle plate.

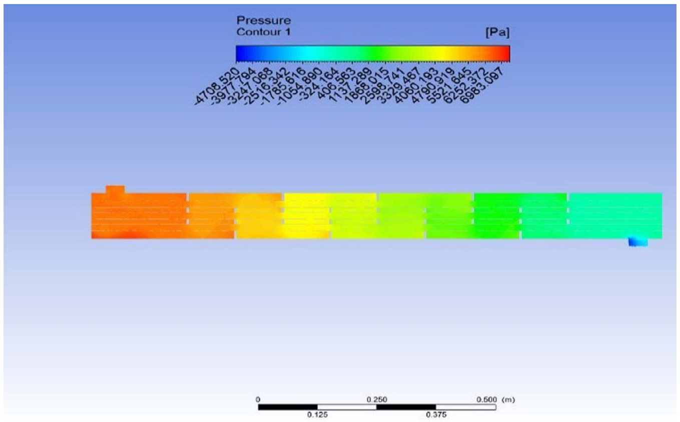


Figure 6. *Pressure distribution of conventional type baffle plate heat exchanger at maximum mass flow rate = 2.1.*

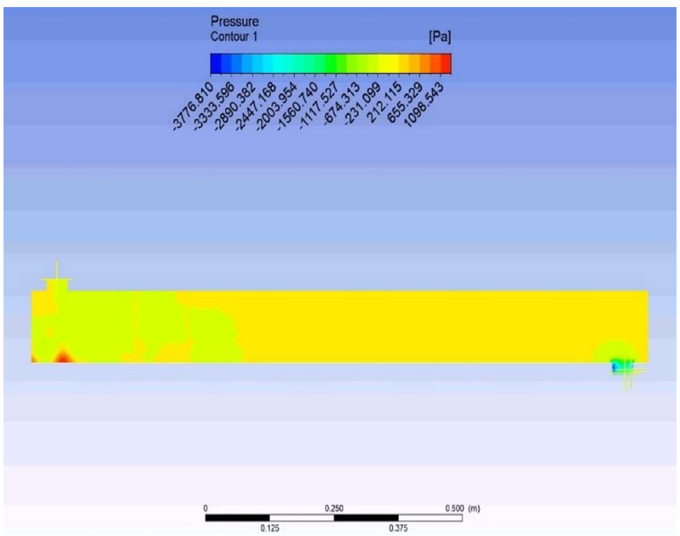


Figure 7. *Pressure distribution of perforated type baffle plate heat exchanger at maximum mass flow rate = 2.1.*

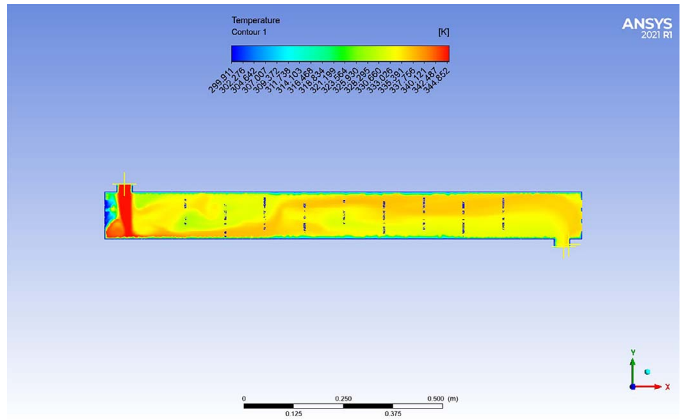


Figure 8. *Temperature distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.8.*

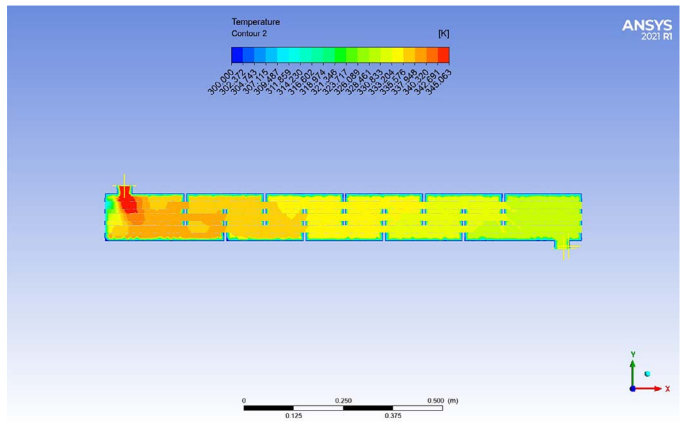


Figure 9. *Temperature distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.8.*

Table 5. *Analysis results when the flow rate of the heat exchangers is at 2,1 kg/h*

Baffle plate type	Mass flow rate (kg/h) $[\dot{m}i\ s]$	$T_{c2,HAD}$ (K)	h_{HAD} ($Wm^{-2}\ K^{-1}$)	ΔP_{HAD} (Pa)
Perforated	2.1	328.81	4055.7	2157.5912
Conventional	2.1	316.767	11499.2	8819.11

Table 6. *Analysis results when the flow rate of the heat exchangers is at 1,8 kg/h*

Baffle plate type	Mass flow rate (kg/h) $[\dot{m}i\ s]$	$T_{c2,HAD}$ (K)	h_{HAD} ($Wm^{-2}\ K^{-1}$)	ΔP_{HAD} (Pa)
Perforated	1.8	329.111	3476.3	1600.44704
Conventional	1.8	316.472	10033.7	6690.24

In the analysis, the pressure distributions of two different types of heat exchangers at maximum mass flow rate were examined. The pressure drop of the heat exchanger designed with a perforated type baffle plate is lower than that of the heat exchanger equipped with a conventional one-piece type baffle plate at maximum flow rate. The results of this analysis are shown in Figure 6 and Figure 7.

As a result of the analysis, the number of baffle plates in the body is taken as 9, and the flow rates are taken as 2.1 kg/h, and the results are given as temperature and pressure distributions in Table 5 with the figures below. Number of baffle plates: Nb = 9, distance between baffle plates: dg = 100 *mm*, numerical analysis results of shell-tube type heat exchangers are given in Table 5.

It is observed that the variation of outlet temperature is $T_{c2,HAD}$ (K), HTC is h_{HAD} ($Wm^{-2}\ K^{-1}$) and the pressure drop is ΔP_{HAD} (Pa) in Table 5 in the case where the mass flow rate of the fluid in the body is $\dot{m}is$= 2.1 kg/h. Accordingly, while the outlet temperature increased in the STHE with a perforated type baffle plate, the HTC decreased. And also, it is seen that the pressure drop in

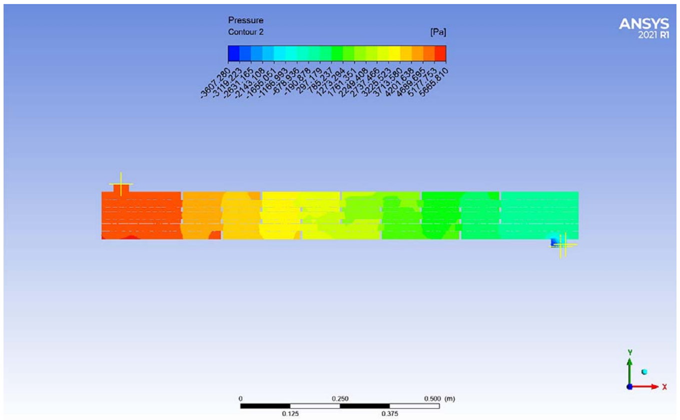


Figure 10. *Pressure distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.8.*

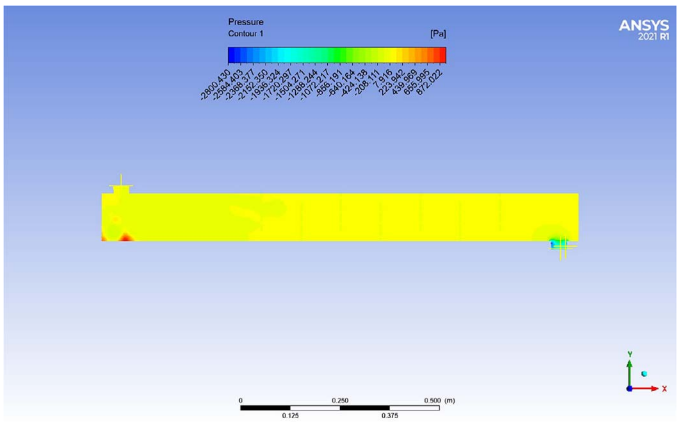


Figure 11. *Pressure distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.8.*

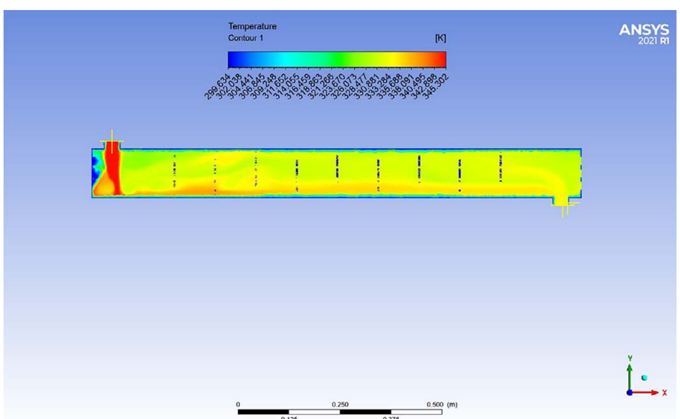


Figure 12. *Temperature distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.5.*

the conventional type heat exchanger is higher than the perforated type STHE.

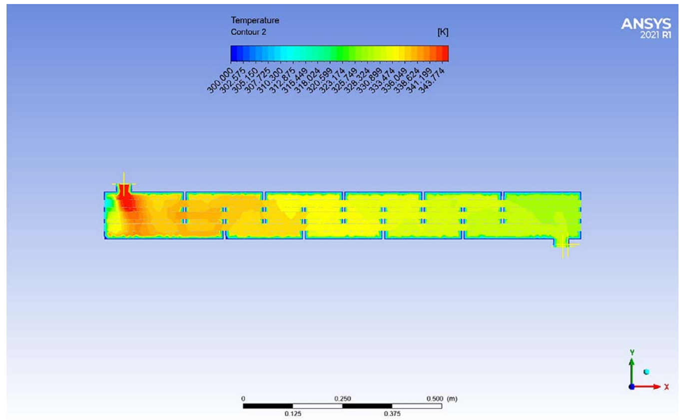


Figure 13. *Temperature distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.5.*

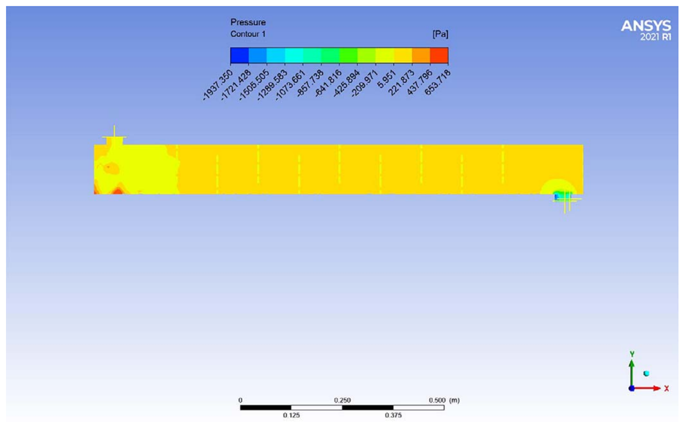


Figure 14. *Pressure distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.5.*

Table 7. *Analysis results when the flow rate of the heat exchangers is at 1,5 kg/h*

Baffle plate type	Mass flow rate (kg/h) [$\dot{mi}$ s]	$T_{c2,HAD}$ (K)	h_{HAD} (Wm^{-2} K^{-1})	ΔP_{HAD} (Pa)
Perforated	1.5	326.794	2896.9	1100.540881
Conventional	1.5	316.211	8494.3	4793.56

As a result of the analysis, the number of baffle plates in the body is taken as 9, and the flow rates are taken as 2.1 kg/h, and the results are given as temperature and pressure distributions in Table 6 with the figures below. Number of baffle plates: $Nb = 9$, distance between baffle plates: dg = 100 mm, numerical analysis results of shell-tube type heat exchangers are given in Table 6.

It is observed that the variation of outlet temperature is $T_{c2,HAD}$ (K), HTC is h_{HAD} (Wm^{-2} K^{-1}) and the pressure drop is ΔP_{HAD} (Pa) in Table 6 in the case where the mass flow rate of the fluid in the body is $\dot{mi}s$ = 2.1 kg/h. Accordingly, while the outlet temperature increased in the STHE with a perforated type baffle plate, the HTC decreased. And also, It is seen that the pressure

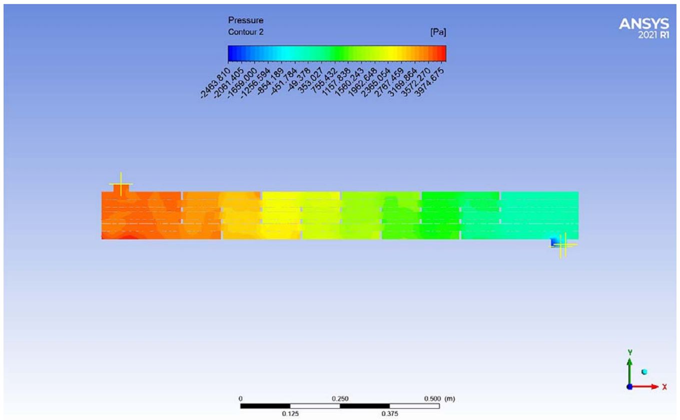


Figure 15. *Pressure distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.5.*

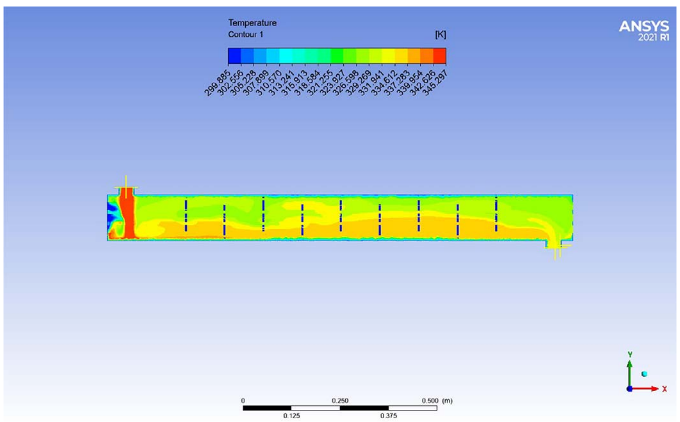


Figure 16. *Temperature distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.2.*

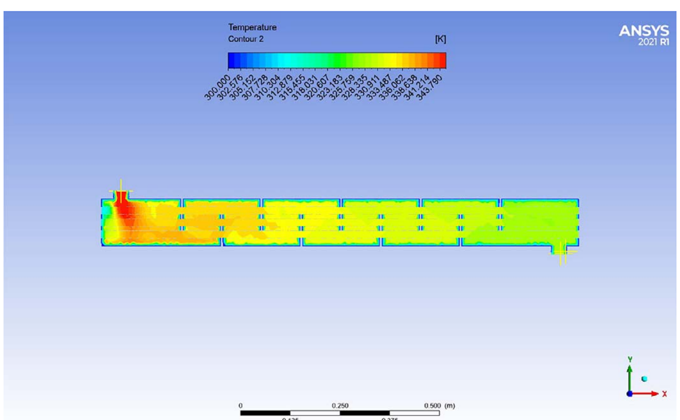


Figure 17. *Temperature distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.2.*

drop in the conventional type heat exchanger is higher than the perforated type STHE.

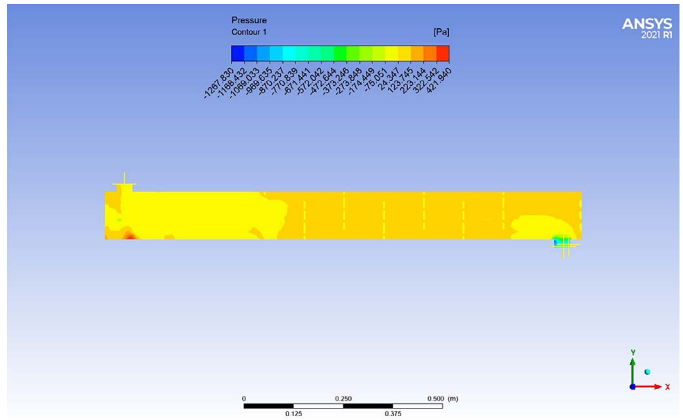


Figure 18. *Pressure distribution of perforated type baffle plate heat exchanger at mass flow rate = 1.2.*

Table 8. *Analysis results when the flow rate of the heat exchangers is at 1,2 kg/h*

Baffle plate type	Mass flow rate (kg/h) [$\dot{m}$ s]	$T_{c2,HAD}$ (K)	h_{HAD} ($Wm^{-2}\ K^{-1}$)	ΔP_{HAD} (Pa)
Perforated	1.2	326.223	2317.5	702.4321
Conventional	1.2	315.862	6940.3	3215.429

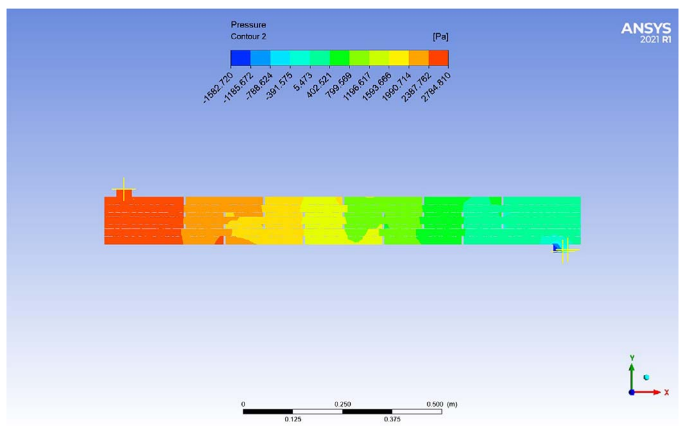


Figure 19. *Pressure distribution of conventional type baffle plate heat exchanger at mass flow rate = 1.2.*

As a result of the analysis, the number of baffle plates in the body is taken as 9, and the flow rates are taken as 2.1 kg/h, and the results are given as temperature and pressure distributions in Table 7 with the figures below. Number of baffle plates: $Nb = 9$, distance between baffle plates: dg = 100 *mm*, numerical analysis results of shell-tube type heat exchangers are given in Table 7.

It is observed that the variation of outlet temperature is $T_{c2,HAD}$ (K), HTC is h_{HAD} ($Wm^{-2}\ K^{-1}$) and the pressure drop is ΔP_{HAD} (Pa) in Table 7 in the case where the mass flow rate of the fluid in the body is $\dot{m}is$ = 2.1 kg/h. Accordingly, while the outlet temperature increased in the STHE with a perforated type baffle plate, the HTC decreased. And also, it is seen that the pressure

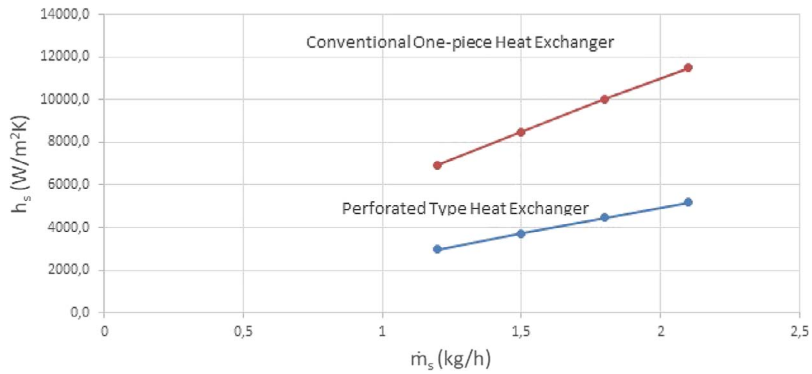


Figure 20. *Results of variation of heat transfer coefficient with mass flow rate.*

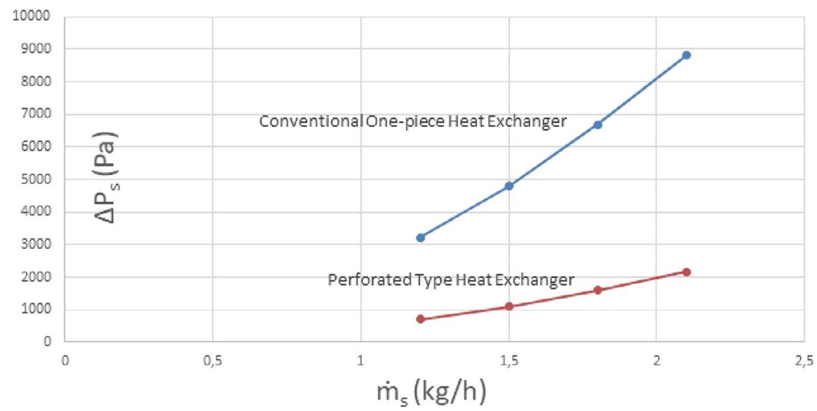


Figure 21. *Results of variation of pressure drop with mass flow.*

drop in the conventional type heat exchanger is higher than the perforated type STHE.

As a result of the analysis, the number of baffle plates in the body is taken as 9, and the flow rates are taken as 2.1 kg/h, and the results are given as temperature and pressure distributions in Table 8 with the figures below. Number of baffle plates: Nb = 9, distance between baffle plates: dg = 100 *mm*, numerical analysis results of shell-tube type heat exchangers are given in Table 8.

It is observed that the variation of outlet temperature is $T_{c2,HAD}$ (K), HTC is h_{HAD} (Wm^{-2} K^{-1}) and the pressure drop is ΔP_{HAD} (Pa) in Table 8 in the case where the mass flow rate of the fluid in the body is $m\dot{i}s$ = 2.1 kg/h. Accordingly, while the outlet temperature increased in the STHE with a perforated type baffle plate, the HTC decreased. And also, it is seen that the pressure drop in the conventional type heat exchanger is higher than the perforated type STHE.

The differentiation curves of the mass flow rate of the fluid on the body side and HTC are seen in Figure 20 separately according to the type of the baffle plate. With the analysis, it has been observed that heat convection coefficient varies in all cases and raises with the increase of the mass flow rate in all cases. As a result of the analysis of HTC, it was observed that HTC of the heat exchanger designed with one-piece baffle plate was higher than the result of the analysis made with the heat exchanger equipped with a perforated type baffle plate. This can be express by the fact that the flow rehabilitates and improves the heat transfer by creating a zigzag movement between the pipe bundles by means of the one-piece baffle plates.

The pressure drop criterion has a significant place in the design of STHE, which are widely used in the facilities, and it is an important criterion to be considered because it is in direct contact with the pumping cost. In the analysis made according to the baffle plate types, the variation of the mass flow rate of the fluid on the body side and the pressure drop is detailed in Figure 21. When we make the conditions for both heat exchangers the same, in addition to the realization of pressure-related decrease in connection with the rise in mass flow rate in both types of heat exchangers in analysis made with the heat exchanger designed with a conventional one-piece baffle plate and the heat exchanger equipped with a perforated type baffle plate; it's been observed that the pressure drop of the heat exchanger equipped with a perforated type baffle plate is less than the heat exchanger designed with a conventional one-piece baffle plate.

Another important criterion in determining the thermohydraulic performance of fluids is the heat transfer rate per pressure drop. The results of the heat transfer rate per pressure drop, which varies depending on mass flow in the horizontal axis according to the baffle plate type, are shown in Figure 22. Accordingly, in the

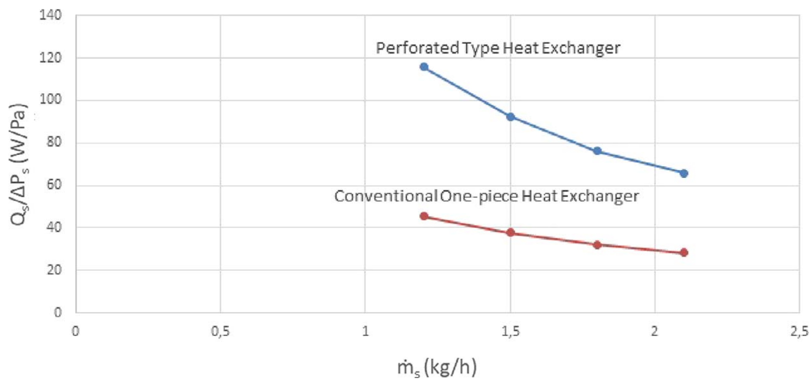


Figure 22. *Results of variation of heat transfer rate per pressure drop with mass flow rate.*

analysis made, it was observed that the heat exchanger equipped with a perforated type baffle plate was higher than the heat transfer rate per pressure drop in the analysis results made with the heat exchanger designed with a conventional one-piece baffle plate.

4 CONCLUSIONS

In this study, the effects of conventional one-piece baffle plate and perforated type baffle plate on the pressure drop and heat transfer on the body side of STHE were analysed numerically, and the analysis results were enriched with figures.

Analyses were made to investigate the effects of HTC and pressure drop. As a result, it's been determined that the pressure drop and HTC increase with the rise in the mass flow rate of the fluid on the body side.

Beside to the analysis results of the heat exchanger equipped with a perforated type baffle plate, both the pressure drop and HTC are lower crosscheck to the analysis outcomes made with the heat exchanger designed with a traditional one-piece baffle plate, and it has been determined that the results of the analysis performed to observe the change of the heat transfer rate per pressure drop of the heat exchanger equipped with a perforated type baffle plate are higher than the heat exchanger designed with a traditional one-piece baffle plate.

In another analysis, if the tested mass flow rate of the heat exchanger equipped with a perforated type baffle plate is 1.2 kg/h, the highest proportional value was determined as the heat transfer rate per pressure drop compared to other flow rates. Thus, the heat transfer rate per pressure drop, for the perforated type baffle plate; it has been concluded that it can be improved between 39% and 42% with the traditional one-piece baffle plate.

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