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Original Research Article

# Performance analysis of the plate heat exchangers for heating systems



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**ABSTRACT**

In this work, thermodynamic analysis of the plate heat exchangers was carried out as experimentally. An experimental heating system with a plate heat exchanger (PHE) was designed and set up for this aim. Thermodynamic analysis of the experimental system at different temperatures and three different flow rates was carried out. The heat transfer rate and effectiveness values are calculated and obtained results were presented. As a result of the study, it was determined that the heat transfer rate increased for each of the three flow rates in PHE with increased inlet hot water temperature. According to the results of experiments, the highest heat transfer rate which is 2.5 kW, was obtained from a flow rate of 0.239 kg/s. The highest efficiency value was obtained as 44% for this fluid flow rate. It has been seen that the flow rate of 0.321 kg/s, which has the highest heat transfer and efficiency value mathematically, is not suitable for the PHE sizes used.

*Keywords:* Effectiveness; Experimental; Plate heat exchangers; Thermodynamic analysis

## 1. Introduction

Today, heat recovery constitutes the most important process of energy applications. In this process, the most used heat recovery device is heat exchangers. Among the heat exchanger types, plate heat exchangers (PHE), which offer many superior features compared to others, are the most preferred ones. PHEs are used in a wide range from the chemical industry to comfort systems. PHEs have very good heat transfer properties and have a compact structure and can be used in very different heat capacity ranges. PHEs can be formed from many plates with different surface geometries. Especially, the chevron angles of the plates are the most important parameters that affect the heat transfer rate and effectiveness of the PHE.

Gut et al. have investigated the relation to the heat transfer with the flow distribution in the PHEs. As a result, they have found that relationship as experimentally [2]. Riverol et al. have tried to estimate the average heat transfer coefficient, the critical time, and the layer thickness in the PHEs using ANNs. As a result of their work, they identified that the results are suitable for the current industry practice techniques [3]. Zhu et al. have studied the optimum flow rate and the optimum design in the PHEs used in geothermal heating systems. Their study, identified the optimum design and the flow rate with the help of a computer program. Furthermore, they have shown how to select the PHEs [4]. Bansal et al. have investigated the PHEs for two different plate geometry. In this study, they have focused on the three parameters. These parameters are the flow rate, volume and surface temperature. They have identified a strong relationship between the flow and plate geometry [5]. Dwivedi et al. have worked on the performance of the PHEs for different types of flow. As a result, they are determined that poor distribution of flow is a negative impact on the performance of the heat exchanger [6]. Tae-Woo et al. used a plate heat exchanger as the evaporator and condenser in the organic Rankine cycle. They made the thermodynamic analysis of this system. As a result of the study, they obtained a correlation for heat transfer and compared this correlation with the literature [7]. Mohamed et al. used an adaptive neuro-fuzzy inference system to improve the heat transfer coefficient in a heat exchanger. Experimental results show that the proposed method has a high predictive ability [8]. Bhupal et al. investigated the effects of geometric parameters on hydraulic and thermal performance in the plate heat exchanger. They showed that the chevron angle affects the fluid flow distribution in the channels, and in this case, affects the thermal performance of the plate heat exchanger [9]. In this study, in order to contribute to the literature, a thermodynamic analysis of a plate heat exchanger with a plate surface angle of 30° was carried out for different temperatures and flow rates.

## 2. Experimental System

The experimental system, a heater with a thermostat-controlled at a set temperature, can operate at three different flow rates. The experimental setup consists of PHE, boiler, valves, two heaters, two pumps, flow meter, expand box, thermocouples and datalogger. The heater heats water and sends it to the PHE using a pump when the experimental system is operated. Water from the hot water tank inputs the PHE by the means of a pump. Afterward, heat transfer occurs between two fluids in PHE. Heated water returns to the hot water tank while cooled water returns to the boiler. A schematic diagram of a heating system with a PHE is given in Fig. 1. The experimental system is shown in Fig. 2. Also, the general specifications of the PHE were shown in Table 1.

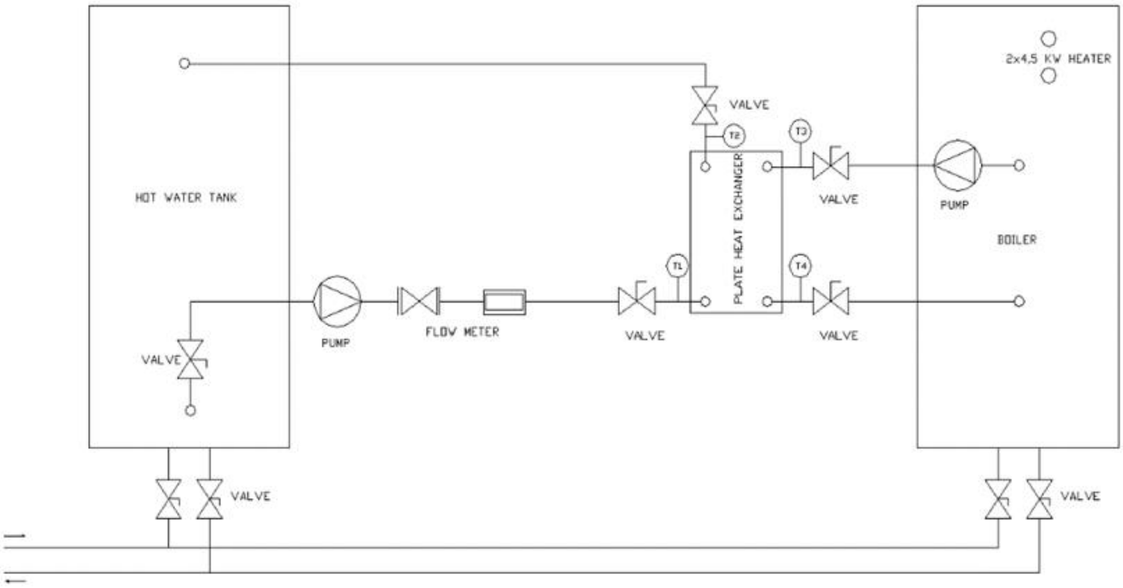


**Figure 1.** Schematic diagram of heating system with PHE

**Figure 2.** Experimental system

**Table 1.** General properties of the PHE

| | |
|---|---|
| Length [mm] | 431 |
| Width [mm] | 125.5 mm |
| Plate material | 0.5 mm SS AISI 316 |
| Angle [°] | 30 |
| Gasket material | EPDM per. |
| Design Temperature [ºC] | 145 |
| Design pressure [bar] | 10 |

## 3. Thermodynamic Analysis

The heat transfer rate in the PHE is expressed as [10-12] (Eq. 1-3):

$$\dot{Q} = \dot{m}_h c_{ph}(T_{hi} - T_{ho}) = \dot{m}_c\, c_{pc}\,(T_{ci} - T_{co}) \quad (1)$$

$$\dot{Q} = UA\Delta T_{LMTD} \quad (2)$$

$$\Delta T_{LMTD} = \frac{(T_{hi}-T_{co})-(T_{ho}-T_{ci})}{ln\frac{(T_{hi}-T_{co})}{(T_{ho}-T_{ci})}} \quad (3)$$

Maximum heat capacity for fluids in PHE is [11] (Eq. 4-5):

$$C_h = \dot{m}_h c_{ph} \quad (4)$$

$$C_c = \dot{m}_c c_{pc} \quad (5)$$

The effectiveness of PHE is given as [13]:

$$\varepsilon = \frac{\dot{Q}}{\dot{Q}_{max}} \quad (6)$$

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Here the peak possible heat transfer rate $Q_{max}$ is determined as [13]:

$$\dot{Q}_{max} = C_{min}(T_{hi} - T_{ci}) \quad (7)$$

## 4. Results and Discussion

The plate surface angle of the PHE used in the experimental system is 30 degrees. The boiler's thermostat in the experimental system is set to 60 °C. Inlet-outlet temperatures of heated and cooled water are set as the temperature of the network water. Circuit of heated water was targeted to reach the water temperature of 60 °C. The pump in the system was set to the first stage. The flow rate was determined as 0.167 kg/s. The total heat transfer rate in the PHE was calculated and shown in Fig. 3. It is seen that the highest heat transfer rate for these operating conditions is approximately 2250 W.

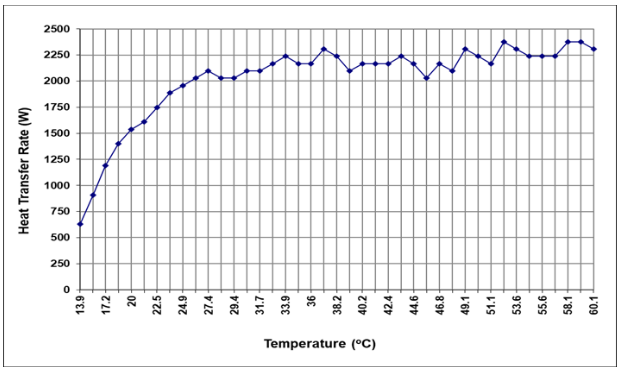


**Figure 3.** Variation of heat transfer rate depending on inlet hot water temperature ($\dot{m}$=0.167 kg/s)

The effectiveness of the PHE is calculated and shown in Fig. 4. It was determined that the effectiveness of PHE increases with increasing inlet hot water temperature. In this experiment, the average effectiveness value was obtained as %42.

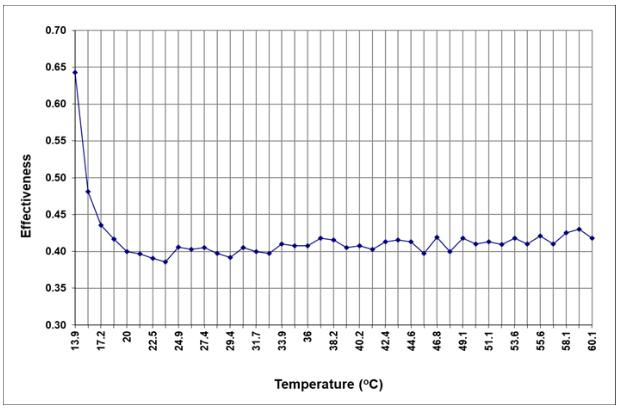


**Figure 4.** Variation of effectiveness depending on inlet hot water temperature ($\dot{m}$=0.167 kg/s)

In the next experiment, the experimental system variables are kept constant but the pump in the system is set to the second stage. The flow rate is determined as 0.239 kg/s. The total heat transfer rate in the PHE was calculated and shown in Fig. 5. It was determined that the heat transfer rate increases with increasing inlet hot water temperature. Figure 5 shows that the highest heat transfer rate for these operating conditions is approximately 2500 W.

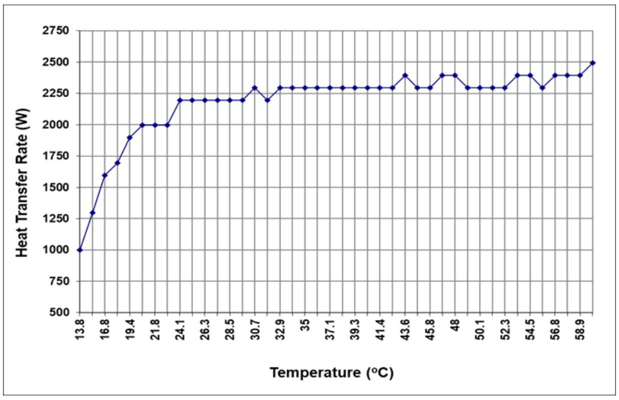


**Figure 5.** Variation of heat transfer rate depending on inlet hot water temperature ($\dot{m}$=0.239 kg/s)

The effectiveness of the PHE is calculated and shown in Fig. 6. It was determined that the effectiveness increases with increasing inlet hot water temperature. The average effectiveness value was obtained as %44. The effectiveness value increased by 2% with the increasing flow as a result of the pump stage being set to 2.

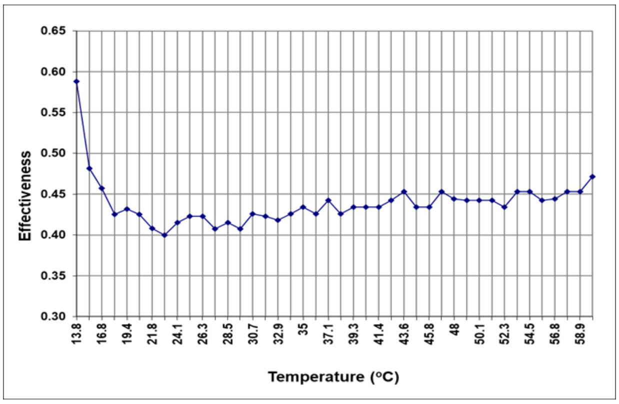


**Figure 6.** Variation of effectiveness depending on inlet hot water Temperature ($\dot{m}$=0.239 kg/s)

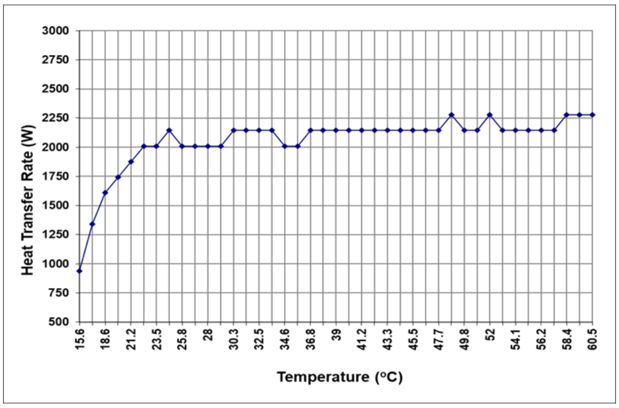


**Fig. 7.** Variation of heat transfer rate depending on inlet hot water temperature ($\dot{m}$=0.321 kg/s)

In the final experiment, experimental system variables are kept constant but the pump in the system is set to the second stage. The flow rate is determined as 0.321 kg/s. The total heat transfer rate in the PHE was calculated and shown in Fig. 7. It was determined that the heat transfer rate increases with increasing inlet hot water temperature.

The effectiveness of the PHE is calculated and shown in Fig. 8. It was determined that the effectiveness increases with increasing inlet hot water temperature. The highest effectiveness was obtained at about %48 for these working conditions. In figure 8, it was seen that the average effectiveness values were below the value of 44%.

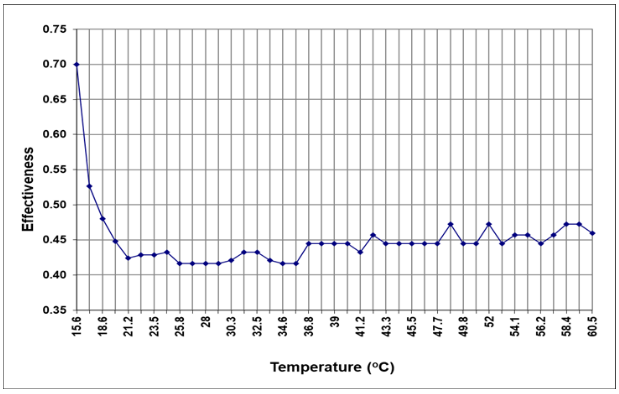


**Figure 8.** Variation of effectiveness depending on inlet hot water temperature ($\dot{m}$=0.321 kg/s)

The heat transfer rate in the PHE is calculated for different flow rates and shown in Fig. 9. It was determined that the heat transfer rate increased for each of the three flow rates in PHE with increased inlet hot water temperature. In addition, when the flow rate in the PHE raises from 0.167 kg/s to 0.239 kg/s, the heat transfer rate was raised as expected. However, when the flow rate in the PHE raised to 0.321 kg/s, it was determined that the heat transfer rate is decreased. In this case, it was determined that the size of the PHE was not sufficient for this flow rate. As the result of experiments, the peak heat transfer rate was obtained from a flow rate of 0.239 kg/s. Therefore, the most suitable working conditions were determined as these working conditions.

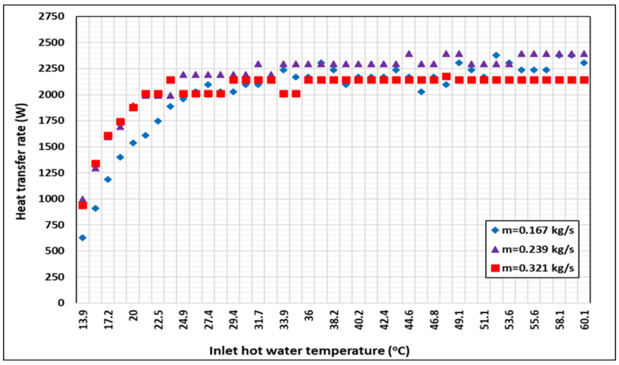


**Figure 9.** Variation of heat transfer rate depending on inlet hot water temperature

## 5. Conclusions

In this work, thermodynamic analysis of the PHEs was carried out as experimentally. An experimental heating system with PHE was designed and set up for this aim. Thermodynamic analysis of the experimental system at different temperatures and three different flow rates was carried out. The heat transfer rate and effectiveness values are calculated and obtained results were presented. As a result of the study, it was determined that the heat transfer rate increased for each of the three flow rates in PHE with increased inlet hot water temperature. According to the results of experiments, the highest heat transfer rate which is 2.5 kW, was obtained from a flow rate of 0.239 kg/s. The highest efficiency value was obtained as 44% for this fluid flow rate. PHEs are broadly used in chemical, heating and cooling systems, and thermal power plants. It must be determined optimum operating conditions of the heat exchangers for these facilities to increase energy efficiency and hence contribute to the energy economy can provide. Results of this work, optimum operating conditions, design and manufacture of the systems used in the PHE will contribute to practices in the future.

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**Authorship contribution statement for Contributor Roles Taxonomy**

Bayram Kılıç and Osman İpek designed the structure. Bayram Kılıç carried out the experiments work, the theoretical calculations, in collaboration with Osman İpek, and wrote up the article. Osman İpek is the overall supervisor of the project. Both authors read and approved the manuscript.

**Conflict of interest**

The author(s) declares that he has no conflict of interest.

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