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SECOND LAW ANALYSIS OF A PLATE HEAT EXCHANGER

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Abstract

In the present paper, second law analysis of plate heat exchangers has been carried out. For this, heating-cooling system with plate heat exchanger was experimentally designed. First law and second-law analysis of experimental plate heat exchanger in the different temperature and flow rate values were carried out. The heat transfer rate and irreversibility values depending on the inlet hot water and inlet cold water temperatures are calculated. Obtained results were graphically presented.

Keywords: Plate heat exchanger, Thermodynamic analysis, second law analysis

1. Introduction

Heat exchangers transfer the heat continuously from one fluid to another without using any energy. Plate heat exchangers are widely used in warming, heating, cooling applications, food, and cosmetic and chemistry. The plate heat exchanger is widely recognized today as the most economical and efficient type of heat exchanger on the market. With its low cost, flexibility, easy maintenance, and high thermal efficiency it is unmatched by any type of heat exchanger. Plate heat exchanger consists of a number of gasketed plates which are fixed between a top carrying bar and a lower guide bar. The plates are compressed by means of tie bolts between a stationary frame part (called the head) and a movable frame part (called the follower). Fluids enter the plate heat exchanger through frame connections and are distributed to plates. The flow to alternate passages between the plates is controlled by alternating the placement of gaskets. In Fig.1, principles of flow and heat transfer in a plate heat exchanger are shown [1-3].

2. Experimental System

The experimental system was operated for heating and cooling case. The experimental set-up used in this investigation is shown in Fig. 2. The experimental setup consists of plate heat exchanger for heating case, plate heat exchanger for cooling case, two heater, hot water tank, refrigeration system with compressor, cold water tank, flow meters, pumps, valves, expand box, thermocouples. The plate heat exchangers used in experiments are in countercurrent flow [4]. Further details of the experimental procedure can be found in Ref. [5].

Fig.1. Principles of flow and heat transfer in a plate heat exchanger.

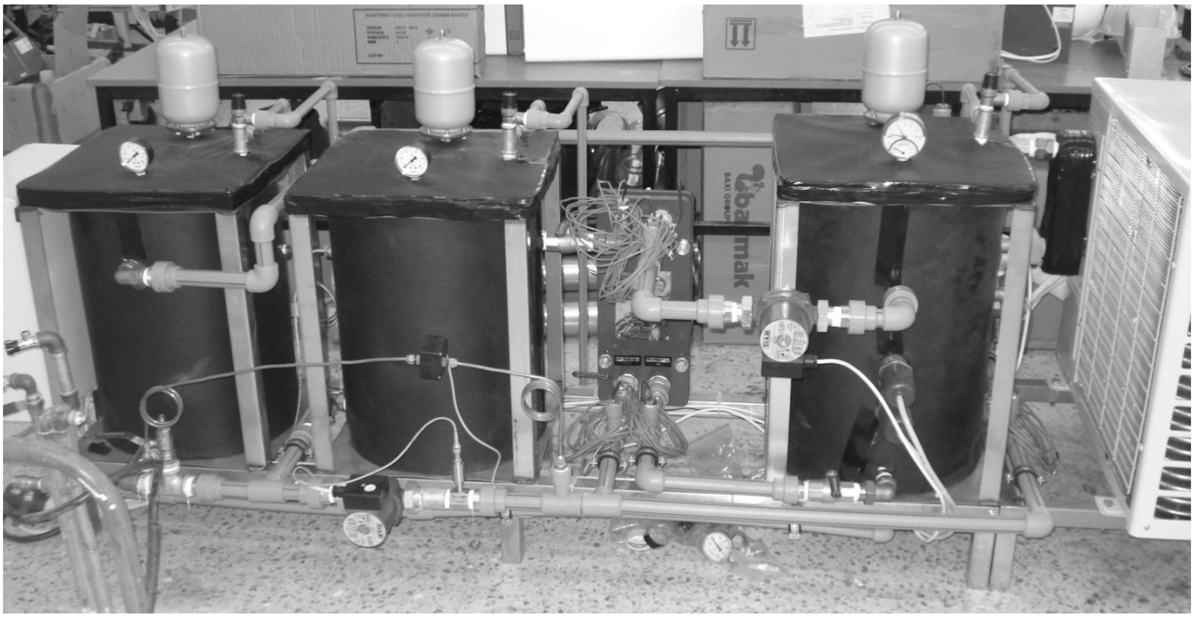

Fig.2. The experimental system

3. First and second law analysis

3.1. The first law analysis

The first law of thermodynamic deals with the quantity of energy and asserts that energy cannot be created and destroyed. The second law, however, deals with quality of energy. The heat transfer rate in the heat exchanger is defined as [6,7]:

$$Q = \dot{m}_h . c_{ph} . (t_{hi} - t_{ho}) = \dot{m}_c . c_{pc} . (t_{ci} - t_{co}) \tag{1}$$

Heat capacity for hot and cold fluids [6,7]:

$$C_{hot} = \dot{m}_h . c_{ph} \tag{2}$$

$$C_{cold} = \dot{m}_c . c_{pc} \tag{3}$$

The effectiveness of heat exchanger is given as [6,7]:

$$\varepsilon = \frac{Q}{Q_{max}} \tag{4}$$

Here the maximum possible heat transfer rate Q_{max} is determined as [6,7]:

$$Q_{max} = C_{min} . (t_{hi} - t_{ci}) \tag{5}$$

where C_{min} represents the smaller of heat capacity for hot and cold fluids.

3.2. The second law analysis

Due to inherent irreversibility, engineering systems are not capable of following a reversible course, which would have been most efficient thermodynamically. Thus, irreversibility can be considered as the loss of exergetic potential. The exergy fed to a heat exchanger is destroyed due to two main reasons [8-12]:

1. Lack of thermal equilibrium arising out of finite temperature difference in and outside the apparatus.
2. Dissipative effect of fluid friction.

The flow exergy can be expressed with negligible kinetic and potential energies as [13-15]:

$$\psi = (h - h_o) - T_o (s - s_o) \tag{6}$$

where h is the enthalpy, s is the entropy and the subscript zero indicates properties at the dead state of P_0 and T_0.

Entropy generation can be written as [13-15]:

$$S_{gen} = \sum m_o s_o - \sum m_i s_i - \sum \frac{Q}{T} \tag{7}$$

The irreversibility rate from the following equation can be calculated [13-15]:

$$I = T_0 \, S_{üretim} \tag{8}$$

4. Results and discussion

Fig. 3 illustrates the variation of the effectiveness value with inlet hot water temperature for 1,05 m^3/h volume flow rate. As seen in Fig.3, the effectiveness value increase with increasing inlet hot water temperature.

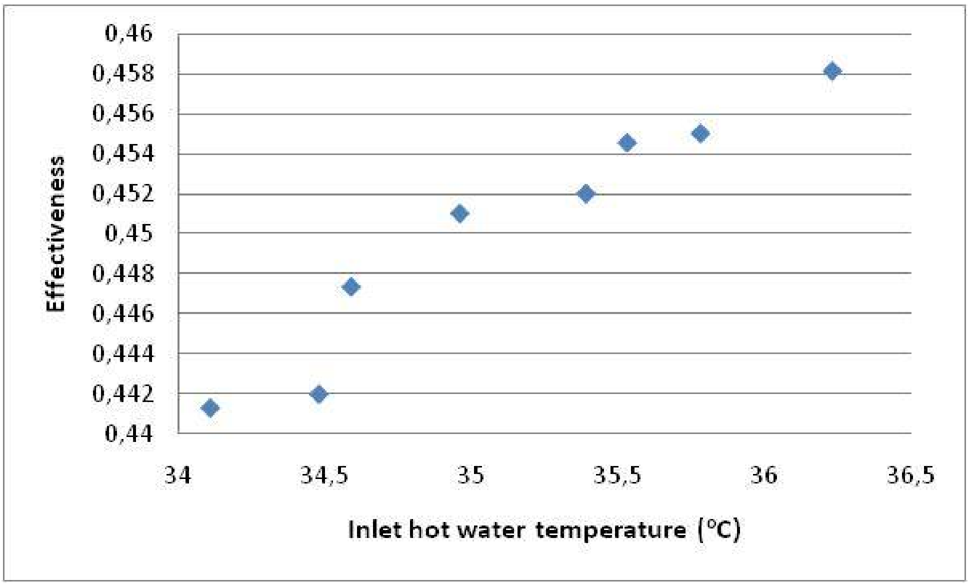

Fig.3 Variation of effectiveness value with inlet hot water temperature for 1,05 m^3/h.

Fig. 4 illustrates the variations of the heat transfer rate and irreversibility values with inlet hot water temperature for 1,05 m^3/h volume flow rate.

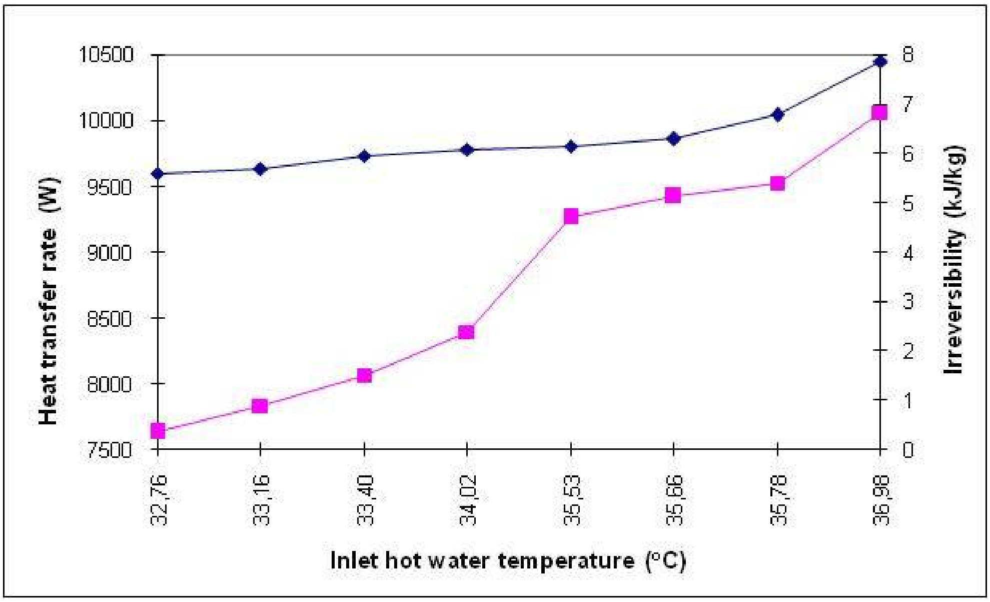

Fig.4 Variation of heat transfer rate and irreversibility with inlet hot water temperature for 1,05 m^3/h.

Fig. 5 illustrates the variations of the heat transfer rate and irreversibility values with inlet cold water temperature for 1,05 m^3/h volume flow rate.

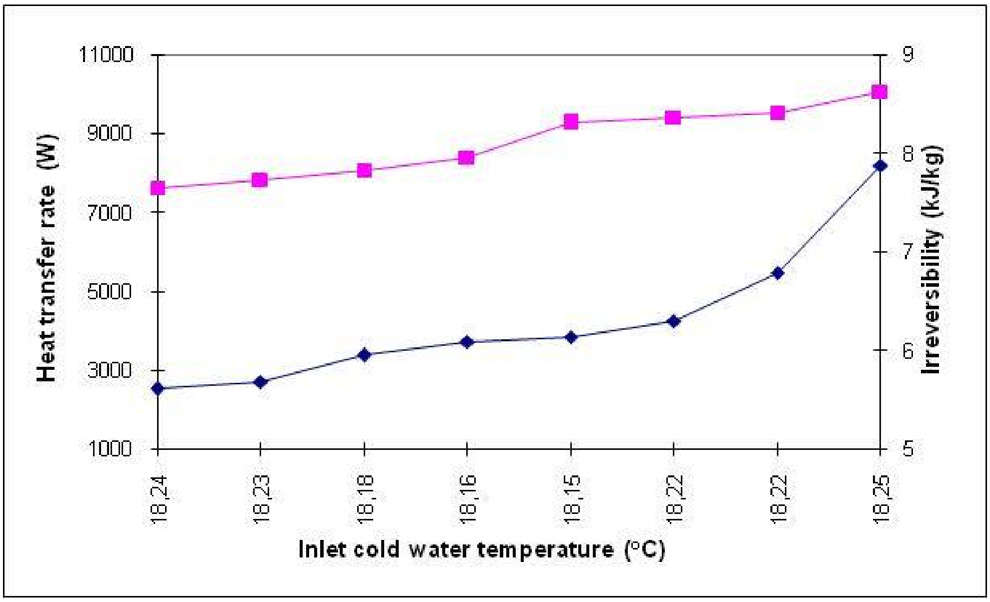

Fig.5 Variation of heat transfer rate and irreversibility with inlet cold water temperature for 1,05 m^3/h.

Fig. 6 illustrates the variations of the heat transfer rate and irreversibility values with inlet hot water temperature for 1,13 m^3/h volume flow rate.

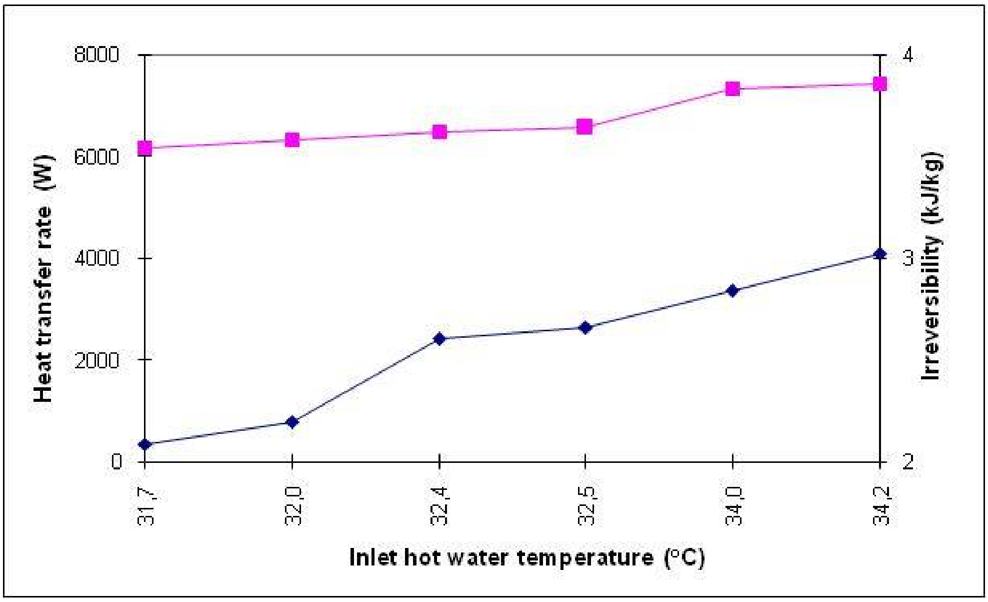

Fig.6 Variation of heat transfer rate and irreversibility with inlet hot water temperature for 1,13 m^3/h.

Fig. 7 illustrates the variations of the heat transfer rate and irreversibility values with inlet cold water temperature for 1,13 m^3/h volume flow rate.

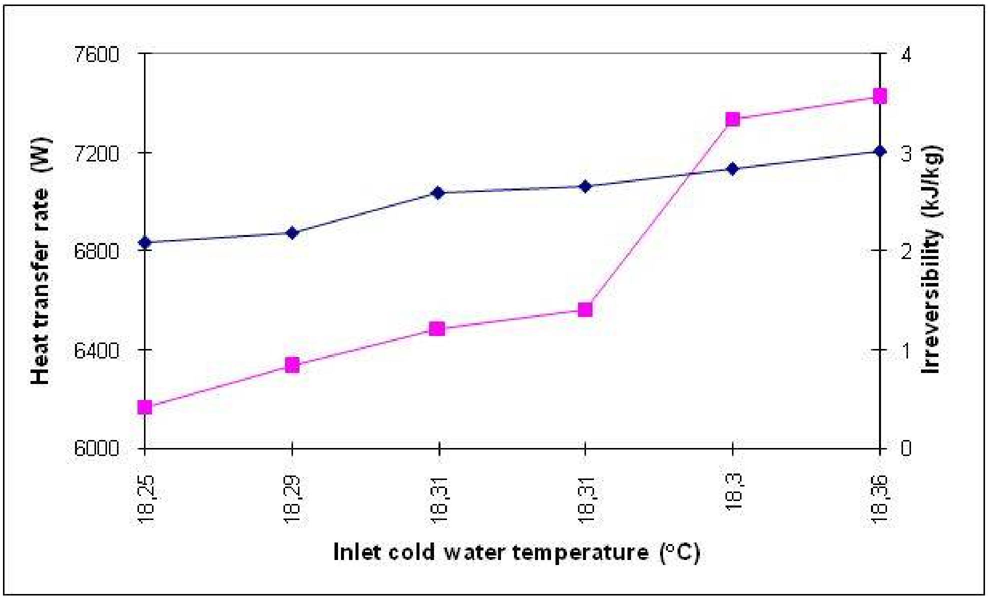

Fig.7 Variation of heat transfer rate and irreversibility with inlet cold water temperature for 1,13 m^3/h.

Fig. 8 illustrates the variations of the heat transfer rate and irreversibility values with inlet hot water temperature for 1,15 m^3/h volume flow rate.

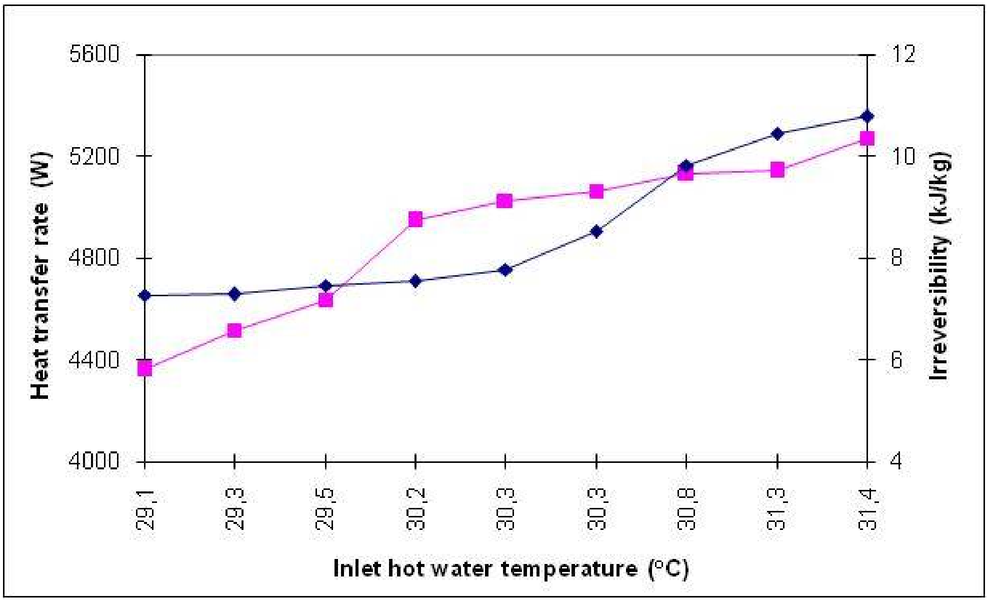

Fig.8 Variation of heat transfer rate and irreversibility with inlet hot water temperature for 1,15 m^3/h.

Fig. 9 illustrates the variations of the heat transfer rate and irreversibility values with inlet cold water temperature for 1,15 m^3/h volume flow rate.

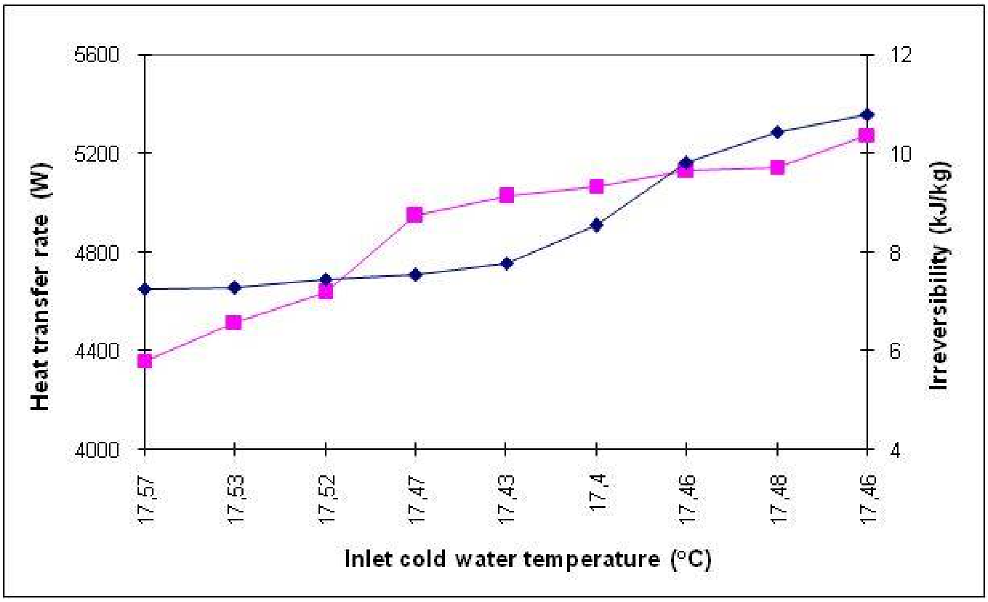

Fig.9 Variation of heat transfer rate and irreversibility with inlet cold water temperature for 1,15 m^3/h.

5. Conclusions

Plate heat exchangers are widely used in warming, heating, cooling applications, food, and cosmetic and chemistry. The plate heat exchanger is widely recognized today as the most economical and efficient type of heat exchanger on the market.

In this study, the second law analysis and heat transfer analysis of the experimental plate heat exchanger are presented. Effect of inlet hot and cold water temperature on the irreversibility and heat transfer are investigated. It is found that the heat transfer rate increases with increasing inlet cold and hot water temperatures at various volume flow rate. In addition, it is found that the irreversibility rate increases with increasing inlet cold and hot water temperatures for all volume flow rate. As expected, the heat transfer rate and irreversibility increases with increasing inlet temperatures.

Acknowledgements

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Nomenclature

c	specific heat capacity (kJ/kgK)
C	heat capacity (W/K)
h	enthalpy (kJ/kg)
I	irreversibility (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
Q	heat transfer rate (W)
s	entropy (kJ/kgK)
t	temperature (^{o}C)
ε	effectiveness
y	flow exergy

Subscripts

c	cold fluid
h	hot fluid
i	inlet
max	maximum
min	minimum
o	outlet