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Entransy Dissipation of Shell and Double Concentric Tubes Heat Exchanger

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Abstract

The concept of entransy dissipation was determined for new type of heat exchanger (shell and double concentric tubes heat exchanger). Three parameters, hot oil flow rate, temperature of inlet hot oil and pressure drop of system were investigated with this concept (entransy dissipation). The results showed that the value of entransy dissipation of oil and of system which represents the summation of entransy dissipation of both oil and water increased with increasing the flow rate of hot oil and these values were larger when cold water flow rate was doubled. Also they were increased with increasing the hot oil inlet temperature at a certain flow rate of hot oil. Furthermore, the pressure drops for hot oil in both shell side and inner tubes side was constant and increased according to the increase of its flow rate. At different hot oil flow rate and a certain hot oil inlet temperature, the entransy of hot oil was increased with its pressure drop. In order to keep up with modern technology, infrared thermography camera was used in order to measure the temperatures which were higher than the temperatures obtained by thermocouples. For that reason the entransy dissipation was determined with lower values compared with their values obtained by using thermocouples.

Key Words: Entransy, Entransy Dissipation, Heat Exchangers, Concentric Tubes

Introduction

In the last few years, heat transfer optimization was based on the concept of entransy. The concept of entransy was proposed by the analogy between electrical conduction and heat conduction [1]. According to this analogy the electric current is compatible with heat flow, electrical resistance with the thermal resistance, electric voltage with the temperature and capacitance with the heat capacity. So, the potential energy of the heat stored in a body was defined as entransy, and it complies with the electrical energy in a capacitor [2]. In this sense, the electricity conduction will be obtained if there is a difference of potential voltage also heat conduction will be obtained if there is a difference of temperature. Many studies usually use this analogy in complex systems to facilitate the study of steady state or unsteady state heat conduction problems [3].

Comparable to the electric energy when transported accompanied to the electric charge during electric conduction, entransy is transported along with the heat during heat transfer. For this reason entransy will be reduced and some of entransy is dissipated during the heat transport when a quantity of heat is transferred from a high temperature to a low temperature. So entransy dissipation can be defined as the lost entransy which is dissipated during the heat transfer and it is an evaluation of the irreversibility of heat transport ability [4]. Also according to the second law of thermodynamics, the entransy dissipation represents the energy dissipated from the object of high temperature to the object of low temperature [2, 5 and 6].

One of the most important and widely used devices in the human life and industry which is used to transfer thermal energy between fluids is the heat exchanger. So, it is necessary to look for new ways for optimization of heat exchanger by maximizing their performance for heat transfer and reduce the cost of energy used.

In this sense many studies have been done investigating entransy dissipation and/or entropy generation to represent the optimum performance of heat exchanger. In two streams single pass heat exchanger as shown in figure 1; entransy dissipation was studied by Qian and Li [7]. They derived the equation of entransy dissipation based on the energy balance equation for the heat exchanger as shown in the equation below:

$$G_{\emptyset} = \left(\frac{1}{2}C_h T_{h,i}^2 + \frac{1}{2}C_c T_{c,i}^2\right) - \left(\frac{1}{2}C_h T_{h,o}^2 + \frac{1}{2}C_c T_{c,o}^2\right) \quad \dots (1)$$

Qian and Li [7] showed that the entransy dissipation in heat exchanger does not depend on the flow arrangement and it can be calculated by the inlet and outlet temperatures, and it is applicable for all types of flow arrangements even though it is derived for a single-pass heat exchanger.

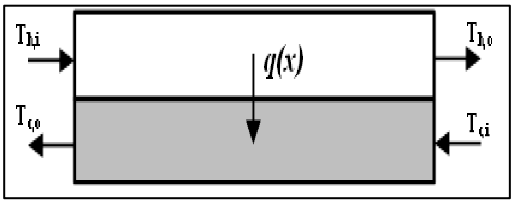

Fig. 1, two streams single pass heat exchanger [7].

Also optimization of heat transfer processes by entransy and entransy dissipation was done by Zhu and Guo [8] and Guo and Chen [9]. Furthermore, they considered that the measures of loss the ability to heat transfer is by the entransy dissipation. In the same manner, the loss of ability to produce work is relative to entropy generation. So problem in materials of high thermal conductivity related to temperature distribution were analyzed and optimized by using these concepts. Also Chen et al. [10] used the concept of entransy to examine a problem of heat conduction by determining the optimal distribution of a material of high thermal conductivity in a given volume.

Other authors like Wu and Liang [11] utilized entransy and entransy dissipation in the heat transfer by radiation. They deduced that, as a result of irreversibility, entransy was slightly dissipated during the processes of heat transfer by radiation. Also a problem between three bodies during the heat transfer by radiation was optimized by using the extreme principle of entransy dissipation.

The main goal of this research is to study the entransy dissipation which is to be studied and investigated using a new type of heat exchanger that differs from the conventional one consisting of double bundles of tubes instead of one bundle called the shell and double concentric tubes heat exchanger. Behavior of entransy dissipation will be studied through different parameters such as flow rate of inlet hot oil, temperature of inlet hot oil, pressure drop of both hot oil and cold water and flow rate of inlet cold water.

Experimental Work

1- Heat Exchanger Description

The shell- and -double concentric tubes heat exchanger was used instead of the conventional one, where the tubes were replaced by double concentric tubes as in figure 2. This will improve the heat transfer through an additional flow passage which gives larger heat transfer area. The hot oil flows though the shell and the inner tubes sides while the cold water flow through the annulus side.

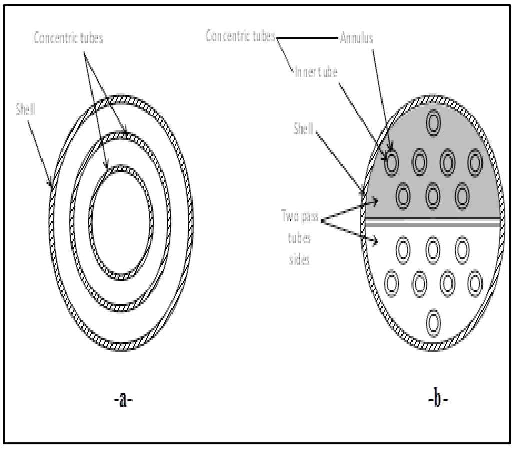

Fig. 2, Shell- and -double concentric tube heat exchanger. (a) Conventional one (b) Modified one.

2- Description for the Parts of the Unit

A tank of 250 liters was used as a supplier for the cold water, which is pumped by single stage centrifugal pump passing through a flow meter to measure its flow rate. The outlet cooling water was collected in a vessel of 100 liters to measure its temperature using a portable thermocouple, where the water was drained to the sewage. On the other side, a cubical tank (reheater tank) supplied with two electrical heaters was used to heat the oil to the desired temperature controlled by thermostats and measured by thermocouple. A centrifugal pump was used to pump the hot oil through the flow meter where the flow was controlled by gate valves.

The outlet hot oil leaving the heat exchanger was collected in a 200 liters tank where the temperature was measured using a thermocouple. Six pressure gauges were used to measure the pressure for the fluids streams. Two pressure gauges were used for the inlet and outlet streams of cold water, the other four gauges were used for the inlet and outlet streams of hot oil, two of them for hot oil flow through the shell and the others for the hot oil flow through the inner tubes. Figure 3 illustrate the schematic diagram of operating system unit.

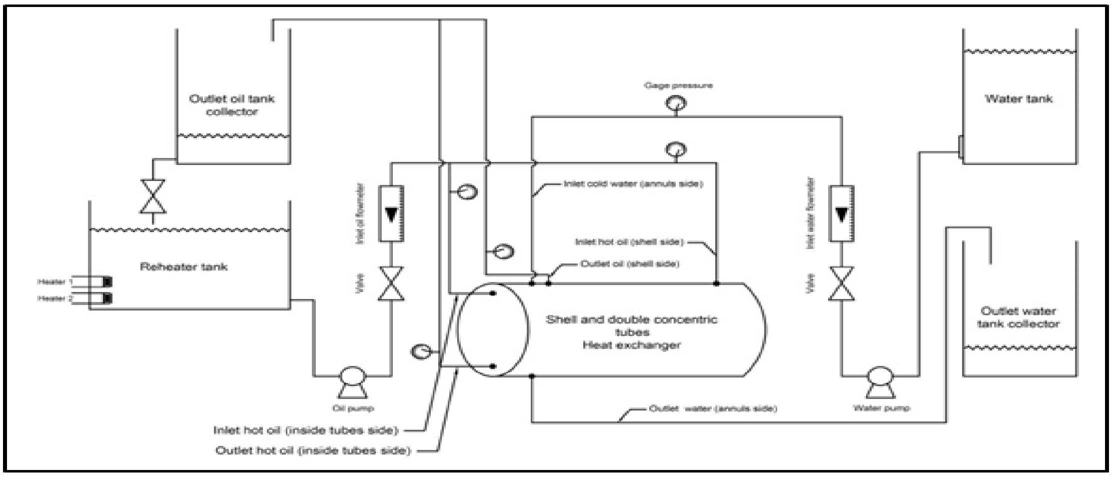

Fig. 3, Schematic diagram of operating system unit

3- Experimental Procedure

The two heaters were switched on for heating oil to the required temperature (50, 60, 70 and 80°C). After that the hot oil was pumped to the shell side and the inner tubes side in the heat exchanger after controlling the flow rate to its desired value (15, 25, 35 and 45 l/min.).

The cold water was pumped in the annuals side at the same time with the hot oil to the desired flow rate (20 and 40 l/min.). At steady state, the temperatures and pressures were constantly measured during the flow rate variation. The results were analyzed for the different conditions.

Infrared thermography camera (Thermo Gear G100EX/G120EX) was used to measure the temperatures of fluids in the system (figure 4). The results obtained from the Infrared thermography camera were analyzed and compared with the results obtained by using thermocouples.

Fig. 4, Infrared thermography camera (Thermo Gear G100EX/G120EX) [12]

Results and Discussions

Parameters Effect on Entransy Dissipation in Heat Exchanger

1- Effects of Heated Oil Flow Rate

Entransy dissipation of oil with different oil flow rate at different oil inlet temperatures (50, 60, 70, and 80°C) are shown in the figure 5. It can be seen from figure that entransy dissipation of oil increases with increasing the flow rates of hot oil (15, 25, 35, and 45 l/min.). This is correct since the entransy dissipation represent the energy dissipated from the hot oil of high temperature to the cold water of low temperature [2, 5 and 6]. So by increasing the flow rate of hot oil, an increase in the dissipation of energy is obvious.

2- Effects of Heated Oil Inlet Temperatures

Entransy dissipation at different temperatures of inlet hot oil which changed from 50, 60, 70 and 80°C were investigated for each hot oil flow rates 15, 25, 35 and 45 l/min as seen in figure 6. Figure show that entransy dissipation of oil increases with increasing temperature at a certain flow rate of oil. That is to say, the higher the hot oil inlet temperature is, the higher the energy dissipated will be [6]. This is compatible with Guo et al. [1] that heat transfer is an irreversible process and the entransy dissipation occurs since the entransy is not conserved and the temperature difference is finite [3].

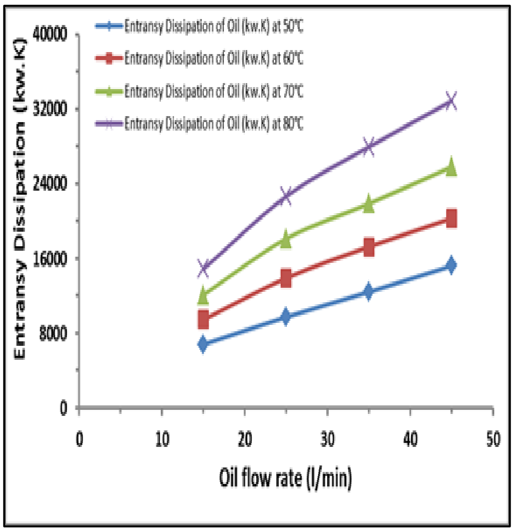

Fig. 5, Comparing entransy dissipation of oil with hot oil flow rate at different oil inlet temperatures, water flow rate 20 l/min.

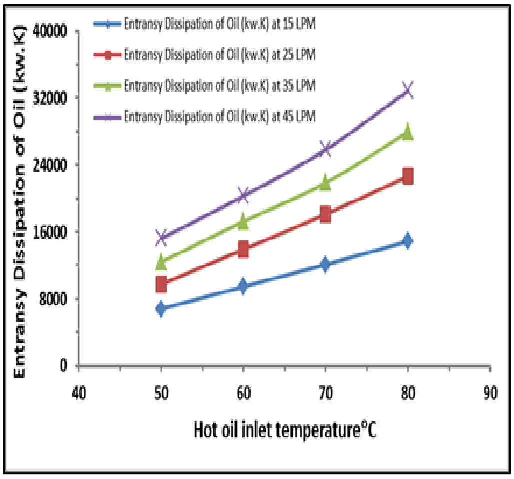

Fig. 6, Entransy dissipation of oil at different temperatures of inlet hot oil (50, 60, 70 and 80°C) at different hot oil flow rates (15, 25, 35 and 45 l/min) and water flow rate 20 l/min.

3- Effects of Heated Oil Pressure Drop

In the heat exchanger there are two kinds of irreversibility, one comes from the temperature finite differences causing heat conduction and the other comes from the finite pressure drops causing flow friction [5].

The experimental results shows that the pressure drops in each shell side, inner tubes side and annulus side are constant for a specified hot oil flow rate and at any hot oil inlet temperatures.

The entransy dissipation of oil with pressure drop at different hot oil inlet temperatures (50, 60, 70, and 80°C) are shown in figures 7. Curves in the figure show that at a certain hot oil inlet temperature, the entransy dissipation of oil increased with the pressure drop at different hot oil inlet flow rates (15, 25, 35, and 45 l/min), but there is no different in the value of the pressure drop at a certain inlet hot oil flow rate.

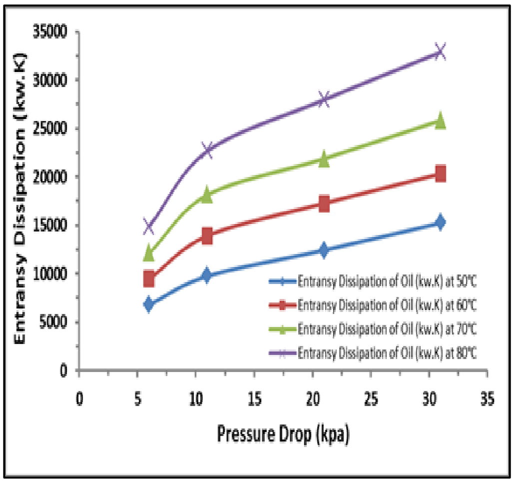

Fig. 7, Comparison between entransy dissipation of oil with pressure drop at different hot oil inlet temperatures (50, 60, 70, and 80°C). Water flow rate is 20 l/min.

4- Effects of Cold Water Flow Rate

Experiments were done by doubling the flow rate of cold water (40l/min) to investigate the effects of cold water flow rate on the values of entransy dissipation. The results of entransy dissipated from shell and inner tubes of heat exchanger for different oil inlet flow rates at a certain hot oil temperature or different hot oil temperatures at a certain oil flow rate for both 20 and 40 l/min cold water flow rates are illustrated in figure 8 and figure 9 respectively. Figures show that the entransy dissipation of oil was increased but with a larger values when 40 l/min of cold water was used. So when the flow rate of cold water increasing, the dissipation of energy increases, leading to increase in the entransy dissipation.

Infrared Thermography Camera Results

To keep up with development in the use of modern techniques and devices, an infrared thermography camera has been used to obtain the temperatures of hot oil and compare these results with the results that were obtained when using the conventional thermocouples.

The comparison between the entransy dissipation obtained using the data of outlet oil temperatures determine by different techniques are shown in figure 10. It was noticed from figure 10 that the entransy dissipation calculated from using infrared camera in some points was less than the entransy dissipation calculated from using thermostat. This is because the values of outlet oil temperature obtained by infrared camera in some points are higher than these temperatures obtained by thermostat at a certain oil flow rate. So the values of temperature finite difference which are used to calculate the entransy dissipation will be lower.

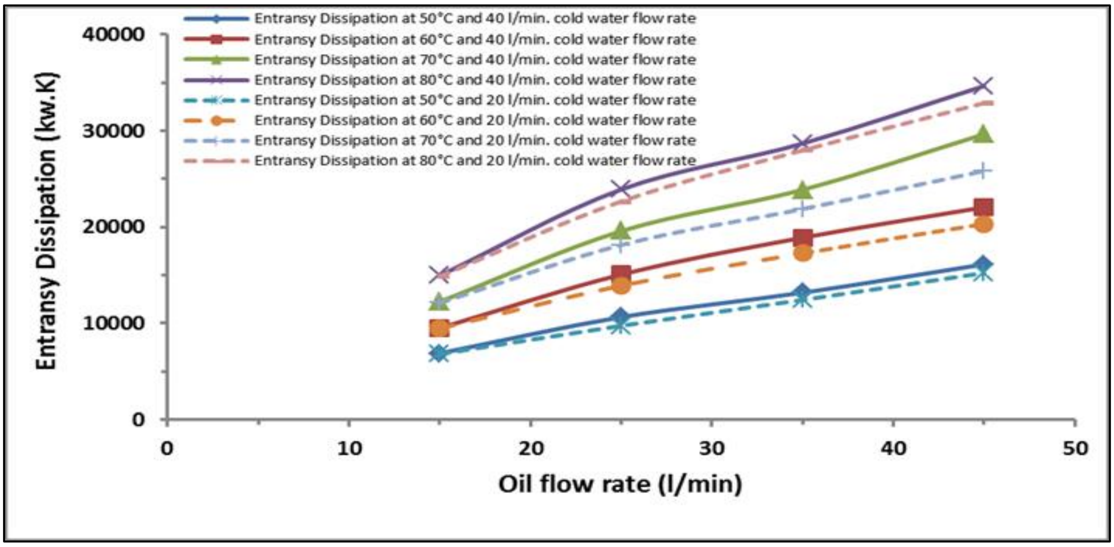

Fig. 8, Comparison between the entransy dissipated from shell and inner tubes of heat exchanger for different oil inlet flow rates at a certain hot oil temperature for both 20 and 40 l/min cold water flow rates. The dotted lines represent the entransy at 20 l/min cold water flow rate.

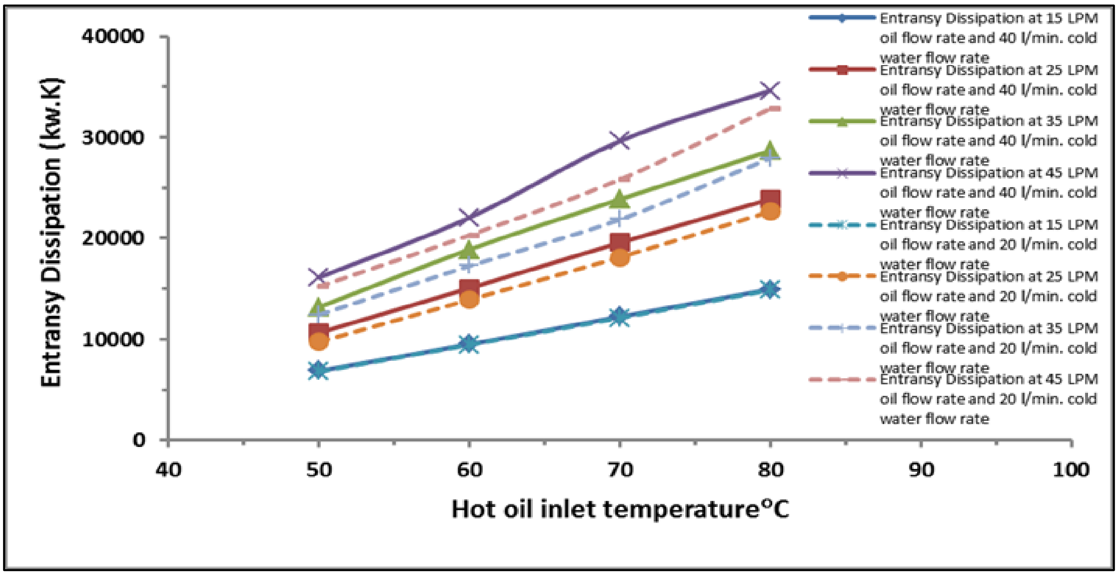

Fig. 9, Comparison between the entransy dissipated from shell and inner tubes of heat exchanger for different hot oil inlet temperatures at a certain hot oil flow rate for both 20 and 40 l/min cold water flow rates. The dotted lines represent the entransy at 20 l/min cold water flow rate.

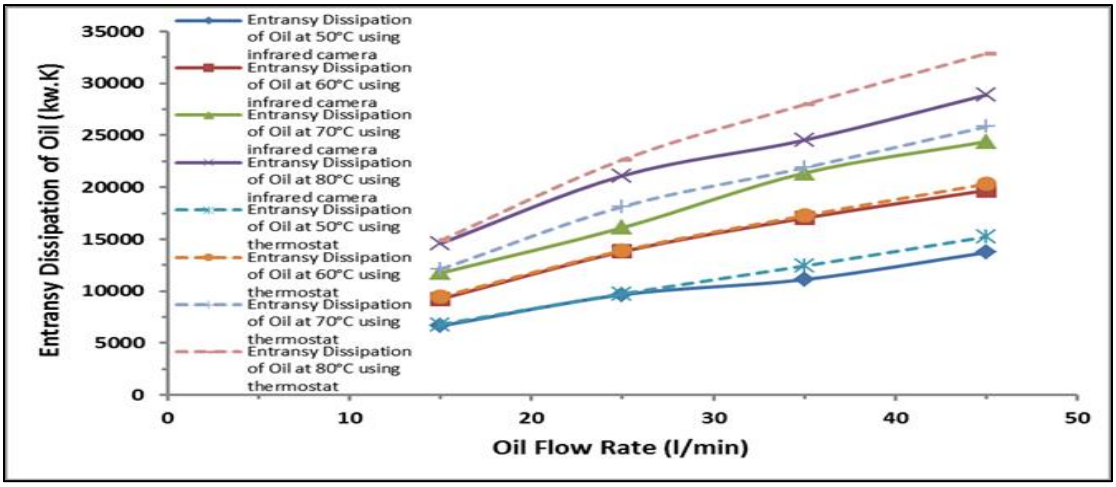

Fig. 10, Comparison the entransy dissipation obtained using the data of outlet oil temperatures determine by different techniques. The dotted curves represent the entransy obtained using thermostat. Cold water flow rate 20 l/min.

Conclusions

The concept of entransy dissipation was determined for a new type of heat exchanger (shell and double concentric tubes heat exchanger). The relation between entransy dissipation and parameters of hot oil flow rate, temperature of inlet hot oil and pressure drop of system were investigated and the results showed that the entransy dissipation of oil increases with increasing the flow rate of hot oil. Also entransy dissipation of oil increased with increasing the hot oil inlet temperature at a certain flow rate of hot oil. Furthermore, the pressure drops in each shell side, inner tubes side and annulus side are constant for a specified hot oil flow rate and at any hot oil inlet temperatures. At different hot oil flow rate and a certain hot oil inlet temperature, the entransy dissipation of hot oil increases with its pressure drop. On the other hand, entransy dissipation of oil increased with increasing the flow rate of hot oil when cold water flow rate was doubled and the values of entransy dissipation are higher. Finally, the entransy dissipation was determined with lower values when infrared thermography camera was used to measure the temperatures, compared with their values obtained by using thermocouples.

Nomenclatures

Symbols	Description	Units
G_ϕ	Entransy dissipation	W.K
C_c	Heat capacity rate of cold stream	$W.K^{-1}$
C_h	Heat capacity rate of hot stream	$W.K^{-1}$
$T_{c,i}$ & $T_{c,o}$	Inlet and outlet temperatures of cold stream	K
$T_{h,i}$ & $T_{h,o}$	Inlet and outlet temperatures of hot stream	K

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