Entropy Generation of Shell and Double Concentric Tubes Heat Exchanger

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ABSTRACT

Entropy generation was studied for new type of heat exchanger (shell and double concentric tubes heat exchanger). Parameters of hot oil flow rate, temperature of inlet hot oil and pressure drop were investigated with the concept of entropy generation. The results showed that the value of entropy generation increased with increasing the flow rate of hot oil and when cold water flow rate was doubled from 20 to 40 l/min, these values were larger. On the other hand, entropy generation increased with increasing the hot oil inlet temperature at a certain flow rate of hot oil. Furthermore, at a certain hot oil inlet temperature, the entropy generation increased with the pressure drop at different hot oil inlet flow rates. Finally, in order to keep up with modern technology, infrared thermography camera was used in order to measure the temperatures. The entropy generation was determined with lower values when infrared thermography camera was used to measure the temperatures, compared with the values obtained by using thermocouples.

Key Words: entropy, entropy generation, heat exchangers, concentric tubes.

العشوائية المتولدة لمبادل حراري من نوع الغلاف والأنابيب المزدوجة المتحدة المركز

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الخلاصة

لقد درست العشوائية المتولدة لنوع جديد من المبادلات الحرارية (المبادل الحراري ذي الغلاف والأنابيب المزدوجة المتحدة المركز). تمت دراسة تأثير كل من معدل جريان الزيت الساخن، ودرجة حرارة الزيت الداخل للمبادل الحراري والهبوط في الضغط مع مقدار العشوائية المتولدة. أظهرت النتائج أن قيمة العشوائية المتولدة زادت مع زيادة معدل تدفق الزيت الساخن. وعندما تضاعف معدل جريان الماء البارد من 20-40 لتر/دقيقة، كانت هذه القيم للعشوائية المتولدة عالية. من ناحية أخرى، ارتفعت قيمة العشوائية المتولدة مع زيادة درجة حرارة الزيت الداخل للمبادل الحراري عند معدل تدفق معين من الزيت الساخن. علاوة على ذلك، عند درجة حرارة معينة للزيت الداخل للمبادل الحراري، فإن العشوائية المتولدة إزدادت بزيادة انخفاض ضغط الزيت عند معدلات تدفق مختلفة للزيت الساخن. وأخيرا، من أجل مواكبة التكنولوجيا الحديثة، تم استخدام كاميرة حرارية تعمل بالأشعة تحت الحمراء لقياس درجات الحرارة، حيث تم تحديد قيم للعشوائية المتولدة منخفضة عندما استخدمت الكاميرة الحرارية لقياس درجات الحرارة، مقارنة مع القيم التي تم الحصول عليها باستخدام المتحسسات الحرارية الإعتيادية.

الكلمات الرئيسية: العشوائية، العشوائية المتولدة، المبادل الحراري، الأنابيب المتحدة المركز.

1. INTRODUCTION

As a result of the worsening global crisis of energy, attention to the heat transfer enhancement has increased significantly, taking into account that heat transfer represents about 80% of total energy consumption, **Qian** and **Li, 2011**.

With the increasing decline in energy sources, to use energy in the correct way is one of the important ways to face the growing requirements for energy. One of thermal system devices is heat exchanger and it is used extensively in many fields of industry such as power engineering, petroleum refineries, chemical industries, and so on. So in this sense, it is important to develop ways for decreasing unnecessary dissipated energy and improving the performance of heat exchanger by optimizing their design. This may be done by either reducing their cost or reducing irreversibility within heat exchanger. That's why some of the different methods and theories that have been developed to optimize heat transfer, such as the constructed theory, **Bejan, 1997.** and the minimum entropy generation, **Bejan, 1982** and the entransy theory, **Guo et al., 2007**.

Two important functions in thermodynamics are considered, the concepts entropy and entropy generation. These two concepts are used to estimate the irreversibility of process and optimizing heat transfer based on the premise that the minimum entropy generation (MEG) will lead to the most efficient heat transfer performance, **Chen Q. et al., 2011**.

Optimization of heat transfer based on minimum principle of entropy generation was conducted by many researchers, **Poulikakos** and **Bejan, 1982** and **Erek** and **Dincer, 2008**. **McClintock, 1951.** was the first who proposed the entropy generation minimization and he developed equations for optimum design of fluid passages for a heat exchanger.

In 1854 Clausius investigated the Carnot cycle (heat-work conversion). The concept of entropy was introduced, **Zhao** and **Luo, 2002**. It was defined based on the reversible cycle of the Carnot engine. In thermodynamics, entropy was commonly understood as a measure of disorder. It was a measure of the irreversibility of process and a criterion describing the thermal equilibrium of a system.

In non-equilibrium state of system the thermal gradient between two media results in entropy generation. It is produced in any irreversible process. Over a physical process; system will lose more ability to do work as more entropy generation is, **Zhao** and **Luo, 2002**. According to this consideration, entropy generation was used to optimize or analyze the thermodynamics processes to improve the performance of thermodynamic systems, **Chen et al., 2010 and Myat et al., 2011**.

Kim and **Kim, 2015.** investigated the effect of entropy generation and entransy dissipation on the optimal design of heat exchanger in both cases of parallel and counter flow. They determined the relation of entropy generation according to several assumptions, where the “heat exchanger is a control volume and the surface is adiabatic”, as in Eq.(1).

$$\mathrm{S_g} = C_h \ln\left(\frac{T_{ho}}{T_{hi}}\right) + C_c \ln\left(\frac{T_{co}}{T_{ci}}\right) \quad (1)$$

On the other hand, **Cheng et al., 2012,** developed the expression of entropy generation for a multi-stream heat exchanger with several assumptions that “the fluids in the heat exchangers are incompressible, the influence of the viscous dissipation on the entransy could be ignored, and there was no heat exchange between the heat exchangers and the environment”. The expression of this physical quantity is presented bellow in Eq.(2).

$$\mathrm{S_g} = \sum_{\mathrm{i=1}}^{\mathrm{n}} c_i m_i \ln \frac{T_{out-i}}{T_{in-i}} \quad (2)$$

Additionally, entropy generation was used to measure the irreversibility for any irreversible process, while the concept of irreversibility as a result to finite temperature difference and fluid friction in heat transfer processes was presented by **Bejan, 1977, 1996**. Also the expression of entropy generation for heat and fluid flows was improved by the same author **Bejan, 1982 and 1996**. As well as the entropy generation minimization method was utilized by **Ahmadi et al., 2011** to optimize a cross-flow plate fin heat exchanger. In the analysis of an absorption chiller, **Myat et al., 2011** found that maximum coefficient of performance (COP) can be obtained through the minimization of entropy generation.

The main goal of this research will be to study the entropy generation with 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. From the response of entropy generation at different operating conditions, the efficiency of heat transfer will be investigated to ensure minimum energy consumption and reduction of operating costs.

2. EXPERIMENTAL WORK

2.1 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 rates. 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 equipped with the two heaters 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.

2.2 Heat Exchanger Description

Fadhil, 2013 was used the shell-and-double concentric tubes heat exchanger instead of the conventional one, where the tube was replaced with double concentric tubes, **Fig.2**. This will improve the heat transfer through an additional flow passage which gives larger heat transfer area. The hot oil flow though the shell and the inner tubes sides while the cold water flow through the annulus side.

2.3 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, **Fig.3**. The results obtained from the

Infrared thermography camera were analyzed and compared with the results obtained by using thermocouples.

3. RESULTS AND DISCUSSIONS

3.1 Parameters Effect on Entropy Generation in Heat Exchanger

3.1.1 Effects of heated oil flow rate

Entropy generation of oil with different oil flow rates at different oil inlet temperatures 50, 60, 70, and 80°C are shown in the **Fig.4**. It was noticed from the figure that by increasing the oil inlet temperature the entropy generation increases.

The figure shows that the absolute value of entropy generation of oil increases with increasing the flow rates of hot oil 15, 25, 35, and 45 l/min at a certain hot oil inlet temperature. This is true since the entropy generation is caused from the fluid friction and heat transfer, so by increasing the flow rate of hot oil, this causes an increase in the generation of entropy, **Asadi** and **Tabrizi, 2014**.

3.1.2 Effects of heated oil inlet temperatures

Entropy generation of oil was tested for different hot oil inlet temperatures. The conditions for inlet cold water are 20°C temperature and 20 l/min flow rate. Entropy generation was investigated for different hot oil inlet temperatures 50, 60, 70 and 80°C and at different hot oil flow rates 15, 25, 35 and 45 l/min as seen in **Fig.5**. The figure shows that entropy generation of oil increases with increasing temperature at a certain flow rate of oil. This is in agreement with the results obtained by **Kim** and **Kim, 2015**. where the entropy generation increases with increasing the inlet temperature. Also, the figure shows that by increasing the hot oil inlet flow rate the entropy generation increases. The reason behind this increase is caused by the high flow rate of the hot stream resulting in high convective heat transfer.

3.1.3 Effects of heated oil pressure drop

The relation between entropy generations of oil with pressure drop at different hot oil inlet temperatures 50, 60, 70, and 80°C were also studied and shown in **Fig.6**. Curves in the figure show that at a certain hot oil inlet temperature, the entropy generation increased with the pressure drop at different hot oil inlet flow rates, but there is no different in the value of the pressure drop at a certain inlet hot oil flow rate.

3.1.4 Effects of cold water flow rate

To investigate the effects of cold water flow rate on the values of entropy Generation, the experiments were repeated for a double flow rate of cold water 40 l/min. Results of comparison between the entropy generation of oil for different oil inlet flow rates at a certain hot oil temperature for both 20 and 40 l/min cold water flow rates illustrated in **Fig.7**. The results show that when 40 l/min cold water flow rate was used the values of entropy generation is larger compared with the values of entropy generation obtained when 20 l/min cold water flow rate was used.

3.2 Infrared Thermography Camera Results

In order to keep up with modern technology, infrared thermography camera was used in order to measure the temperatures of hot oil and compare these results with the results that were obtained when using the conventional thermocouples.

The experiments were repeated with different hot oil flow rate 15, 25, 35, and 45 l/min and 20 l/min cold water flow rate. The oil outlet temperatures were obtained using infrared thermography camera and the data are illustrated in the **Table 1**. Images of temperature distributions for inlet and outlet paths of oil when hot oil passes at 35 l/min are presented in the **Fig.8**. The color gradients in the images of **Fig.8** represents the temperature distribution in the units. As it can be seen, the intensity of the color gradients is more when the inlet temperature of oil was 80°C. Other image of temperature distribution for the whole heat exchanger can be seen in the **Fig.9**.

The comparison between the entropy generations for the different techniques i.e. the infrared thermography camera and conventional thermocouples is shown in **Fig.10**. The figure shows that for different hot oil inlet flow rates 15, 25, 35, and 45 l/min at certain hot oil inlet temperatures 50, 60, 70, and 80°C, the values of entropy generation obtained from using infrared camera in some points were lower than these values obtained from using conventional thermocouples. This is because that the temperatures obtained by infrared camera were higher than the temperatures obtained by the thermocouples, and according to equation of entropy generation, Eq.(2), as the value of outlet temperature increases, the value of entropy generation decreases. This may be related to the accuracy of the camera and the temperatures can be measured in the real time.

4. CONCLUSIONS

Entropy generation was studied for new type of heat exchanger (shell and double concentric tubes heat exchanger). The relation between entropy generation and hot oil inlet flow rate, temperature of inlet hot oil and pressure drop of oil were studied and the results showed that the entropy generation of oil increases with increasing the flow rate of hot oil. Furthermore, entropy generation of oil increased with increasing the hot oil inlet temperature at a certain flow rate of inlet hot oil. Also, the results showed that there is no change in the pressure drop at a certain hot oil flow rate, but with increasing the hot oil inlet temperature the entropy generation increases. On the other hand, when the cold water flow rate was doubled the entropy generation of oil increased with increasing of the hot oil inlet flow rate and the values of entropy generation are higher. Finally, the entropy generation was determined with lower values when infrared thermography camera was used to measure the temperatures, compared with the values obtained by using thermocouples.

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6. NOMENCLATURE

Symbols	Description	Units
C_c	heat capacity rate of cold stream	$W.K^{-1}$
C_h	heat capacity rate of hot stream	$W.K^{-1}$
c	specific heat	$J.Kg^{-1}.K^{-1}$
m	mass flow rate	$Kg.s^{-1}$
S_g	entropy generation rate	$W.K^{-1}$
$T_{c,i}$ & $T_{c,o}$	inlet and outlet temperatures of cold stream	K
$T_{h,i}$ & $T_{h,o}$	inlet and outlet temperatures of hot stream	K
T_{in} & T_{out}	inlet and outlet temperatures	K

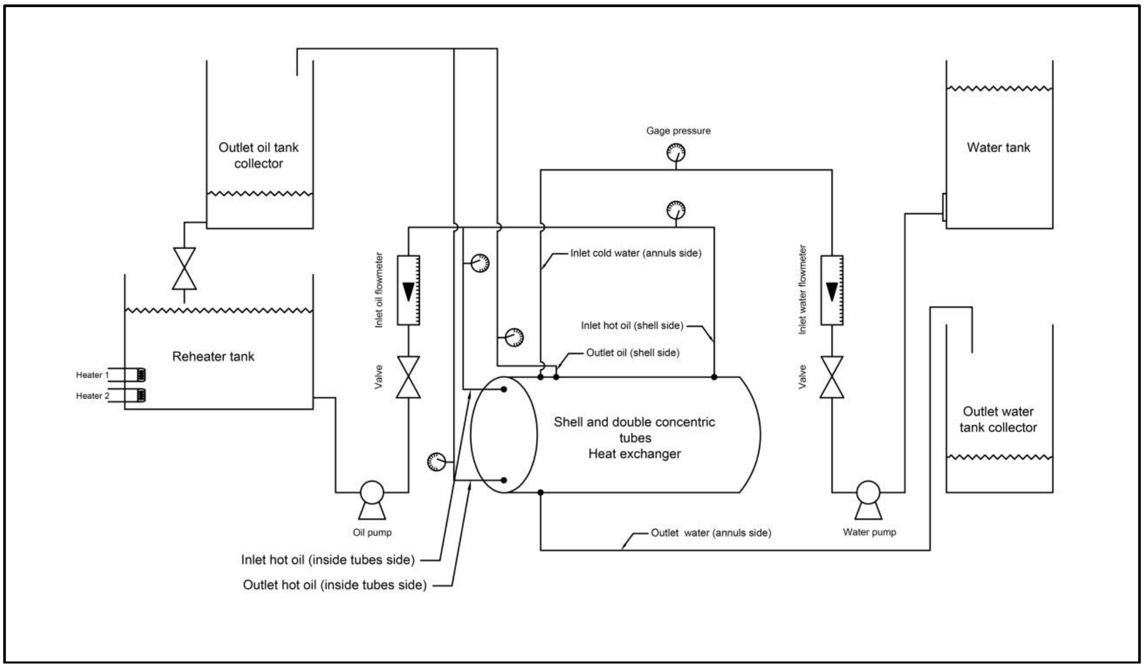

Figure 1. Schematic diagram of operating system unit.

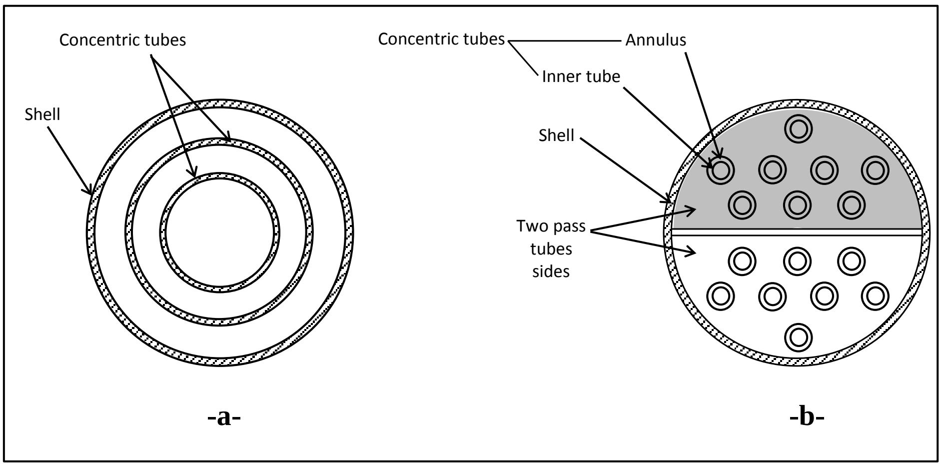

Figure 2. Shell- and -double concentric tube heat exchanger. (a) conventional one (b) modified one.

Figure 3. Infrared thermography camera (Thermo Gear G100EX/G120EX) (www.infrared.avio.co.jp).

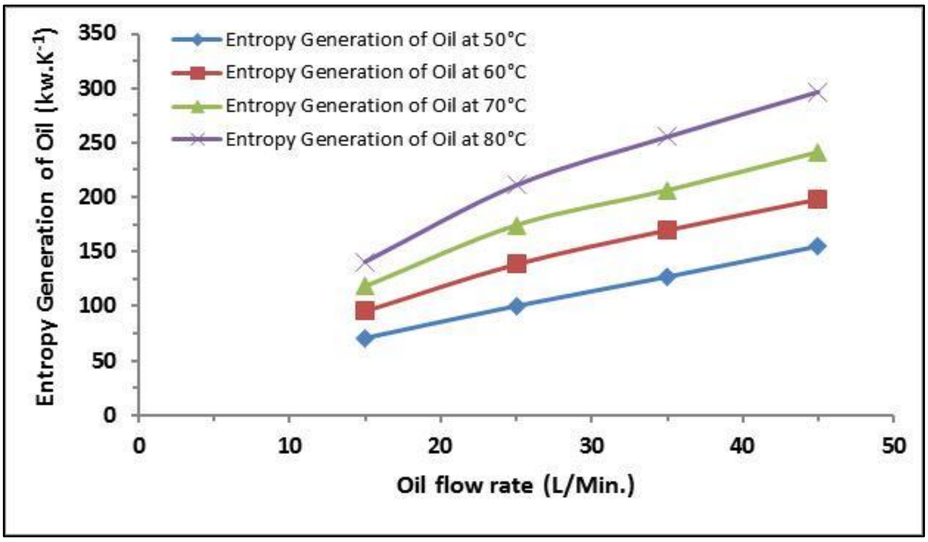

Figure 4. Comparison of entropy generation with hot oil flow rate at different oil inlet temperatures, water flow rate 20 l/min.

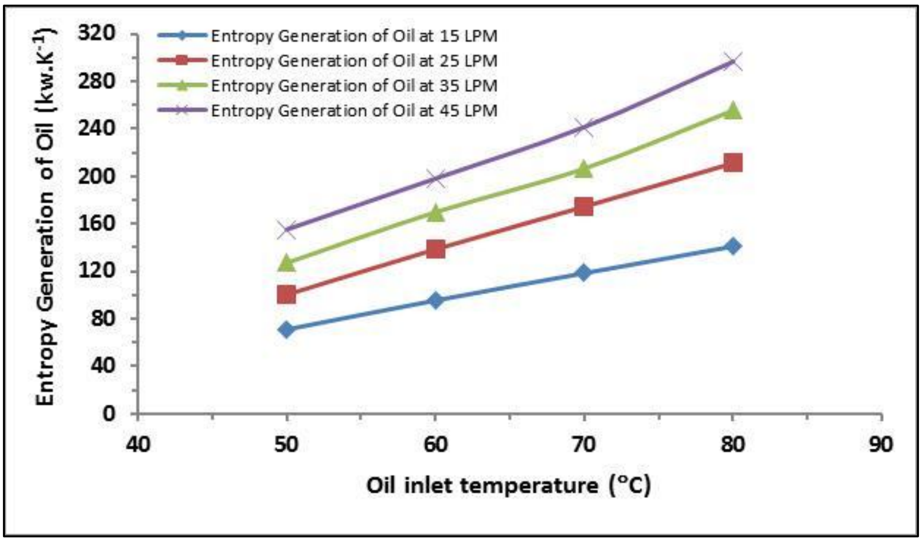

Figure 5. Entropy generation of oil for different hot oil inlet temperatures 50, 60, 70 and 80°C; at different hot oil flow rates 15, 25, 35 and 45 l/min and water flow rate 20 l/min.

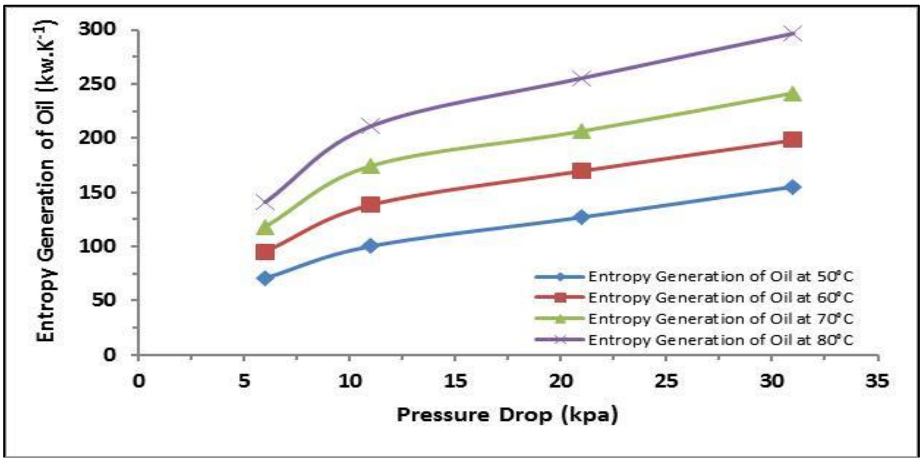

Figure 6. Comparison between entropy generation of oil with pressure drop at different hot oil inlet temperatures 50, 60, 70, and 80°C. Water flow rate is 20 l/min.

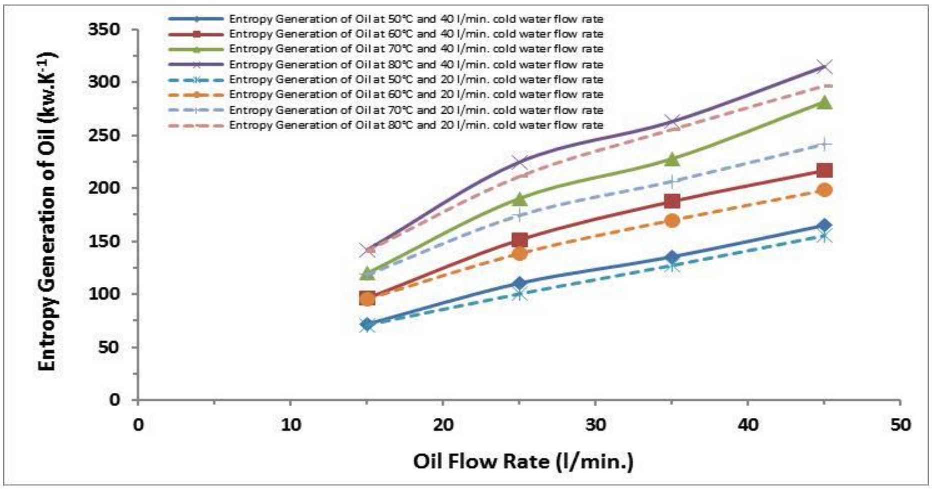

Figure 7. Comparison between the total entropy generation of oil for different oil inlet flow rates at a certain hot oil temperature for both 20 and 40 l/min cold water flow rates.

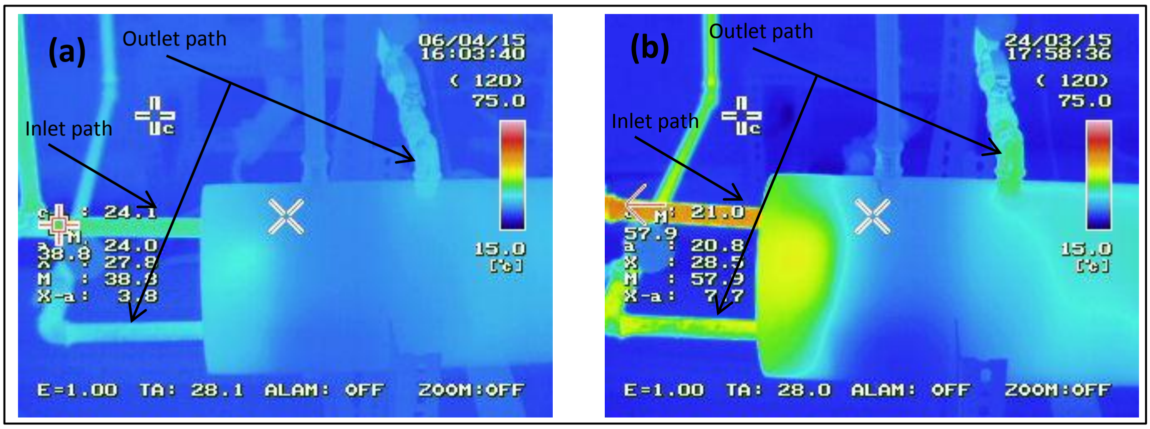

Figure 8. Images of temperature distributions for inlet and outlet paths of oil when hot oil passes at 35 l/min. (a) at 50°C of hot oil inlet temperature. (b) at 80°C of hot oil inlet temperature.

Figure 9. Image of temperature distributions for whole heat exchanger.

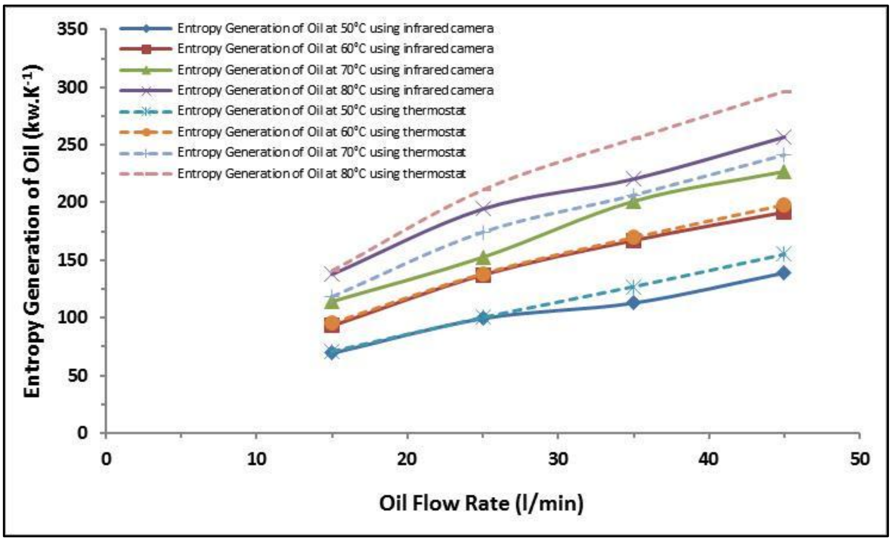

Figure 10. Comparison between the entropy generations for the different techniques (infrared camera and thermostat). The dotted curves represent the entropy generation obtained using thermostat. Cold water flow rate 20 l/min.

Table 1. Outlet temperatures of hot oil obtained by infrared thermography camera at different hot oil inlet flow rates.

Oil flow rate (LPM)	Oil inlet temperature = 50°C		Oil inlet temperature = 60°C		Oil inlet temperature = 70°C		Oil inlet temperature = 80°C	
	$T_{tube\ out}$ °C	$T_{shell\ out}$ °C	$T_{tube\ out}$ °C	$T_{shell\ out}$ °C	$T_{tube\ out}$ °C	$T_{shell\ out}$ °C	$T_{tube\ out}$ °C	$T_{shell\ out}$ °C
15	24.3	23.5	24.7	24	25.8	25.2	26	25.1
25	28	26.8	28.5	28	35.3	32.4	36.3	30.3
35	32.4	30.7	33.1	31.3	37	34.7	45.5	37.9
45	32.8	31.8	36	34.2	41.9	37.8	48.8	41.4