Entransy dissipation of Shell and Double Concentric Tube Heat Exchanger Calculations and Analysis

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ABSTRACT

Shell-and-double concentric tube heat exchanger is one of the new designs that enhance the heat transfer process. Entransy dissipation is a recent development that incorporates thermodynamics in the design and optimization of heat exchangers. In this paper the concept of entransy dissipation is related to the shell-and-double concentric tube heat exchanger for the first time, where the experiments were conducted using hot oil with temperature of 80, 100 and 120°C, flow rate of cold water was 0.667, 1, and 1.334 kg/m^3 respectively and the temperature of inlet cold water was 20°C. The entransy dissipation rate due to heat transfer and to fluid friction or pressure drop was studied.

Key Words: entransy, dissipation rate, heat exchanger, heat transfer enhancement, concentric tubes.

حسابات وتحليل منظومة المبادل الحراري ذو القشرة والانابيب المتداخلة المتمركزة باستخدام تبديد الانترانسي

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الخلاصة

ان المبادل الحراري ذو القشرة والانابيب المتمركزة المتداخلة هو احد التصاميم الجديدة لتفعيل عملية انتقال الحرارة.ان عملية تبديد الانترانسي والتي توظف الثرموداينمك في عملية تصميم المبادلات الحرارية المثلى هو تطبيق حديث. في هذا البحث سوف يتم تطبيق مبادئ الانترانسي على المبادل الحراري الحراري ذو القشرة والانابيب المتمركزة المتداخلة ولاول مرة، حيث تمت دراسة التجارب عند درجة حرارة الزيت الساخن مساوية لـ 80، 100 و120°م و معدل جريان الماء البارد كان 0,667 و1 و1,334 كغم/م^3 و درجة حرارة الماء البارد الداخل مساوية لـ 20°م. تمت دراسة معدل تبديد الانترانسي نتيجة انتقال الحرارة والاحتكاك او انخفاض الضغط.

الكلمات الرئيسية: الانترانسي، معدل التبديد، مبادل حراري، تعزيز انتقال الحرارة، الانابيب المتمركزة

1. INTRODUCTION

A shell and double concentric tubes heat exchanger is a new invention in heat transfer devices that is used for transfer of internal thermal energy between three fluids at different temperatures (two hot flows and a cold flow H-C-H or opposite C-H-C). They are used in different industrial applications, where enhancement of heat transfer is needed in addition to increasing compactness. Accordingly, both weight and cost of the exchanger will be decreased to a good extent, **,Fadhil Abid A., 2013.**

The new heat exchangers differ in the use of double concentric tubes instead of the ordinary tubes used. The shell outside is the envelope of the double concentric tubes.

Principally, the second tube (inner tube) improves heat transfer through an additional flow passage and a larger heat transfer area per the same length of heat exchanger. In this new heat exchanger the application of two different streams leads to new heat transfer area which is equal to the heat transfer area of shell-and tube heat exchanger plus of inner tubes heat exchange area

First fluid (the same temperature level or the same nature as the third fluid) enters and is distributed between the shell and inner tubes. Whereas second fluid penetrates into annulus shape formed with the inner tubes and the second tube sheet.

Heat transfer enhancement is considered to have great role in the studies of the scientists since it affects the energy consumption all over the world. Studies led to different developments like heat transfer optimization and entransy dissipation for describing the heat transfer ability and irreversibility of heat conduction, respectively **,Zeng-Yuan et al., 2007.** and **,Mingtian, 2011.**

,Guo et al., 2007. defined a new physical quantity called entransy. They also defined heat transfer potential capacity and heat transfer potential capacity dissipation function **,Guo et al., 2003. and ,Chen, 2012.** By analogy between heat conduction process and electrical conduction process, a new term called entransy which can describe total heat transfer ability was introduced by **,Zeng-Yuan et al., 2007.**

,Guo et al., 2008. introduced an entransy dissipation number. They non-dimensionalized the entransy dissipation of heat exchanger. This can be used as thermodynamic figure to assess heat exchanger performance.

,Guo et al., 2010. defined an equivalent thermal resistance of a heat exchanger based on the entransy dissipation rate. They developed relationships between heat exchanger effectiveness and the thermal resistance which can be used to compare the irreversibility of a heat exchanger and its effectiveness.

,Xiaodong et al., in 2011. defined in their work the heat exchanger thermal resistance basing their work on entransy dissipation rate. They based the results on that the minimum entransy dissipation resistance corresponds to the highest heat transfer rate.

,Li Xuefang et al., in 2011. studied the optimization of a water-water counter current heat exchanger based on the entransy dissipation rate. They showed that increasing heat transfer area will reduce the irreversible dissipation in the studied heat exchanger.

,Mingtian, 2011. showed that entransy is a state variable which may be employed to describe the second law of thermodynamics.

,Mingtian, 2011. wrote a chapter studying the entransy dissipation theory and its application in heat transfer; convection and heat exchangers.

,Liu et al., in 2011. showed in a study that the considering the principle of entransy decrease in processes of heat transfer, that entransy would never increase when heat is transferred from higher to lower temperature in both equilibrium or non-equilibrium states.

,Xuetao, and ,Xingang in 2012. showed that for any thermodynamic process, it is found that some of net entransy flow from the heat sources is dissipated during process of heating or cooling of the working fluid and the other part is lost in doing work process.

,Jiangfeng and ,Mingtian, 2012. studied the optimization of heat exchanger using entransy dissipation theory and genetic algorithm.

,Chen, in 2012. summarized in his study entransy theory and its applications on heat conduction, heat convection, heat radiation, and heat exchanger design etc.

,Xuetao et al., in 2012. developed expressions of entransy dissipation, entransy dissipation based thermal resistance and entropy generation using the assumptions of incompressible fluids, ignored the influence of viscous dissipation on entransy and they assumed that there is no heat exchange between environment and the considered heat exchanger.

,Xuetao and ,Xingang, 2013. discussed the entransy expressions on thermodynamic laws. For the first law they showed that any thermodynamic system is in balance. The entransy expression for the second law of thermodynamics showed that entransy flow will not be transported from low temperature level to a higher one. Considering the third law of thermodynamics, the entransy expression showed that it is impossible to reach zero entransy for anybody.

,Xuetao and Xingang, 2013. used concepts of entropy generation and heat entransy loss to analyze the conversion of heat-work and heat transfer processes.

,Jia et al., 2014. studied the convective heat transfer optimization based on minimum entransy dissipation. Heat transfer is enhanced at relatively small flow resistance. This indicates that the investigated optimization method is useful in design of heat transfer enhancement.

,Puranik and ,Maheshwari, 2014. introduced a new heat exchanger design based on minimized entransy dissipation number which yields higher performance great savings in terms of energy and protection of environment.

,Kim and Kim, 2015. showed that the minimum entropy generation or the entransy dissipation does not represent the optimum performance for a counter-flow heat exchanger while the minimum entransy dissipation-based thermal resistance corresponds to the maximum heat transfer rate. It is found that the behavior of entropy generation is very similar to that of entransy dissipation.

The aim of the present research is the application, calculation and analysis of the concept of entransy dissipation rate to shell and double concentric tube heat exchanger at certain conditions.

2. THEORETICAL BACKGROUND

Entransy can be related to enthalpy by the following equations, **,Mingtian, 2011.**

$$dE = T dH \tag{1}$$

$$dH = \dot{m}\, cp\, dT \tag{2}$$

The shell and double concentric tube heat exchanger is assumed to work under adiabatic condition.

Entransy dissipation rate as a result of heat conduction in the considered heat exchanger can be written for the shell side as:

$$\dot{E}_1 = \int_{outside}^{inside} (\dot{m}\, T\, dH)_1 = \int_{outside}^{inside} (\dot{m}\, cp\, T\, dT)_1 = \frac{1}{2}\, (\dot{m}\, cp)_1 \left(T_{1,inside}^2 - T_{1,outside}^2\right) \tag{3}$$

while for the outer tube it can be written as:

$$\dot{E}_2 = \int_{outside}^{inside} (\dot{m}\, T\, dH)_2 = \int_{outside}^{inside} (\dot{m}\, cp\, T\, dT)_2 = \frac{1}{2}\, (\dot{m}\, cp)_2 \left(T_{2,inside}^2 - T_{2,outside}^2\right) \tag{4}$$

and finally for the inner tube side:

$$\dot{E}_3 = \int_{outside}^{inside} (\dot{m}\, T\, dH)_3 = \int_{outside}^{inside} (\dot{m}\, cp\, T\, dT)_3 = \frac{1}{2}\, (\dot{m}\, cp)_3 \left(T_{3,inside}^2 - T_{3,outside}^2\right) \quad (5)$$

And the equation for the total entransy as a result of heat transfer is:

$$\dot{E}_T = \dot{E}_1 + \dot{E}_2 + \dot{E}_3 = \frac{1}{2}\, [(\dot{m}\, cp)_1 \left(T_{1,inside}^2 - T_{1,outside}^2\right) +$$

$$\frac{1}{2} (\dot{m}\, cp)_3 \left(T_{3,inside}^2 - T_{3,outside}^2\right)] \quad (6)$$

Since the hot oil is divided into two parts, one part flows in the shell side and the other part flows into the inner tubes, and since the temperature readings represent the inlet one of the hot oil while the outlet one represents the hot oil reading after mixing the two streams of hot oil, then the first two terms can be added together and equation (6) can be written as:

$$\dot{E}_T = (m\, cp)_1 \left(T_{1,inside}^2 - T_{1,outside}^2\right) + \frac{1}{2}\, (\dot{m}\, cp)_3 \left(T_{3,inside}^2 - T_{3,outside}^2\right) \quad (7)$$

Flow friction in heat exchanger causes also entransy dissipation rate. Assuming a finite pressure drop between inlet and outlet sides, and the flow is adiabatic and stationary. Then:

$$dE_p = -T\, dp/\rho \quad (8)$$

And the entropy dissipation rate due to friction is given by:

$$\dot{E}_p = \int_{inside}^{outside} \dot{m} \frac{T}{\rho} dp \quad (9)$$

Replacing the temperature with the logarithmic mean temperature difference, assuming incompressible fluid:

$$\dot{E}_p = \frac{\dot{m}\ \Delta \mathrm{p}\, \Delta T_{lm}}{\rho} \quad (10)$$

where: $\Delta p = p_{inside} - p_{outside}$

Considering the shell and double concentric heat exchanger studied, the entransy dissipation rate due to friction is given by the following equation:

$$\dot{E}_p = \left(\frac{\dot{m}\ \Delta \mathrm{p}}{\rho}\right)_1 \frac{T_{1,outside} - T_{1,inside}}{lnT_{1,outside} - lnT_{1,inside}}$$

$$+ \left(\frac{\dot{m}\ \Delta \mathrm{p}}{\rho}\right)_2 \frac{T_{2,outside} - T_{2,inside}}{lnT_{2,outside} - lnT_{2,inside}} + \left(\frac{\dot{m}\ \Delta \mathrm{p}}{\rho}\right)_3 \frac{T_{3,outside} - T_{3,inside}}{lnT_{3,outside} - lnT_{3,inside}} \quad (11)$$

As mentioned above, the first two terms of equation (11) can be added to give the following equation:

$$\dot{E}_p = 2\left[\left(\frac{\dot{m}\ \Delta \mathrm{p}}{\rho}\right)_1 \frac{T_{1,outside} - T_{1,inside}}{lnT_{1,outside} - lnT_{1,inside}}\right] + \left(\frac{\dot{m}\ \Delta \mathrm{p}}{\rho}\right)_3 \frac{T_{3,outside} - T_{3,inside}}{lnT_{3,outside} - lnT_{3,inside}} \qquad (12)$$

The total entransy dissipation rate due to both heat transfer and fluid friction can be written as:

$$\dot{E}_{total} = \dot{E}_T + \dot{E}_p \qquad (13)$$

The entransy dissipation number can be introduced as the heat exchanger performance criteria, where:

$$\dot{E}_T^* = \frac{\dot{E}_T}{\dot{Q}(T_{1inside} - T_{3\ inside})} \qquad (14)$$

where, $T_{1\ inside}$ and $T_{3\ inside}$ represent the maximum hot inlet temperature and the minimum cold inlet temperature, respectively.

According to **Li Xuefang et al in 2011**, eq. (14) can be written in another form as:

$$\dot{E}_T^* = \frac{\dot{E}_T}{\varepsilon(m\ cp)_1(T_{1\ inside} - T_{3\ inside})} \qquad (15)$$

where, $\varepsilon = \frac{actual\ heat\ transfer\ rate}{maximum\ possible\ heat\ transfer\ rate}$

3. EXPERIMENTAL WORK

The laboratory unit of the shell and double concentric tube heat exchanger was built in the laboratories of Chemical Engineering Department, College of Engineering, University of Baghdad. It included: the heat exchanger, tanks with their heating coils to heat the oil, water tank, measuring instruments and control panel of temperature, flow rate and pressure drop. The heat exchanger was designed to perform counter currently, where the hot oil passed through the concentric tubes and the shell, while the cold water passed through the new construction or the annulus formed between the concentric tubes. The heat exchanger unit was built in the laboratories of Chemical Engineering Department, College of Engineering, University of Baghdad.

The new heat exchanger design was conducted according to Kern method. The volumetric flow rates were 4 m^3/hr and 8.35 m^3/hr for the hot oil and water respectively. The hot oil inlet temperature to the heat exchanger was 80ºC to 120ºC, while for water the inlet and outlet temperatures was 20ºC.

The experimental parameters studied were: temperature, flow rate of hot oil, and pressure drop. The temperatures studied were: 80ºC to 120ºC with an increase of 20ºC for each stage. For each temperature, the volumetric flow rate of hot oil was changed from 0.822 kg/m^3 to 0.274 kg/m^3. For cold water, the change in volumetric flow rate of water was 40l/min to 80l/min with an increase of 20l/min for each stage.

The test section was a shell- and - double concentric tube heat exchanger with dimensions of 1.3 m in length and 1.08 m effective tube length.

The shell and double concentric tube heat exchanger was designed for counter flow configuration. The heat exchanger constituted of: a bundle of 16 carbon steel tubes of 20 mm inside diameter and 25 mm outside diameter was used; the tubes are distributed as a triangular 30° tube pattern. The clearance between two adjacent tubes is 6.25 mm, with the tubes pitch of 31.25 mm. A second bundle of 16 carbon steel tubes of 6 mm inside diameter and 10 mm outside diameter, were added concentrically in each of the mentioned tubes. Plate of carbon steel with 8 mm thickness was used to construct the shell. The shell inner diameter is 203 mm, and the shell outer diameter is 220 mm. Baffles of thickness 6 mm were spaced by a distance of 100 mm. The free section left was of 25%. Two fluids were used to complete the cycle of the heat exchanges. The first one which passed through the shell side and the inner tubes side is forty stock oil (lube oil) from Dorra Refinery, while the other counter current stream is water. Figure (1) shows the concentric tubes arrangement of the heat exchanger studied.

The parameters to be measured during the test were:

1. The inlet and outlet temperatures of the tube side (inner and annulus) and shell side.
2. The inlet and outlet pressures of the tube (inner and annulus) side and shell side.
3. The flow rates of the tube side and the shell side.

The cold and hot oil are switched at the same time and the required flow rate was set.

After reaching the steady state conditions, the flow rate of cold water in the annulus is fixed, and the hot oil temperature is set by a thermostat. The range of hot oil temperature studied is 120-80°C with a step change of 20°C. The flow rate of hot oil is regulated. The temperatures of water are recorded with the variation in flow rate. The inlet and outlet pressures are also measured. The procedure was repeated with the change in flow rate of cold water.

4. RESULTS AND DISCUSSION

Table (1.a) to **table (3.c)** give the results of equation (7) for different inlet oil temperature, constant flow rate of cold water and inlet temperature of cold water.

Plotting the entransy dissipation rate of **table (1.a)** to **table (3.c)** against the outlet temperature of the hot stream, an increase in the entransy dissipation rate is pronounced with the temperature as shown in **Fig. 2** to **Fig. 10**.

Fig. 2 to **Fig. 10** shows that there is almost a unique trend, where an increase at the beginning, a maximum value and finally a decrease is noticed. This is in accordance with an increase in the heat transfer process with the flow of the hot oil in both the inner tubes and the shell counter-currently with the cold water in the annulus. It must be known that the entransy is dissipated due to the irreversibility of the heat transfer process. Also, it should be noted that increasing or improving the heat transfer performance of a heat exchanger normally corresponds to an increase in its heat transfer area and to a reduction in its cost due to the decrease in its mass or compactness. The newly used heat exchanger provides all the above mentioned parameters. From figures 2 to 10 it can be deduced that the higher the entransy dissipation rate the smaller is the reversibility in the heat exchanger. This was in agreement with **,Jiangfeng, and Mingtian, 2012.**

The hot oil flow rate was plotted vs. entransy dissipation rate in Fig.11. The dissipation rate shows the same trend, where a maximum is noticed for a certain value of flow rate. According to **,Li Xuefang et al., in 2011.** the reduction in the irreversible entransy dissipation rate is gained by increasing the heat transfer area with the minimum possible flow rate.

Using Eq.(12), the entransy dissipation rate due to friction effect or pressure drop across the heat exchanger is shown in Fig.12. It is shown that a small difference is found for all the experiments.

Comparing the values of entransy dissipation rate due to heat transfer with that due to pressure drop shows that the last can be neglected. This proves that heat transfer plays the great role in calculation of entransy dissipation rate. These findings were in agreement with **,Jiangfeng and ,Mingtian, 2012.** viewpoint. Thus it is important to optimize the heat exchanger design according to the heat transfer process.

It is must be noticed that to get the most optimum thermodynamically performance of a process, it is very important to minimize the entransy dissipation rate. Thus working in the range before maximum values in figures 2 to 11 will give such phenomena.

Entransy dissipation number can be calculated from Eq.(14). The results are represented in Fig. 13. The figure showed that entransy dissipation number values ranged from 3 to more than 9. The figure also showed that the values of entransy dissipation number decreased with the increase in heat transfer rate for the cases studied (80°C hot oil inlet temperature, 20°C cold water inlet temperature and three values of cold water flow rate; 0.667, 1 and 1.334 kg/s). According to **,Guo JiangFeng et al., 2009.** the decrease in the entransy dissipation number leads to an increase in the effectiveness of the heat exchanger. Or, it can be said that increasing the entransy dissipation number will increase the effectiveness of the heat exchanger. Considering the thermodynamics point of view of this process, entransy dissipation number can be used to assess the performance and effectiveness of such heat transfer process.

5. CONCLUSIONS

A study was made to analyze the idea of entransy dissipation rate on a shell and double concentric tubes heat exchanger. The study included both entransy dissipation rate due to heat transfer and that due to friction or pressure drop. It was found that the first played the greatest role in the calculations in comparison to that of friction or pressure drop.

The study also showed that there was a decrease in the value of entransy dissipation number with the increase in heat transfer rate, which emphasize the increase in the effectiveness of heat exchanger.

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NOMENCLATURE

Cp = specific heat, J/Kkg
E = Entransy
$\dot{E}_P$ = Entransy Dissipation Rate due to friction or pressure drop, WK
$\dot{E}_T$ = Entransy Dissipation Rate due to heat transfer, WK
$\dot{E}_{total}$ = Total entransy dissipation, WK
$\dot{E}_T^*$ = Entransy dissipation number
$\dot{m}$ = Mass flow rate, kg/s
$\dot{Q}$ = Heat transfer rate, J/s
T = Temperature, K
$T_{1inside}$ = Hot oil inlet temperature, K
$T_{1,outside}$ = Hot oil outlet temperature, K
$T_{3inside}$ = Cold water inlet temperature, K
$T_{3inside}$ = Cold water outlet temperature, K
Δp = Pressure drop, Pa
ρ = Density, Kg/m^3
ε = Heat exchanger effectiveness

Table (1.a) Entransy dissipation rate for hot oil inlet temperature of 80˚C, 0.667 kg/m^3 flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	300	322	25.33
0.685	299.5	321	26.17
0.548	299	317	23.27
0.411	298	314	18.71
0.274	297	309	13.75

Table (1.b) Entransy dissipation rate for hot oil inlet temperature of 100˚C, 0.667 kg/m^3 flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	302	331.5	20.52
0.685	301	329	21.02
0.548	300	328	18.01
0.411	299	325	14.24
0.274	298	320	11.19

Table (1.c) Entransy dissipation rate for hot oil inlet temperature of 120˚C, 0.667 kg/m^3 flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	305	335	11.73
0.685	303	332	12.73
0.548	302	329.5	11.3
0.411	301	328	8.315
0.274	300.5	324	5.28

Table (2.a) Entransy dissipation rate for hot oil inlet temperature of 80˚C, 1 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	301.5	330	26.8
0.685	300	326	27.55
0.548	299	324	25.5
0.411	298	322	19.61
0.274	297	316	14.69

Table (2.b) Entransy dissipation rate for hot oil inlet temperature of 100˚C, 1 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	299.5	321	17.01
0.685	298.5	318	18.14
0.548	297	314	15.55
0.411	296.5	312	12.18
0.274	295.5	307	9.55

Table (2.c) Entransy dissipation rate for hot oil inlet temperature of 120˚C, 1 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	304	333	10.25
0.685	302	330	11.78
0.548	300.5	326	12.15
0.411	299.5	323	9.74
0.274	298	318	7.56

Table (3.a) Entransy dissipation rate for hot oil inlet temperature of 80˚C, 1.334 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	299	320	28.07
0.685	297.5	316	28.79

0.548	297	314	23.85
0.411	296	311	19.54
0.274	295	306	14.84

Table (3.b) Entransy dissipation rate for hot oil inlet temperature of 100˚C, 1.334 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

M_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	301	329	16.07
0.685	299.5	326	17.6
0.548	298.5	323	14.66
0.411	297	319	13.47
0.274	296	315	9.92

Table (3.c) Entransy dissipation rate for hot oil inlet temperature of 120˚C, 1.334 kg/s flow rate of cold water and 20˚C inlet temperature of cold water.

m_1, kg/m^3	$T_{3outside}$, K	$T_{1outside}$, K	Entransy dissipation rate*10^{-6}
0.822	302	332	10.32
0.685	301	329	10.69
0.548	300	325	10.63
0.411	299	322	8.46
0.274	297	317	7.53

Figure 1 The concentric tubes arrangement.

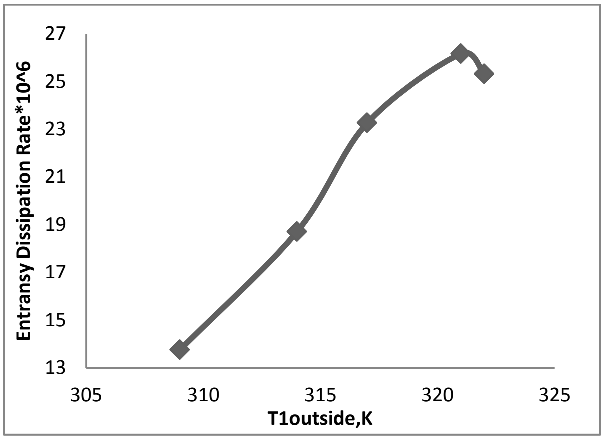

Figure 2. Entransy dissipation rate vs. $T_{1outside}$ for 0.667 kg/s flow rate and 20˚C inlet temperature of cold water.

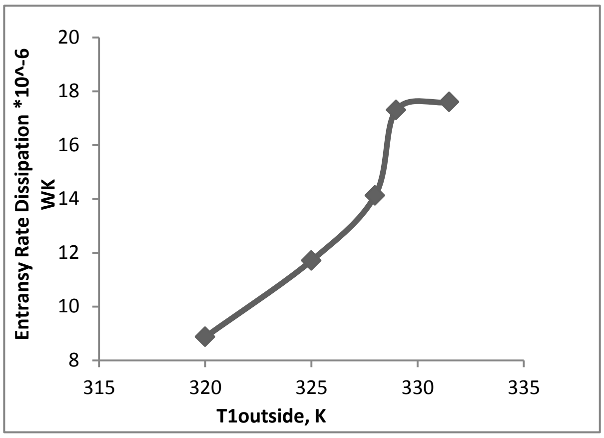

Figure 3. Entransy dissipation rate vs. $T_{1outside}$ for 0.667 kg/s flow rate and 20˚C inlet temperature of cold water.

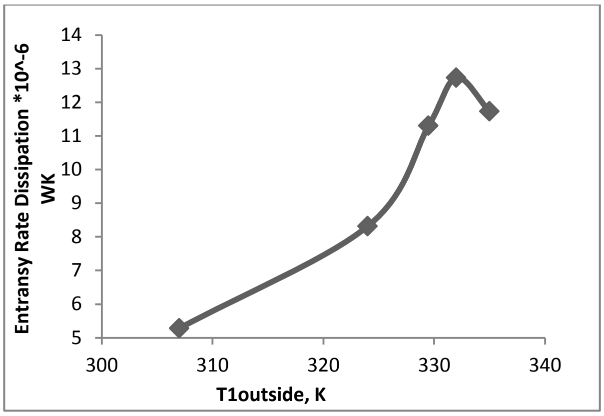

Figure 4. Entransy dissipation rate vs. $T_{1outside}$ for 0.667 kg/s flow rate and 20˚C inlet temperature of cold water.

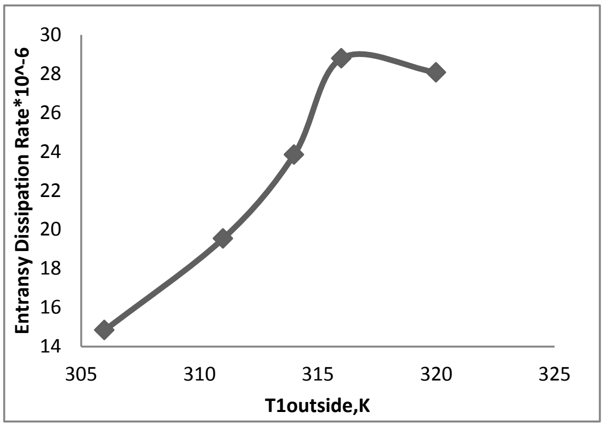

Figure 5. Entransy dissipation rate vs. $T_{1outside}$ for 1 kg/s flow rate and 20˚C inlet temperature of cold water.

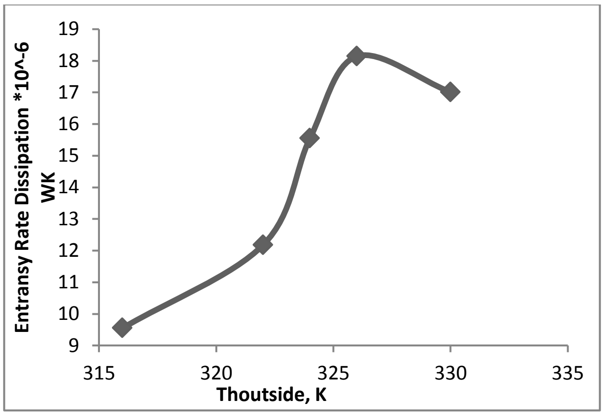

Figure 6. Entransy dissipation rate vs. $T_{1outside}$ for 1 kg/s flow rate and 20˚C inlet temperature of cold water.

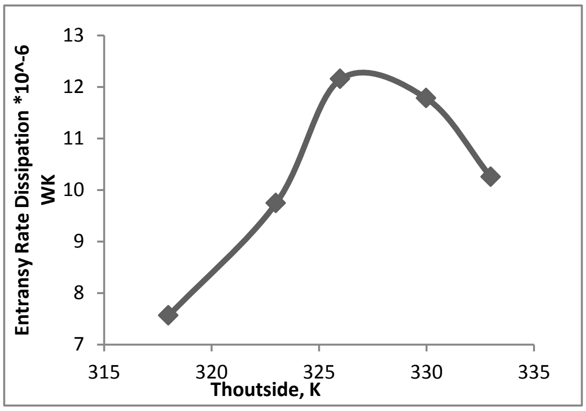

Figure 7. Entransy dissipation rate vs. $T_{1outside}$ for 1 kg/s flow rate and 20˚C inlet temperature of cold water.

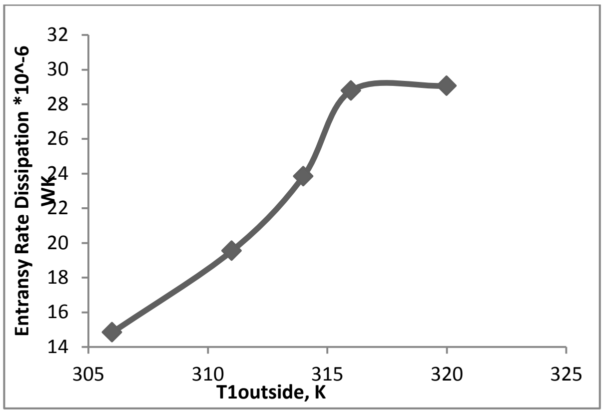

Figure 8. Entransy dissipation rate vs. $T_{1outside}$ for 1.334 kg/s flow rate and 20˚C inlet temperature of cold water.

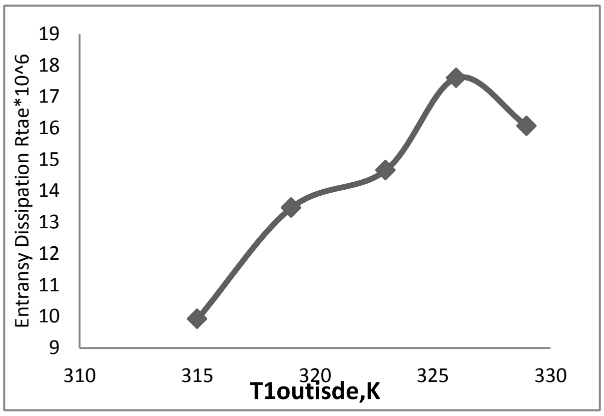

Figure 9. Entransy dissipation rate vs. $T_{1outside}$ for 1.334 kg/s flow rate and 20˚C inlet temperature of cold water.

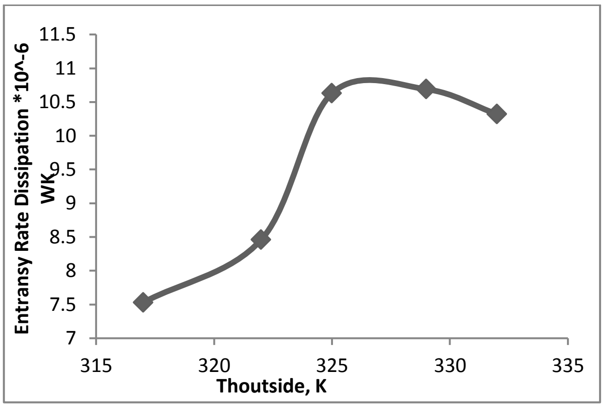

Figure 10. Entransy dissipation rate vs. $T_{1outside}$ for 1.334 kg/s flow rate and 20˚C inlet temperature of cold water.

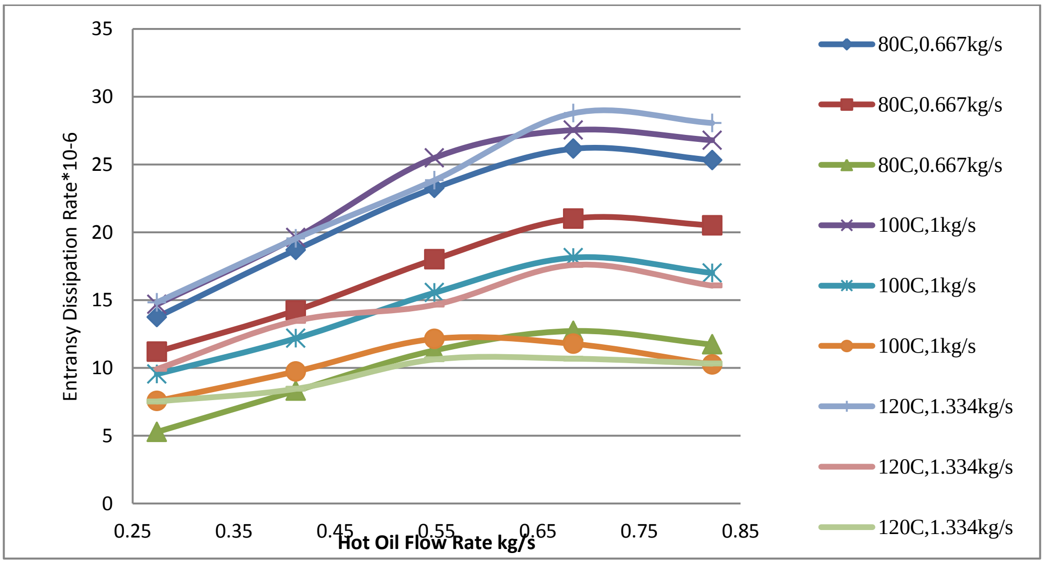

Figure 11. Entransy Dissipation Rate vs. Hot Oil Flow Rate.

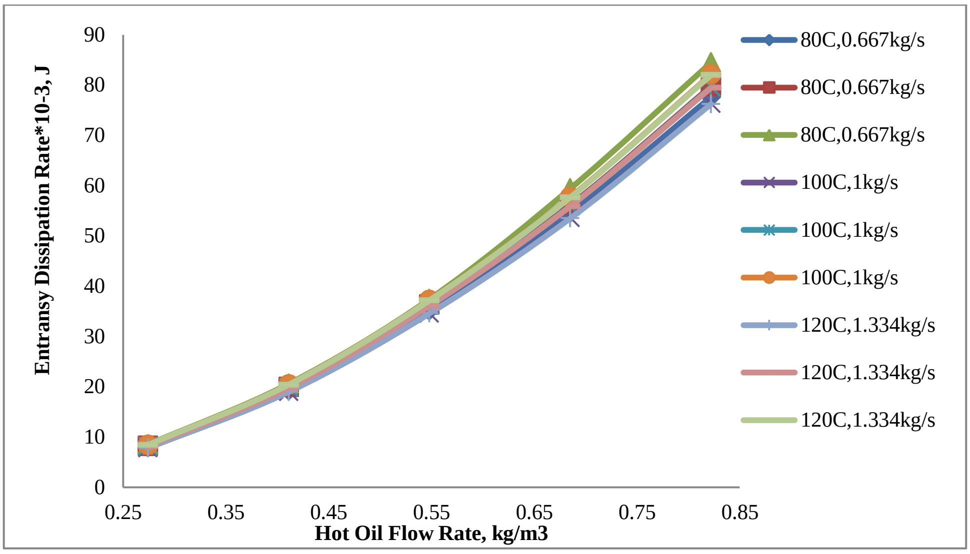

Figure 12. Entransy Dissipation Rate of friction factor vs. Hot Oil Flow Rate.

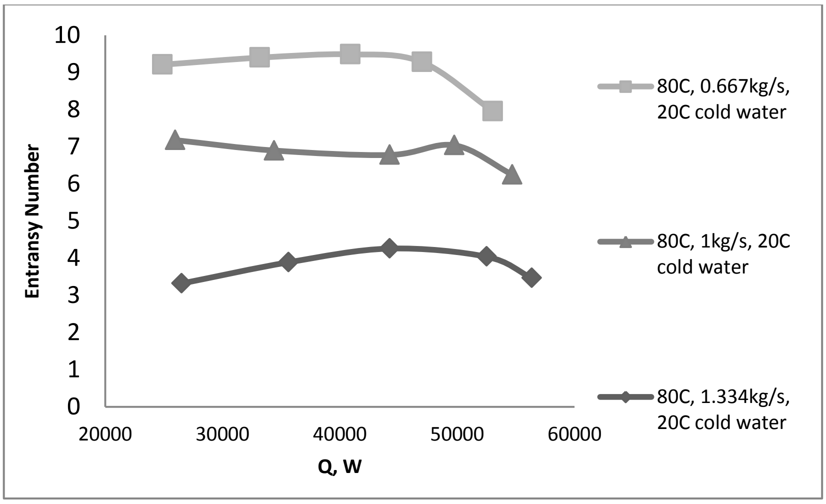

Figure 13. Entransy Dissipation number vs. Heat transfer rate.