ENTRANSY DISSIPATION ANALYSIS OF A HEAT EXCHANGER SUBJECTED TO EXTERNAL HEAT LEAK

Roopesh Tiwari
Department of Mechanical Engineering, SAGE University, Indore

Govind Maheshwari
Department of Mechanical Engineering, Institute of Engineering and Technology, DAVV, Indore

ABSTRACT-The concept of heat leak has been utilized in this work to determine the entransy dissipation number of a parallel flow and counter flow heat exchanger. The analytical solution is presented here by considering hot fluid having the minimum heat capacity. The effect of varying the heat capacity ratio on the entransy dissipation number has been depicted graphically for both parallel flow and counter flow heat exchanger, when the heat exchanger is subjected to external heat leak. The entransy dissipation number decreases with increase in Number of Transfer Units for both parallel and counter flow heat exchanger. Further, the increase in heat leak increases the entransy dissipation for parallel flow as well as counter flow heat exchanger. As compared to parallel flow, the counter flow arrangement gives the better results for different values of heat capacity ratio.

***KEY WORDS* -Heat leak, Entransy dissipation, Entransy dissipation Number, Heat Capacity Ratio, Heat exchanger**

INTRODUCTION

Since the inception of the concept of entransy [1], lot of work has been done by the researchers in the field of heat transfer by applying the concept of entransy [2-8].The fossil fuels are vanishing rapidly owing to the greater demand of energy by the industries. Heat exchangers are a major part of many industries. To reduce the energy consumption utilized in heat exchangers, the concept of entransy has been used to enhance the heat exchanger performance [9-11].The concept of entransy dissipation number has been given by Guo *et al* [12], with the finding that the decrease in entransy dissipation number increases the heat exchanger performance in terms of effectiveness.

Further the heat leakage affects drastically the performance of a heat exchanger. Chowdhury and Sarangi [13] studied the effect of heat leak on counter flow heat exchanger by assuming that the minimum heat capacity is on the hot fluid side. Barron [14] analyzed the counter flow heat exchanger by considering heat leak to be on the hot side or the cold side. The other author included the effect of heat leakage on effectiveness-NTU relations for parallel flow heat exchanger [15]. Recently the analysis has been done based on efficiency-NTU relations for parallel flow and counter flow heat exchanger subjected to heat leak [16-17].

This paper analyzes the entransy dissipation of parallel flow and counter flow heat exchangers in the presence of heat leak. The entransy dissipation number as defined by an author earlier [12], is referred. The heat leak is introduced and the mathematical model for the entransy dissipation number is developed.

ANALYTICAL SOLUTION

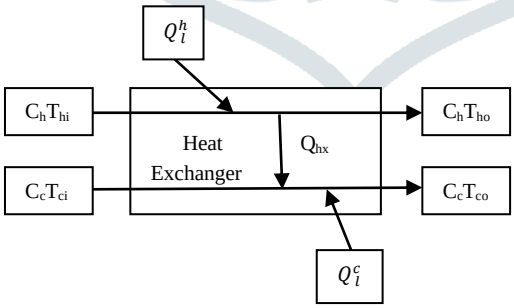

Fig. 1 Heat transfer in hot side and cold side of the parallel flow heat exchanger.

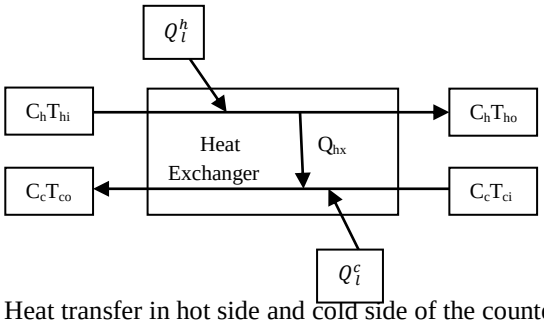

Fig. 2 Heat transfer in hot side and cold side of the counter flow heat exchanger.

Heat transfer in presence of heat leak is depicted in fig.1 and fig.2. Where Q_l^h and Q_l^c are the heat leaks in the hot fluid side and cold fluid side respectively (J). C_h and C_c are the heat capacities of hot fluid and cold fluid (J/K), T_{h_i} and T_{h_o} are the inlet and outlet temperatures of hot fluid (K), T_{c_i} and T_{c_0} are the inlet and outlet temperatures of the cold fluid (K), Q_{hx} is the heat transferred to the cold fluid by the hot fluid (J).

The entransy dissipation number (E) is the ratio of actual entransy dissipation (E_{act}) (J·K) to the maximum entransy dissipation (E_{max}) (J·K).

$$E = \frac{E_{act}}{E_{max}} \tag{1}$$

Actual entransy dissipation is the difference of entransy dissipation of the cold fluid and hot fluid at the inlet and entransy dissipation of the cold fluid and hot fluid at the outlet of the heat exchanger. Whereas the maximum entransy dissipation is the product of actual heat transfer and the maximum temperature difference of the cold and hot fluid.

Thus from eq (1), the entransy dissipation number can be written as,

$$E = \frac{\frac{1}{2}(C_h T_{hi}^2 + C_c T_{ci}^2) - \frac{1}{2}(C_h T_{ho}^2 + C_c T_{co}^2)}{Q_{act}(T_{hi} - T_{ci})} \tag{2}$$

Considering the heat capacity of the hot fluid to be the minimum, the effectiveness (ε) of the heat exchanger is given as, $\varepsilon = \frac{Q_{act}}{Q_{max}} = \frac{T_{h_i} - T_{h_o}}{T_{h_i} - T_{c_i}}$ (3)

Thus eq (2) transforms to

$E = \frac{\frac{1}{2}(C_h T_{hi}^2 + C_c T_{ci}^2) - \frac{1}{2}(C_h T_{ho}^2 + C_c T_{co}^2)}{\varepsilon \cdot Q_{max} \cdot (T_{hi} - T_{ci})}$, on substituting the value of maximum heat transfer, the equation for entransy dissipation number is obtained as

$$E = \frac{C_h(T_{hi}^2 - T_{ho}^2) + C_c(T_{ci}^2 - T_{co}^2)}{2\varepsilon \cdot C_{min} \cdot (T_{hi} - T_{ci})^2} \tag{4}$$

On rearranging, the eq (4) modifies as,

$$E = \frac{\varepsilon(T_{hi} - T_{ci})(T_{hi} + T_{ho}) + \frac{(T_{ci} + T_{co})(T_{ci} - T_{co})}{R}}{2\varepsilon \cdot (T_{hi} - T_{ci})^2} \tag{5}$$

From fig. 1 and fig. 2, energy balance on the hot fluid side and cold fluid side of the parallel and counter flow heat exchanger gives,

$C_h(T_{h_i} - T_{h_o}) + Q_l^h = Q_{hx}$ and $C_c(T_{c_0} - T_{c_i}) - Q_l^c = Q_{hx}$

Therefore, $C_h(T_{h_i} - T_{h_o}) + Q_l^h = C_c(T_{c_0} - T_{c_i}) - Q_l^c$ (6)

From eq (6) the outlet temperature of the cold fluid is obtained as,

$$T_{co} = T_{ci} + R\varepsilon(T_{hi} - T_{ci}) + \frac{Q_l^c}{C_c} + \frac{Q_l^h}{C_c} \tag{7}$$

using eq (3) the outlet temperature of the hot fluid is given as ,

$$T_{h_o} = T_{h_i} - \varepsilon(T_{h_i} - T_{c_i}) \tag{8}$$

Substituting eq (7) and eq (8) in eq (5) and on modification the entransy dissipation number in terms of heat leak is obtained as,

$$E = \frac{2 - \varepsilon(1+R)}{2} - \left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\left[R + \frac{1}{\varepsilon}\left\{\frac{R}{2}\left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{9}$$

τ is the inlet temperature ratio , $\tau = \frac{T_{ci}}{T_{hi}}$

Effectiveness for the parallel flow and counter flow in terms of number of transfer units (NTU) is given as,

$$\varepsilon_{PF} = \frac{1 - exp\{-NTU(1+R)\}}{1+R} \tag{10}$$

$$\varepsilon_{CF} = \frac{1 - exp\{-NTU(1-R)\}}{1 - R \cdot exp\{-NTU(1-R)\}} \tag{11}$$

Using eq (10) and eq (11) in eq (9), the entransy dissipation number for parallel flow and counter flow heat exchanger turns out to be,

$$E_{PF} = \frac{2 - \frac{1 - exp\{-NTU(1+R)\}}{1+R}(1+R)}{2} - \left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\left[R + \frac{1}{\frac{1 - exp\{-NTU(1+R)\}}{1+R}}\left\{\frac{R}{2}\left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{12}$$

$$E_{CF} = \frac{2 - \frac{1 - exp\{-NTU(1-R)\}}{1 - R \cdot exp\{-NTU(1-R)\}} \cdot (1+R)}{2} - \left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\left[R + \frac{1}{\frac{1 - exp\{-NTU(1-R)\}}{1 - R \cdot exp\{-NTU(1-R)\}}}\left\{\frac{R}{2}\left(\frac{Q_l^c}{Q_{max}} + \frac{Q_l^h}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{13}$$

With the heat leak only on the hot side the eq (12) and eq (13) reduce to,

$$E_{PF} = \frac{2 - \frac{1 - exp\{-NTU(1+R)\}}{1+R}(1+R)}{2} - \left(\frac{Q_l^h}{Q_{max}}\right)\left[R + \frac{1}{\frac{1 - exp\{-NTU(1+R)\}}{1+R}}\left\{\frac{R}{2} \cdot \left(\frac{Q_l^h}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{14}$$

$$E_{CF} = \frac{2 - \frac{1 - exp\{-NTU(1-R)\}}{1 - R \cdot exp\{-NTU(1-R)\}} \cdot (1+R)}{2} - \left(\frac{Q_l^h}{Q_{max}}\right)\left[R + \frac{1}{\frac{1 - exp\{-NTU(1-R)\}}{1 - R \cdot exp\{-NTU(1-R)\}}}\left\{\frac{R}{2} \cdot \left(\frac{Q_l^h}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{15}$$

Similarly when the heat leak is only on the cold side the eq (12) and eq (13) become,

$$E_{PF} = \frac{2 - \frac{1 - exp\{-NTU(1+R)\}}{1+R}(1+R)}{2} - \left(\frac{Q_l^c}{Q_{max}}\right)\left[R + \frac{1}{\frac{1 - exp\{-NTU(1+R)\}}{1+R}}\left\{\frac{R}{2} \cdot \left(\frac{Q_l^c}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau} - 1}\right] \tag{16}$$

$$E_{CF} = \frac{2-\frac{1-exp\{-NTU(1-R)\}}{1-R\cdot exp\{-NTU(1-R)\}}\cdot(1+R)}{2} - \left(\frac{Q_l^c}{Q_{max}}\right)\left[R + \frac{1}{\frac{1-exp\{-NTU(1-R)\}}{1-R\cdot exp\{-NTU(1-R)\}}}\left\{\frac{R}{2}\cdot\left(\frac{Q_l^c}{Q_{max}}\right)\right\} - \frac{1}{\frac{1}{\tau}-1}\right] \quad (17)$$

When the heat leak ratio is same for the hot side and cold side, the eq (14) and eq (16) give the similar results for entransy dissipation number for parallel flow arrangement. Similarly eq (15) and eq (17) give the similar results for entransy dissipation number for counter flow arrangement when the heat leak ratio has the same value for the hot side and the cold side.

Moreover when the heat leak on both the hot side and cold side is eliminated and made zero, the expression for entransy number dissipation number is reduced to,

$E = \frac{2-\varepsilon(1+R)}{2}$, which is the same as given by a different author.

RESULTS AND DISCUSSION

The variation of entransy dissipation number with respect to NTU has been represented. Figures 3, 4, 5 and figure 6 depict the results for parallel flow arrangement for different values of heat capacity ratio. The graphs show that the entransy dissipation number decreases with the increasing values of NTU. The decline is greater for the lower values of NTU. After the value of NTU=3, the entransy dissipation number is almost constant. This trend of variation is similar for different values of heat capacity ratio R, ranging from R=0.25 to R=0.9.

Further, the entransy dissipation number increases with the increase in the heat leak on the hot side, for different values of heat capacity ratio. This can be explained by the energy balance on the hot side. The increase in the heat leak on the hot side increases the outlet temperature of the hot fluid. The increase in the outlet temperature of hot fluid causes the entransy dissipation to increase as clear from eq (5).

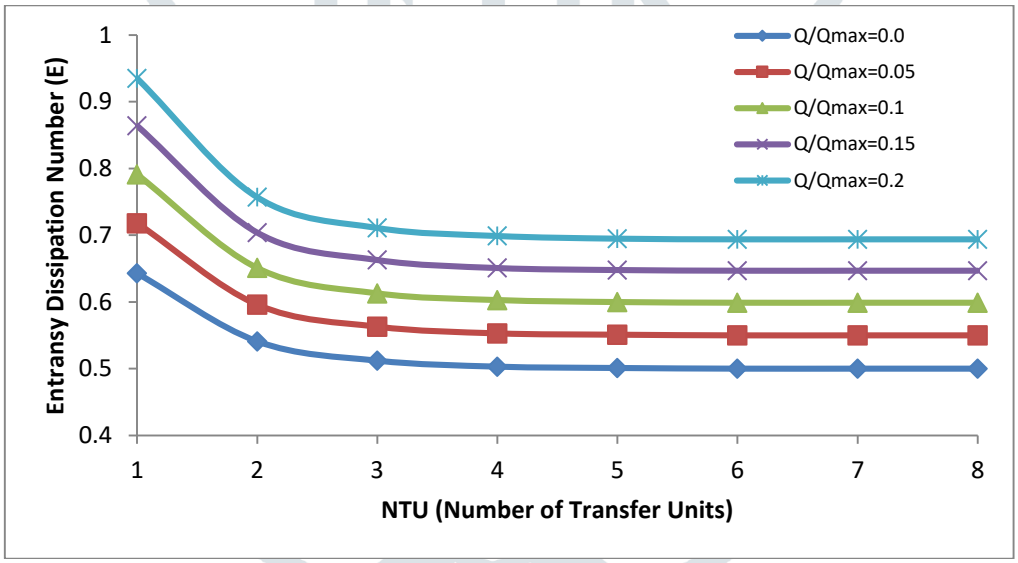

Fig.3 Variation of Entransy dissipation Number with NTU for Parallel flow Subjected to Heat Leak (R=0.25, τ=0.5)

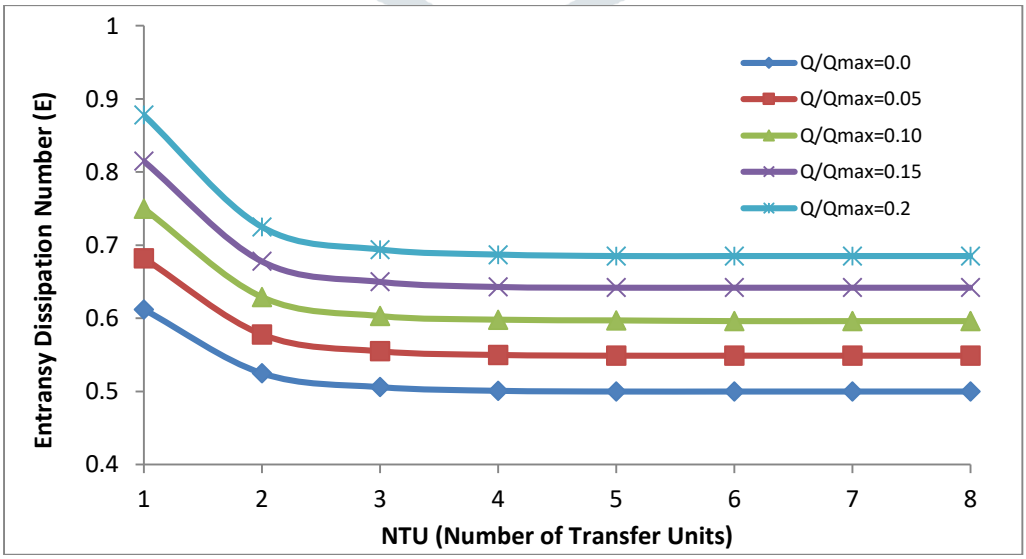

Fig.4 Variation of Entransy dissipation Number with NTU for Parallel flow Subjected to Heat Leak (R=0.5, τ=0.5)

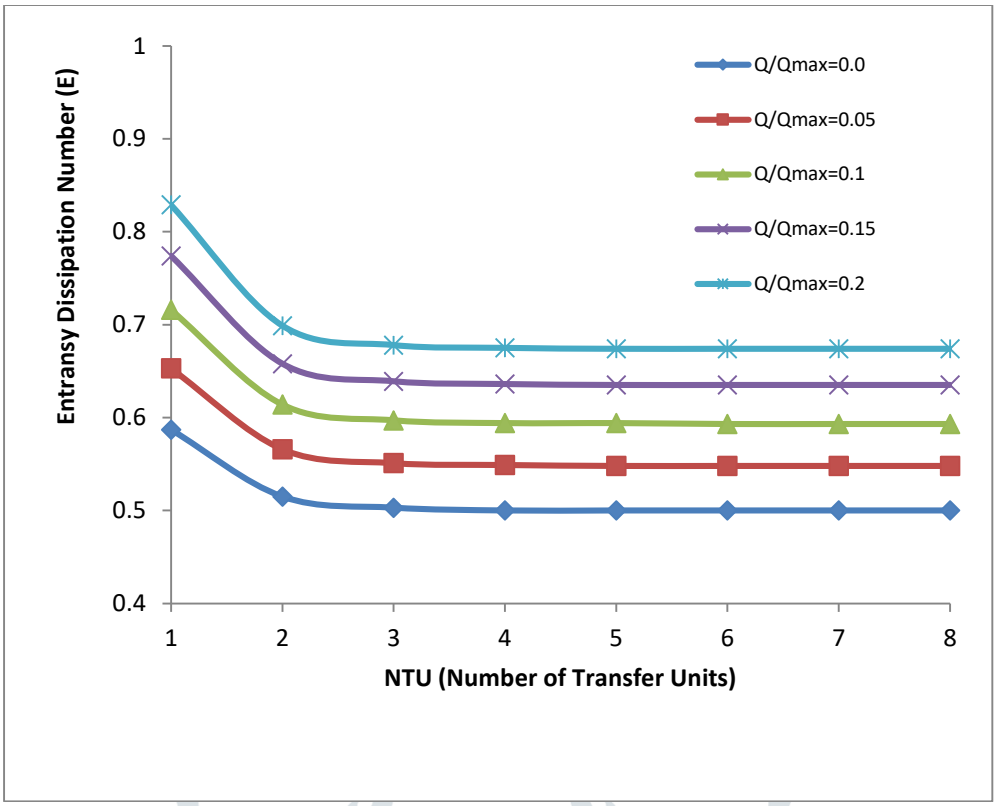

Fig.5 Variation of Entransy dissipation Number with NTU for Parallel flow Subjected to Heat Leak (R=0.75, τ = 0.5)

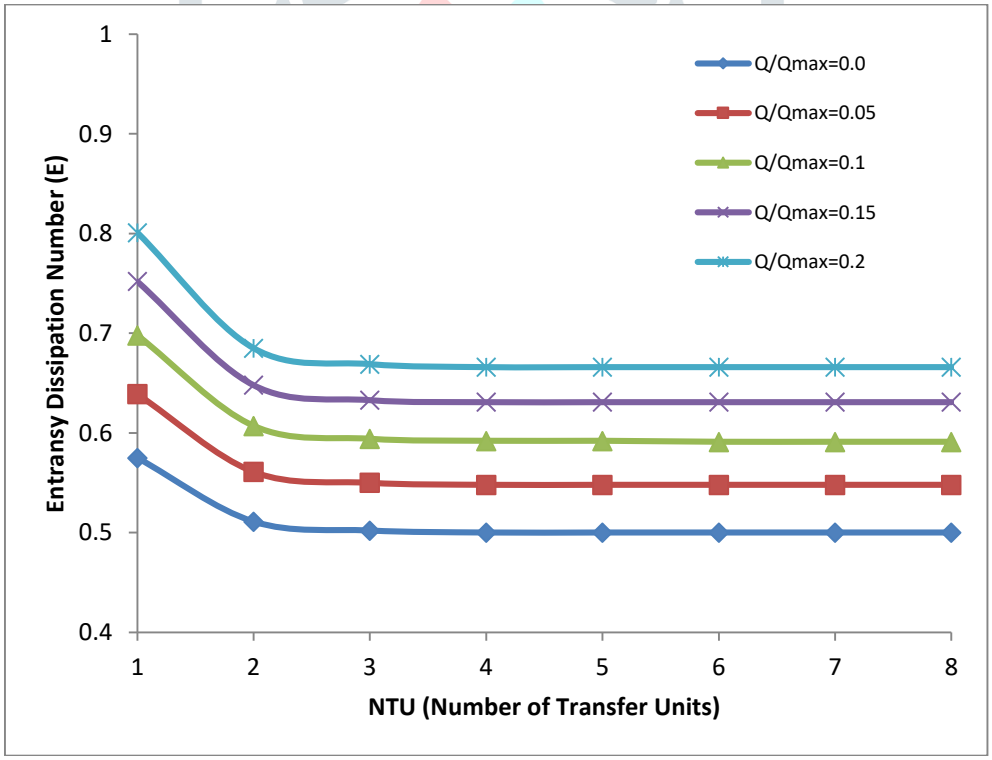

Fig.6 Variation of Entransy dissipation Number with NTU for Parallel flow Subjected to Heat Leak (R=0.9, τ = 0.5)

The results for counter flow arrangement are as shown in figures 7, 8, 9 and figure 10. There is a continuous decrease in the entransy dissipation number with increasing values of NTU. Decrement is gradual after NTU=3 for heat capacity ratio R=0.25. As the value of R is increased, the decline is more and almost reaches E=0.1 for R=0.9.

The results also show that the increase in heat leak on hot side cause the entransy dissipation number to increase. The same reasons are valid for counter flow arrangement as given for parallel flow.

Also it has been found that the counter flow arrangement gives the better results for all the values of heat capacity ratio and heat leak, as compared to parallel flow arrangement.

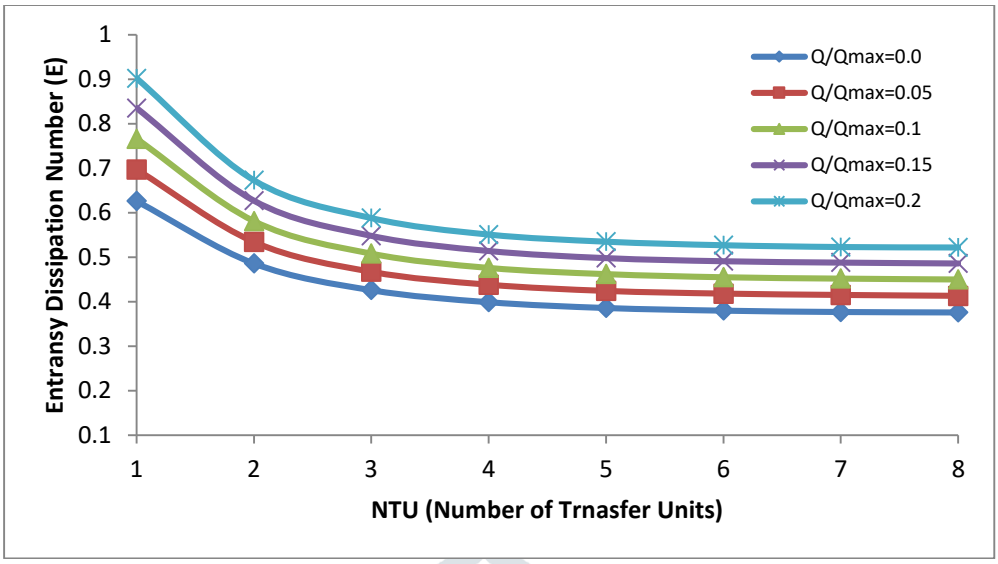

Fig.7 Variation of Entransy dissipation Number with NTU for Counter flow Subjected to Heat Leak (R=0.25, τ=0.5)

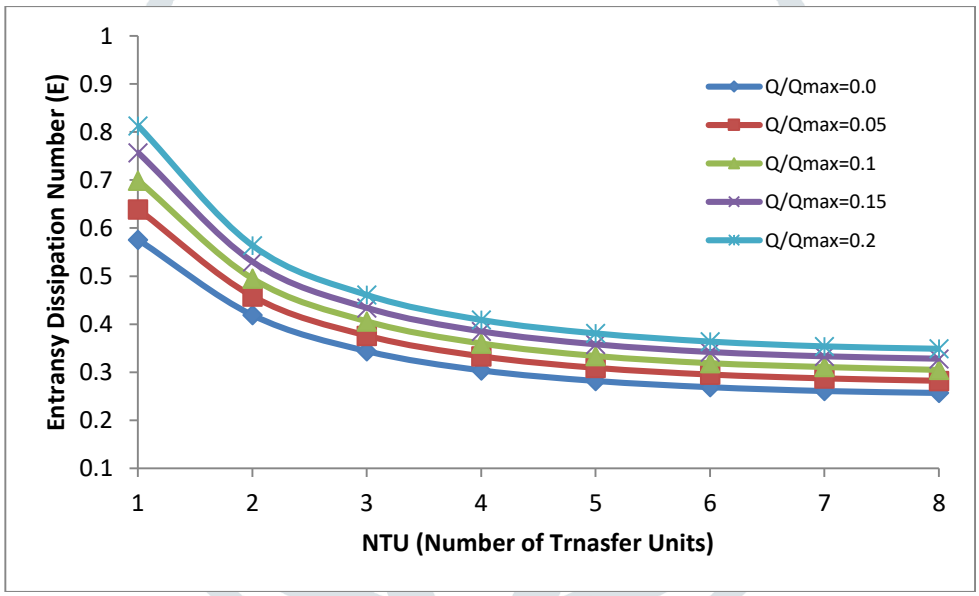

Fig.8 Variation of Entransy dissipation Number with NTU for Counter flow Subjected to Heat Leak (R=0.5, τ=0.5)

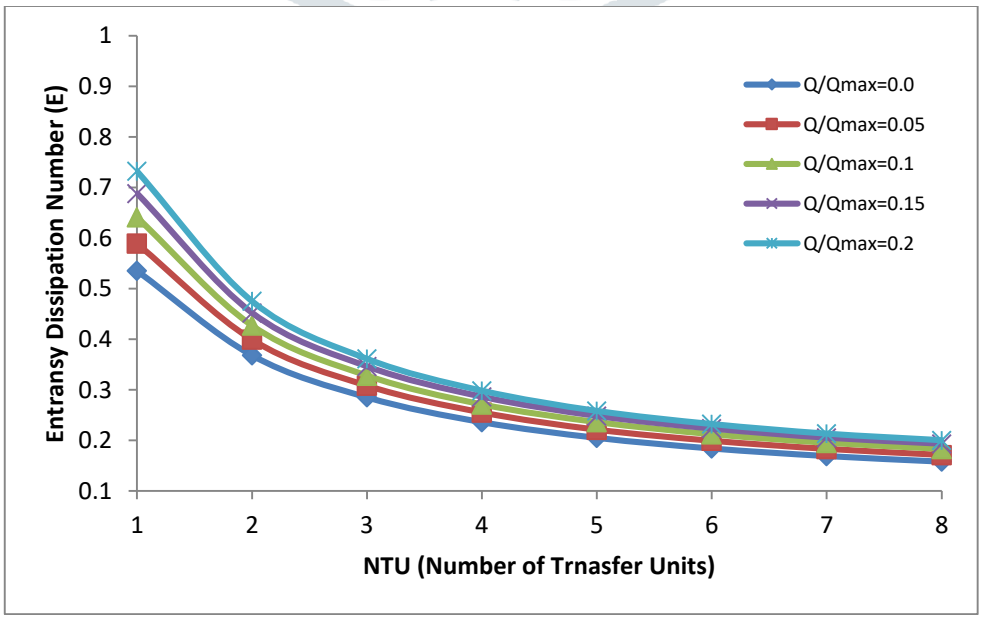

Fig.9 Variation of Entransy dissipation Number with NTU for Counter flow Subjected to Heat Leak (R=0.75, τ=0.5)

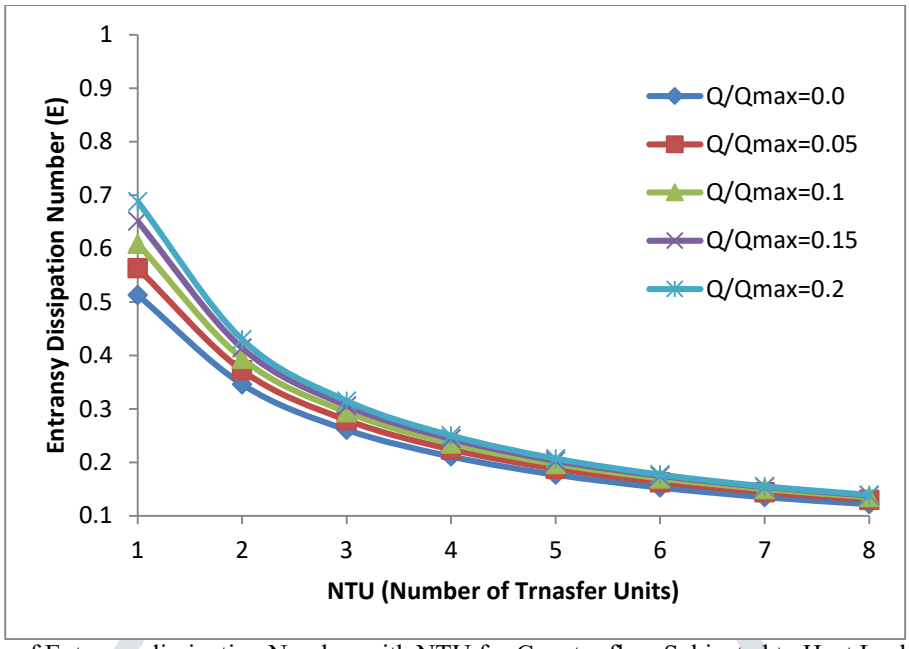

Fig.10 Variation of Entransy dissipation Number with NTU for Counter flow Subjected to Heat Leak (R=0.9, τ=0.5)

CONCLUSION

The results show that the entransy dissipation number decreases with the increasing values of NTU when heat leakage is taken into account. Thus the lower values of NTU give the better performance of heat exchanger in terms of entransy dissipation number. Also the increase in the heat leak leads to increased entransy dissipation number for both parallel flow and counter flow heat exchanger, reflecting the poor performance of the heat exchanger. Further it is observed that the higher the values of heat capacity ratio the better the performance of the heat exchanger. As expected, the counter flow heat exchanger has an edge over the parallel flow heat exchanger.

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