International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 3, May-June-2024, ISSN (Online): 2395-566X

Availability Analysis of Tube in Tube Heat Exchanger

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Abstract- The Heat Exchangers are used to transfer heat between one fluid and another fluid without allowing two fluids to come into direct contact with each other, the fluids may be either liquid or gaseous form. In this paper we are going to perform analysis for tube in tube Heat Exchanger. The availability Analysis involves the identification of the Heat transfer rate, Entropy Generation, Availability loss. In this paper the availability analysis is performed for tube in tube heat exchanger by considering four working fluids, water, N- pentane, Mineral oil, Glycol, with two flow arrangements, parallel flow and counter flow. And the four working fluids are compared each other. After the availability analysis is performed, graphs are drawn for the four working fluids and compared. It seems to be that the water has high heat transfer rate than other working fluids, also the entropy generation and the availability loss is less for the n- pentane, the efficient fluid is n- pentane in this analysis among the four working fluids.

Index Terms- availability, entropy, tube in tube Heat exchanger

I. INTRODUCTION

Heat exchangers are fundamental devices used in various industries to transfer heat between two or more fluids while keeping them physically separated. They play a crucial role in heating, cooling, and thermal management processes across a wide range of applications, from HVAC systems and refrigeration units to power plants and chemical processing facilities. Heat exchangers come in various designs tailored to specific applications and operating conditions. Common types include shell and tube heat exchangers, plate heat exchangers, finned-tube heat exchangers, tube in tube heat exchangers, and spiral heat exchangers. Each type offers unique advantages in terms of heat transfer efficiency, compactness, ease of maintenance, and cost-effectiveness.

There are a number of factors to think about when choosing a heat exchanger. The following are some of the most crucial considerations:

1. Heat Transfer Requirements

The size and type of heat exchanger are determined by the amount of heat transfer required. The type of fluids used, the temperature range, and the required flow rates will all have an impact on this.

2. Material Compatibility

The materials used to design the heat exchanger must be suitable for the fluids being transferred. If the fluids are corrosive or abrasive, this is especially crucial.

3. Operating Conditions

When choosing a heat exchanger, the operating conditions, such as pressure, temperature, and flow rate, must be taken into consideration. Under these circumstances, the heat exchanger must be capable of performing safely and effectively.

4. Energy Efficiency

It is important to optimize energy efficiency when designing the heat exchanger. This can be done by picking the appropriate heat exchanger type and customizing the design for the intended use.

Availability and Entropy Generation

The availability of a system is the maximum useful work that can be produced as the system is brought into equilibrium with its environment by an ideal process. Energy is neither created nor destroyed, but is simply converted from one form to another. In contrast to energy, availability is always destroyed when a process is non-ideal or irreversible.

Entropy Generation: Entropy generation occurs within a heat exchanger due to irreversibilities in the heat transfer process. These irreversibilities can include fluid friction, heat conduction through finite temperature differences, and mixing effects. As heat is transferred from the hot fluid to the cold fluid, entropy increases in both streams due to these irreversible processes.

Mohammad Mahdi et al. [1] studied the experimental study on the effect of air bubble injection as an active method in thermal performance of a double pipe heat exchanger is conducted. Air bubbles are injected into annulus side through different injectors. Experimental data are collected for different tube and annulus side flow rates. The effects of air flow rate and the angle of heat exchanger positioning on its thermal performance are investigated along with exergetic analysis. Obtained results show that the overall heat transfer coefficient can be improved through air bubble injection by 10.3% to 149.5%.

Morteza Hangi et al. [2] has observed Heat transfer enhancement is for all studied configurations of DPHX compared to the plain DPHX. The helical inserts and strips increase the effective surface area, and also create secondary flows and higher mixing in tube- and annulus-side.

Salar Zeinali et al. [3] has investigated the availability and exergoeconomic study of a heat exchanger with a shell and spiral tube, considering different geometries. The Realizable k-ε turbulent model is employed to simulate the heat exchanger and irreversibility calculation in the shell and spiral tube. The numerical results in this study are validated through experimental data from previous research. The influences of the different geometrical parameters on purchased equipment cost, heat exchanger irreversibility as well as efficiency of the second law are investigated.

M. M. Rashidi et al.[4] have studied the entropy generation and availability analysis of shell and tube heat exchanger (as one of the most common types of HEs) are comprehensively reviewed and discussed. It can be concluded that modification in the thermos-physical properties of the fluids would lead to reduction in the entropy generation and consequently higher availability efficiency.

Mohammad H. Ahmadi et al.[5] have studied a transcritical CO2 cycle via geothermal resources to produce electrical energy. Heat sink of this cycle is Liquefied natural gas (LNG) to drop back pressure of the CO2 turbine greatly. It is presumed that the system works under steady state situations to establish the mathematical model of the transcritical CO2 geothermal power generation system.

Audai Hussein Al-Abbas et al.[6] have investigated the availability analysis on shell and helically coiled tube heat exchanger are carried out for free convection heat transfer. The measured data are totally optimised utilizing thermodynamics rules in which availability study is performed to investigate the thermal performance of the helical system under different operating conditions.

The experimental set-up of apparatus are designed and made for cold water and hot water as a working fluid of both the shell side and helical coil side, respectively. The effects of several parameters such as geometry and operational conditions on the availability destruction and dimensionless availability destruction are investigated.

Lun Zhang. Et al. [7] have perfomed Systematic analysis of heat and mass transfer processes which will help researchers better understand the characteristics of heat and mass transfer and improve the design of HVAC systems and equipment.

Throughout the heat and mass transfer process, thermal and humid availability destruction are separated, which illuminates the relationship of heat transfer and mass transfer. Availability destruction caused by the inlet parameters of humid air and water and by the flow rate ratio of air to water will not be eliminated by increasing heat/mass transfer area.

II. AVAILABILITY ANALYSIS WITH DIFFERENT WORKING FLUIDS

Availability of heat exchanger with different working fluids is carried out using different working fluids like water, n-pentane, glycol, and mineral oil.

The analysis is done with varied mass flow rates, inlet and outlet temperatures, and different flow arrangements. The various factors in selecting the working fluids for heat exchanger are viscosity, pressure drop, effectiveness, corrosion resistance, heat transfer rate, Flammability, toxicity etc.

III. AVAILABILITY ANALYSIS

The Availability analysis is done on the four working fluids (water, N- pentane, mineral oil and glycol) and the graphs are produced according to the values obtained in the analysis.

1. Heat Transfer Rate is given by

Q = m*Cp*(T1-T2)
here, m = mass flow rate of fluid.
Cp = Specific heat capacity of fluid.
T1 = Inlet temperature of fluid.
T2 = Outlet temperature of fluid.

2. Effectiveness is given by- (Parallel Flow)

$$\varepsilon = \frac{T_{hi} - T_{ho}}{T_{hi} - T_{ci}}$$

Here T_{hi} is the hot fluid Inlet temperature.
T_{ho} is the hot fluid outlet temperature.
T_{ci} is the cold fluid Inlet temperature.

3. Effectiveness – (Counter Flow)

$$\varepsilon = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}}$$

T_{co} is the outlet temperature of cold fluid.

4. Entropy Generation (Parallel Flow) is given by

$$s_g = m_{h.}c_{ph}.\,ln\frac{T_{ho}}{T_{hi}} + m_{c.}c_{pc}.\,ln\frac{T_{co}}{T_{ci}}$$

Where
c_{ph} and c_{pc} are specific heats of hot and cold fluids.
m_h and m_c are mass flow rates of hot and cold fluids respectively.
For (Counter flow)

$$s_g = m_{h.}c_{ph}.\,ln\frac{T_{ho}}{T_{hi}} + m_{c.}c_{pc}.\,ln\frac{T_{co}}{T_{ci}}$$

4. Availability Loss is given by

$$I = To*Sg$$

here, T_O= reference temperature, 298.15k
S_g = entropy generation

The Availability analysis is carried out in two cases,

Case1: The mass flow rate of the hot fluid is kept constant and the mass flow rate of the cold fluid is varying.

Case2: The mass flow rate of the hot fluid is varying and the mass flow rate of cold fluid is kept constant.
Working Fluid: Water

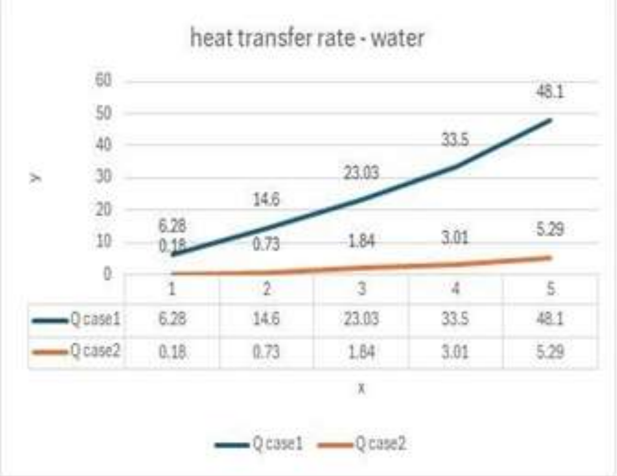

Fig.1 Number of readings Vs Heat transfer rate

Fig.1 shows heat transfer rate is gradually increasing as the mass flow rate of hot fluid is kept constant in case1 and varying in case2. heat transfer rate gradually increases in both cases.

Fig.2 shows With the increased temperatures of inlet and outlet of hot fluid and cold fluid the effectiveness is increased.

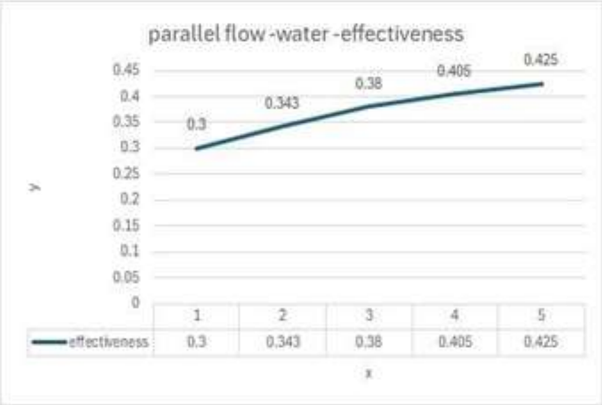

Fig.2 Number of readings Vs Effectiveness.

Fig.3 shows in the counter flow arrangement of heat exchanger, the effectiveness is increased if the temperatures is increasing.

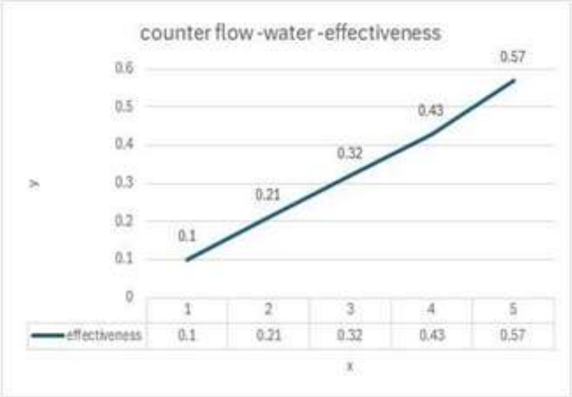

Fig.3 For Counter flow.

Fig.4 shows that if the mass flow rate of hot fluid is kept constant (in case1) the entropy generation for water increases more compared to case.2.

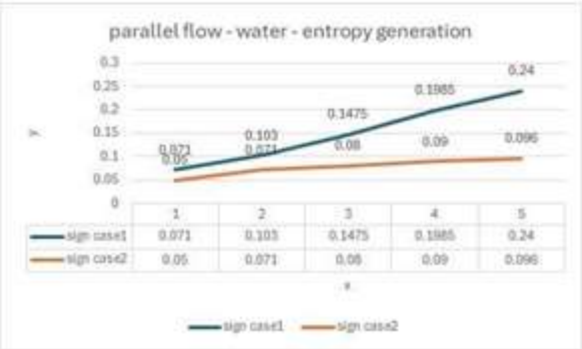

Fig.4. (parallel flow) No.of readings Vs Entropy Generation

Fig.5 shows for counter flow entropy generation is more compared to parallel flow.

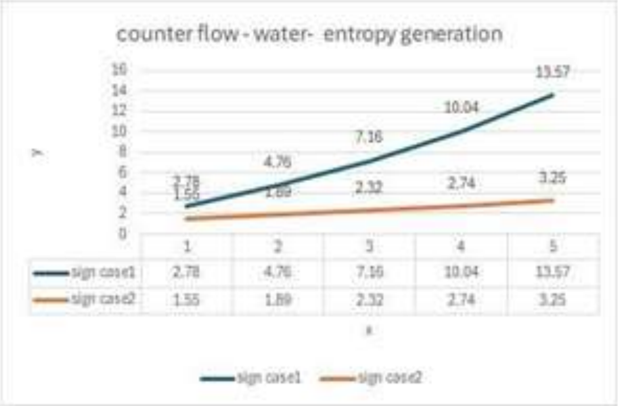

Fig.5 (counter flow) No.of readings Vs Entropy Generation

Fig 6 shows that availability loss increases as entropy increases. It is more in case 1 that in case 2.

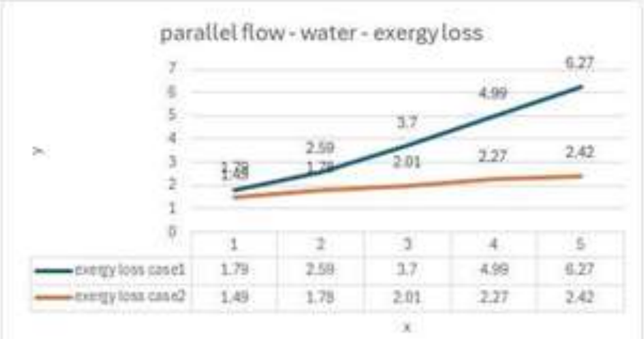

Fig. 6 Availability loss in parallel flow

Availability Analysis of n-pentane

Fig 7 shows the heat transfer rate is more for n- pentane when compared with heat transfer rate of mineral oil.

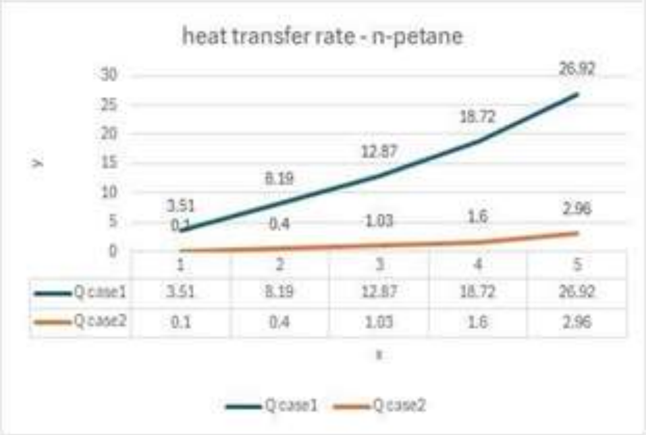

Fig.7 no.of readings Vs heat transfer rate

Fig. 8 Entropy generation for n-pentane is more for n-pentane compared to water.

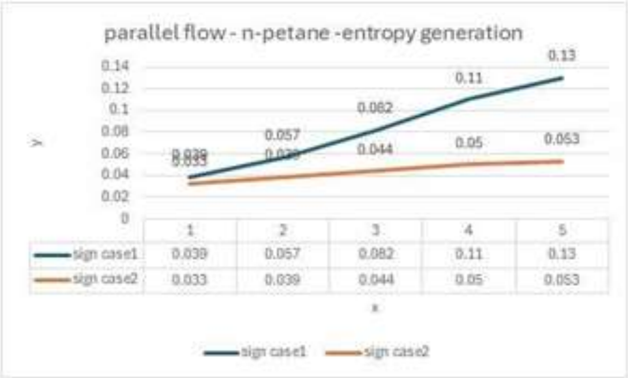

Fig. 8 Entropy generation

Fig. 9 shows the average increment of entropy generation for counter flow arrangement is more than parallel flow arrangement.

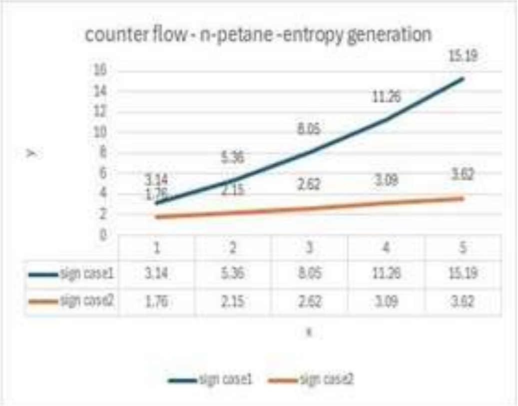

Fig. 9 entropy generation for counter flow for n-pentane

Fig. 10 shows the availability loss for n-pentane is less compared to water in both the cases.

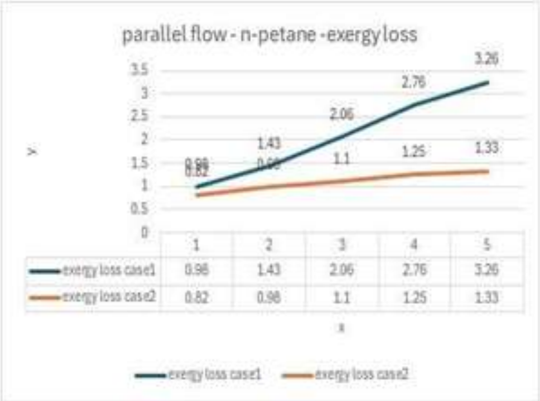

Fig. 10 Availability loss

Fig. 11 shows that availability loss for counter flow is more than compared with availability loss for parallel flow in both the cases.

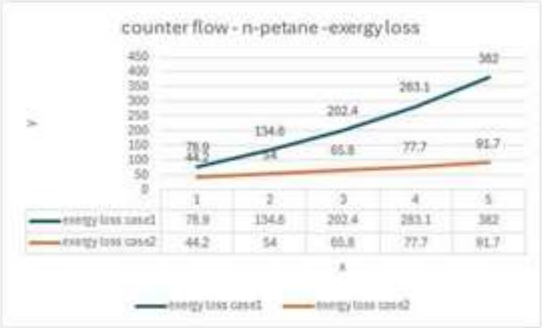

Fig. 11 Availability loss for counter flow

Availability Analysis of Mineral Oil

Fig. 12 shows for constant hot fluid mass flow rate heat transfer rate is high in case 1 than in case 2.

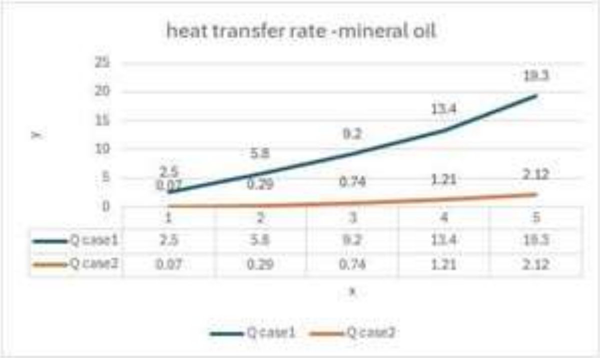

Fig. 12 heat transfer rate

Fig 13 shows The entropy generation for mineral oil in parallel flow arrangement is more than compared with entropy generation of water.

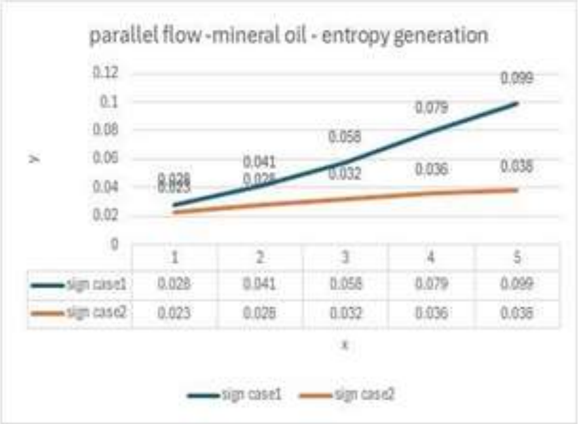

Fig.13 entropy generation

Fig. 14 shows The entropy generation for mineral oil in counter flow arrangement is more than compared with the parallel flow arrangement.

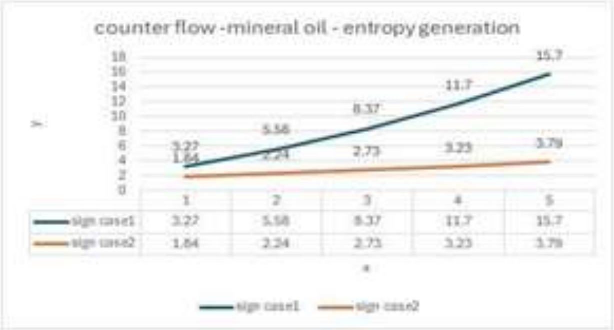

Fig.14 Entropy generation for counter flow

Fig. 15 shows The availability loss for mineral oil in parallel flow arrangement is more when compared with the availability loss for water

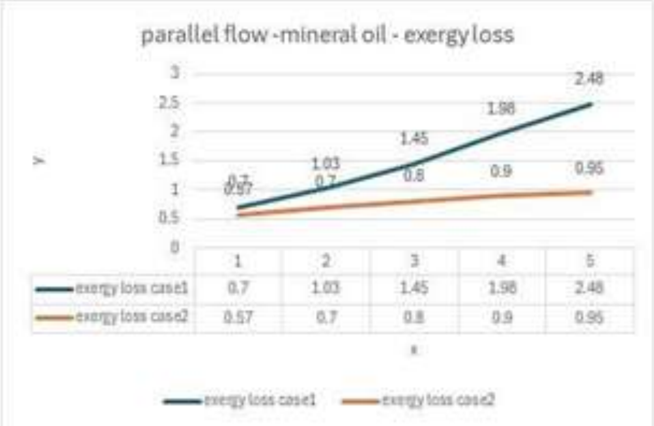

Fig.15 Availability loss in kW for parallel flow

Fig. 16 shows Very high increment is identified in availability loss of mineral oil for counter flow arrangement.

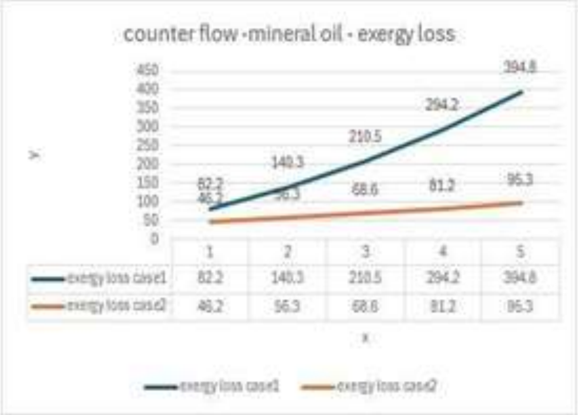

Fig. 16 Availability loss for counter flow

Fig. 17 shows The heat transfer rate for glycol and n- pentane are almost same and are less than heat transfer rate for water.

Fig.17 heat transfer rate

Fig. 18 shows The entropy generation for glycol is more than compared with entropy generation of water.

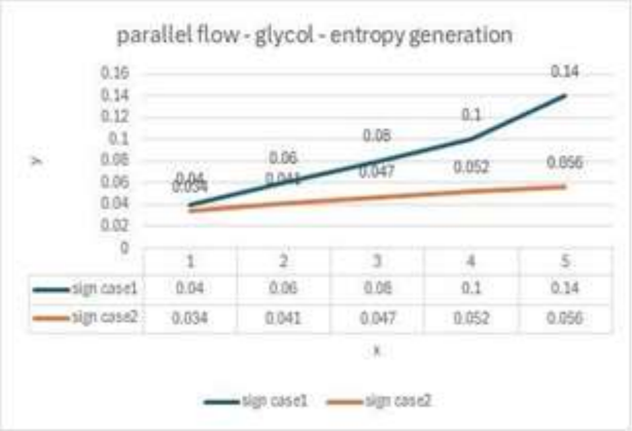

Fig. 18. Entropy generation for parallel flow

Fig. 19 shows The entropy generation of glycol for counter flow arrangement is more when compared with parallel flow arrangement of glycol.

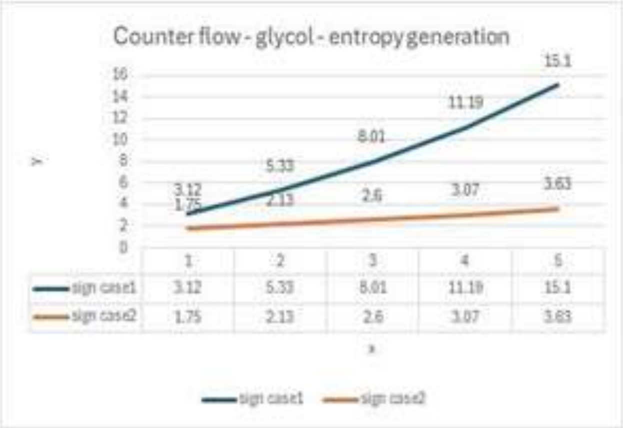

Fig. 19 Entropy generation for counter flow

Fig. 20 shows The availability loss for glycol is more than water in both the cases in parallel flow arrangement.

Fig. 20 Availability loss: Parallel flow

Fig. 21 shows The availability loss for glycol in counter flow arrangement is more than availability loss of water.

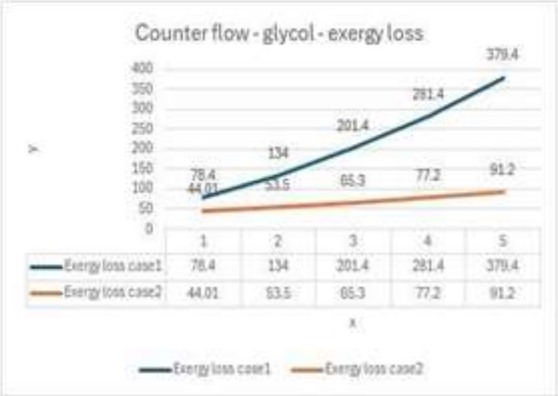

Fig.21 Availability loss for counter flow

The Availability analysis is done on the four working fluids on tube in tube Heat Exchanger with two flow arrangements (parallel flow & counter flow), by taking two cases and the graphs are drawn and also compared.

IV. CONCLUSION

The graphs are drawn for the four working fluids for the parameters- Heat transfer rate, effectiveness, entropy generation and availability loss, all the graphs are compared and got identified the efficient working fluid and also found the conclusions. As the efficient working fluid is taken in concern the heat transfer rate for the fluid must be high as the rate of heat transfer decides the quality and passes heat in less time.

- As the entropy generation is less for the n-pentane it is preferred to be the efficient working fluid which can be used in the heat exchanger.

- Also the heat transfer rate plays the major role to select the working fluid the water is having the more heat transfer rate.
- The availability loss is minimum for the n- pentane and also the mineral oil.
- The graphs for the entropy generation of the four fluids are inversely occurred in the graphs for heat transfer rate of the fluids.
- The parallel flow arrangement is advisable by identifying the graphs than the counter flow arrangement of the heat exchanger.
- The four fluids have different properties, as the results from the graph the fluid n pentane is more efficient fluid than other three fluids.
- The four parameters (heat transfer rate, entropy generation, availability loss) are very high in the counter flow arrangement of the heat exchanger.

Also out of this analysis the water can be taken as the working fluid as it has high heat capacity.

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