Entropy generation is often used for thermodynamic analysis of any thermal system to maximize the work output of the system. In this paper minimum entropy generation principle is discussed and applying on Carnot cycle to optimize it. The analysis of Carnot cycle is based on output power, entropy generation rate and heat work conversion efficiency. Carnot cycle is working between two heat exchangers with variable temperature, relationship is derived for above define parameter can not be achieved in practice [1-2]. In the heat-work conversion optimization, the entropy generation minimization is usually used as the optimization criterion to thermodynamic cycles because the entropy generation represents the ability loss of doing work [3]. The minimization of entropy generation is equivalent to the maximization of power output [4]. To minimize the irreversibility of any proposed design, the engineer must use the relations between temperature differences and heat transfer rates, and between pressure differences and mass flow rates [5]. Heat exchanger is a device which is used to exchange heat between temperature gradient. Improving their effectiveness has often been regarded as the key issue in energy conservation [6]. Any heat transfer process is characterized by two kinds of losses, heat transfer through a finite temperature difference and pressure drop in heat transfer fluids. Entropy generation combines the two processes in one property that can be evaluated; the entropy generation rate could be expressed as

\[ dS = S_g + dS_f \]  

Where \( dS \) is the entropy change rate, \( dS_g \) is the entropy flow rate, and \( S_g \) is the entropy generation rate. As the system is steady, \( dS \) equals zero. The entropy generation rate could be expressed as

\[ S_g = -dS_f. \]  

The entropy flow rate from heat source \( (S_{fh}) \) and sink \( (S_{fl}) \) are governed by following equation [1,6]

\[ S_{fh} = \frac{T_2}{T_1} C_s \frac{dT}{T_0} \]

\[ S_{fl} = C_h \ln \frac{T_2}{T_{ho}} \]
generating device as shown in figure 1. Heat source capacity heat source and heat sink with work. A thermodynamics system consists of finite preconditions for the application of these optimization methods are discussed with Carnot cycle and found that in the presence of various Carnot cycle composed of four processes the working fluid compressed isothermally and reversible adiabatically during processes 1-2 and 2-3 respectively. After compression working fluid expands isothermally and reversible adiabatically during process 3-4 and 4-1 respectively. During isothermal processes 1-2 and 3-4, cycle exchanging heat with variable heat sink and heat source temperature respectively.

Heat transfer to the cycle from hot side heat exchanger is [9]

\[ Q_{hi} = \left[ 1 - \exp \left( -\frac{UA}{C_h} \right) \right] C_h (T_{hin} - T_h) \] (12)

\[ \varepsilon_h = \left[ 1 - \exp \left( -\frac{UA}{C_h} \right) \right] \] (19)

Heat transfer to the cycle from cold side heat exchanger is

\[ Q_{ci} = \left[ 1 - \exp \left( -\frac{UA}{C_i} \right) \right] C_i (T_c - T_{cin}) \] (13)

\[ \varepsilon = \left[ 1 - \exp \left( -\frac{UA}{C_c} \right) \right] \] (17)

UA is the thermal conductance of heat exchanger and \( C_h \) and \( C_i \) are specific heat of hot and cold working fluid respectively. \( T_{cin} \) is highest temperature of Carnot cycle and \( T_{hi} \) is the inlet temperature of source side heat exchanger, \( T_c \) is lowest temperature of Carnot cycle and \( T_{ci} \) is the inlet temperature of sink side heat exchanger.

\[
S_f = \int \frac{C_i}{T_i} \frac{dT_i}{T_i} \\
S_\beta = C_i \ln \frac{T_o}{T_{li}}
\]

Entropy flow rate into the environment [1,4]

\[ S_{fe} = \frac{Q_{eh} + Q_{el}}{T_o} \]

The total entropy generation rate is calculated by adding equation (3), (4) and (5)

\[ S_g = S_{fh} + S_\beta + S_{fe} \] (6)

\[ S_g = \left[ C_h \ln \frac{T_o}{T_{hi}} \right] + \left[ C_i \ln \frac{T_o}{T_{li}} \right] \\
+ \frac{C_h [T_{ho} - T_o] + C_i [T_{lo} - T_o]}{T_o}
\]

Work done by the system is given by the following relation

\[ W = [Q_{sh} - Q_{eh}] + [Q_{lh} - Q_{el}] \] (8)

Where

\[ Q_{sh} = C_h [T_{hi} - T_o] \]
[18]
\[ Q_{eh} = C_h [T_{ho} - T_o] \]
[19]
\[ Q_{lh} = C_i [T_{li} - T_o] \]
[20]
\[ Q_{el} = C_i [T_{lo} - T_o] \]
[21]

Rearranging Equation (8)

\[ W = (Q_{sh} + Q_{lh}) - (Q_{eh} + Q_{el}) \] (9)

The last term of equation (9) may be written as

\[ W = Q_{sh} + Q_{lh} - T_o S_{fe} \] (10)

The equation (6) may be written as [1]

\[ S_g = S_{fh} + S_\beta + \left[ \frac{Q_{sh} + Q_{lh} - W}{T_0} \right] \] (11)

Carnot cycle composed of four processes the working fluid compressed isothermally and reversible adiabatically during processes 1-2 and 2-3 respectively. After compression working fluid expands isothermally and reversible adiabatically during process 3-4 and 4-1 respectively. During isothermal processes 1-2 and 3-4, cycle exchanging heat with variable heat sink and heat source temperature respectively.

\[ Q_{hi} = \left[ 1 - \exp \left( -\frac{UA}{C_h} \right) \right] C_h (T_{hin} - T_h) \] (12)

\[ \varepsilon_h = \left[ 1 - \exp \left( -\frac{UA}{C_h} \right) \right] \] (19)

Heat transfer to the cycle from cold side heat exchanger is

\[ Q_{ci} = \left[ 1 - \exp \left( -\frac{UA}{C_i} \right) \right] C_i (T_c - T_{cin}) \] (13)

\[ \varepsilon = \left[ 1 - \exp \left( -\frac{UA}{C_c} \right) \right] \] (17)
The cycle satisfy the Carnot theorem as follows equation (14)

\[
\frac{Q_{hi}}{T_h} = R \frac{Q_{li}}{T_c}
\]  
(14)

R is the irreversibility parameter.

According to law of energy conservation, the work done by the cycle is calculated as follows

\[
W = Q_{hi} - Q_{li}
\]  
(15)

And the cycle is efficiency is given by the following relation

\[
\eta = \frac{W}{Q_{hi}} = 1 - \frac{Q_{li}}{Q_{hi}}
\]  
(16)

Carnot cycle efficiency is also given by following relation

\[
\eta = \frac{W}{Q_{hi}} = 1 - \frac{T_c}{T_h}
\]  
(17)

Rearranging equation (17)

\[
W = Q_{hi} \left(1 - \frac{T_c}{T_h}\right)
\]  
(18)

\[
W = \left[1 - \exp\left(-\frac{UA}{C_h}\right)\right] \frac{C_h (T_{hin} - T_h)}{T_h}
\]

\[
\left[1 - \frac{RT_h C_{cin}}{C_t} (T_{hin} - T_h)ight]
\]  
(19)

Substituting equation (18) into equation (11), we can get the entropy generation rate as follows

\[
S_g = \left[C_h (T_{hin} - T_o) + C_i (T_{cin} - T_o) - W\right]
\]

\[
+C_h \ln\left(\frac{T_o}{T_{hin}}\right) + C_i \ln\left(\frac{T_o}{T_{cin}}\right)
\]  
(20)

\[
S_g = \left[C_h (T_{hin} - T_o) + C_i (T_{cin} - T_o) - \exp\left(-\frac{UA}{C_t}\right)\frac{C_h (T_{hi} - T_o)}{T_o}\right]
\]

\[
\left[1 - \frac{RT_h C_{cin}}{C_t} (T_{hin} - T_h)\right]
\]

\[
\frac{C_l}{T_l} + C_i \ln\left(\frac{T_c}{T_{cin}}\right)
\]  
(22)

Considering the equations (12), (13) and (14), by using these equations we can find the value of Tc for prescribed values of Th and R. By considering the equation (17), (19) (21) and (22), we can find the values of efficiency work done entropy generation rate and entropy generation number for prescribed operating parameter.

For a specific example [9], Choosing Ch=3 W/K, Th=400 K, Tc=300K, Thermal conductance of heat exchangers UA=100 W/K, Ch=2 W/K, Tc=302 K. Putting prescribed values in above equations, the variation in output power, entropy generation rate with variable Th and R=1.2 shown in figure 3 and the variation in output power, entropy generation rate with variable R and Th=370K as shown in figure 4, when heat capacity rate of fluid remains constant.

![Figure 3: Variation of Work ratio (W/Wmax), Entropy generation rate (S/Smax), Entropy generation number ratio (Ng/Ngmax) and efficiency of cycle with variation T_h at R=0.9](image)

![Figure 4: Variation of Work ratio (W/Wmax), entropy generation rate (S/Smax), entropy generation number ratio (Ng/Ngmax) and efficiency of cycle with variation T_h at R=0.95](image)
Conclusion:-
The Carnot cycle working between variable heat source and heat sink temperature, the results shows the variation of work done to maximum work done, entropy generation rate to maximum entropy generation rate, entropy generation number to maximum entropy generation number and efficiency are obtained for the variable values of $T_h$, $R$ and $T_i$. The maximum work done always corresponds to minimum entropy generation for variable value of $T_i$ and prescribed values of operating parameter. The efficiency of the cycle for prescribed operating parameter is decreased. The maximum work done is obtained if Carnot cycle works between $T_h=379$ K to $382$ K for $T_i=400$ K and different values of $R$. The value of optimum value $T_h$ is found by analysis of figure number 3 to figure 5. For different values of $R$ and $T_i=375$ K, the work done increases and entropy generation rate decreases with increase of value of $R$ is clearly seen from figure 6 to figure 8. The variation of $T_h$ for different value of $T_i$ and $R=0.9$ shows in figure 8 to figure 10, after analyzing above figure, we found that optimum value of $T_h$ is dependent on $T_i$. $T_i$ increases the optimum value of $T_h$ increases. The value entropy generation rate ratio and entropy generation number ratio is same in all operating and prescribed conditions and efficiency of the cycle is decreased for all operating and prescribed conditions.
REFERENCES