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THERMODYNAMIC MODELING AND EXERGY ANALYSIS OF ORGANIC RANKINE CYCLE WITH THE RECEIVER OF THE SUN

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Abstract- ***In this paper the environmental factors that effect on the performance of organic Rankine cycle with a linear parabolic solar receiver is investigated. Due to the fact that the performance of the receiver has an important role in the total efficiency of solar power collection, the amount of heat losses should be minimized. On the other hand, the amount of heat losses is also effective on the exergy losses and minimizing the thermal dissipation will also lead to a reduction of exergy losses. Thus, identifying factors that help to improve the efficiency of the first and second laws of thermodynamics is necessary. Due to this point the different environmental factors (such as the wind blowing speed in the environment, solar radiation intensity, sun radiation angle, flow rate of heat carrier fluid, ambient temperature) in the recipient and also the kind of dry fluid in the Organic Rankine Cycle should be investigated. For this intention the energy and exergy model of organic Rankine cycle with initial stimulus of solar recipient has been developed in the EES software. Results indicate that the greatest amount of irreversibility occurs in the evaporator and receiver. Also the amount of irreversibility is reduced by increasing in the receiver temperature (the average temperature of the inlet and outlet of the recipient). It can be observed from other results that the amount of irreversibility is increased by increasing in the radiation intensity and ambient temperature and decreasing in the angle of the sun radiation.***

Keywords - Irreversibility; Solar receiver; Organic Rankine Cycle.

I. INTRODUCTION

Today, due to the shortage of fossil fuels, humanity is forced to use other energy sources to meet its energy needs and survival on earth. In this regard, solar energy has a special importance because of its abundance and cleanliness. With the advent of the energy crisis of the mid-seventies onwards, research to achieve optimal plans to build solar power plants for electricity production in most industrialized countries began. Two main types of schemes to gather solar radiation energy are: flat Recipient and concentrator recipient. A solar receiver can be regarded as a special case of a heat exchanger in which the solar radiation energy is collected by the flow of fluid, and then it is used or stored. Usually to achieve average temperatures and higher efficiency, solar linear parabolic receivers which are a certain type of concentrator receives, are used. In this type of receivers, Radiation energy is concentrated by a mirror concentrator, and transferred to collector which is a tube containing fluid passing, whit coated glass that is located in the center Parabolas [1,2,3]. One of the ways used to exploit renewable energy sources, especially sources whit low and medium temperature like solar energy, geothermal energy, biomass and utilization of heat losses of gas plants and industrial chimneys, that is taken into consideration in recent years is the use of organic Rankine cycle. Some of the Organic Rankine Cycle advantages are its small size and simplicity. Another important point is the ecological aspect of this cycle and its impact on climate. Since Organic Rankine cycle is closed it does not produce any air pollutant materials Including whether solid or liquid or gases like CO, CO2 and NOX [4,5,6]. Now solar collected energy by interface fluid for heat transfer to the Organic Rankine Cycle unit and more can be considered to generate electric power in the generator. So far, many researches on the operator fluid used, operation and performance of organic Rankine cycle whit solar receiver has been accomplished that Among which it can be note of the umbilical [7,8] Manvlaks [9], Farahat 2, Dynsr [10] and many others. But the remarkable point is that most of these researches has cared about the exergy analysis and examination of organic Rankine cycle or receiver and none of them proceed on the effect of environmental factors on Irreversibility of the receiver with organic Rankine cycle.

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Therefore, the results of this analysis for each change in each variable, whit assuming constant for other factors (parametric analysis) is presented in the following.

II. THE INTRODUCTION OF CYCLE ANALYSIS

The schematic sketch of Organic Rankine Cycle with solar receiver is shown in Figure 1.

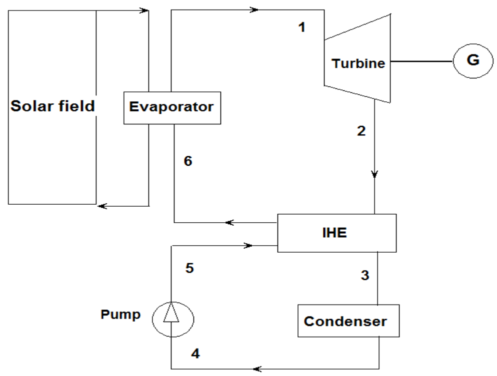

Fig. 1 Schematic diagram of organic Rankine Cycle with solar receiver.

In analyzing the problems, the following assumptions have been made:

All processes are being established in steady state, the dissipation of heat leaks in pipes are ignored in the process as well as turbines, pumps, thermal recoverer, and the receiver is analyzed with the assumption of being adiabatic. Ambient temperature equal to 298 K, isentropic pump and turbine efficiencies of 85% and 75%, respectively, heat recoverer efficiency coefficient is equal to 0.8 and the condenser temperature has been considered 308 K [7,9]. Production or consumption power and excreted or absorbed heat of each of the components of the cycle are calculated by the use of first and second laws of thermodynamic. Energy balance equation used is like equation 1:

$$\sum_i \dot{E}_i + \dot{Q} = \sum_o \dot{E}_o + \dot{W} \quad (1)$$

Irreversibility rate with a steady flow is expressed by equation (2):

$$\dot{I} = T_0 \times \frac{ds}{dt} = T_0 \times \dot{m} \times [\sum s_{exit} - \sum s_{inlet} + (\frac{ds_{system}}{ds}) + \sum_j \frac{q_j}{T_j}] \quad (2)$$

That the last term of equation (2) is related to the heat exchange with the external source and the penultimate term in the steady state is equal to zero.

Thermal efficiency of the cycle, second law efficiency and irreversibility rate of the cycle is respectively derived from using the following equations: [7,8,9]

$$\eta_{cycle} = \frac{\dot{W}_{net}}{\dot{Q}_{evaporator}} \quad (3)$$

$$\eta_{e,total} = \frac{\dot{W}_{net}}{\dot{I}_{total} + \dot{W}_{net}} \quad (4)$$

$$\dot{I}_{total} = \dot{I}_{pump} + \dot{I}_{turbine} + \dot{I}_{recuperator} + \dot{I}_{condenser} + \dot{I}_{collector} + \dot{I}_{evaporator} \quad (5)$$

$$\dot{I}_{collector} = A_{col} \times G_b \times (1 - \frac{T_{amb}}{T_{sun}}) + \dot{m}_{col} \times (h_{i,col} - h_{o,col} - T_{amb} \times (s_{i,col} - s_{o,col})) \quad (6)$$

$$\dot{I}_{turbine} = \dot{m}_{ORC} \times (h_i - h_o - T_{amb} \times (s_i - s_o)) - \dot{W}_{turbine} \quad (7)$$

$$\dot{I}_{condenser} = \dot{m}_{water} \times (h_{i,water} - h_{o,water} - T_{amb} \times (s_{i,water} - s_{o,water})) + \dot{m}_{ORC} \times (h_i - h_o - T_{amb} \times (s_i - s_o))] \quad (8)$$

$$\dot{I}_{pump} = \dot{m}_{ORC} \times (h_i - h_o - T_{amb} \times (s_i - s_o)) + \dot{W}_{pump} \quad (9)$$

III.CONCLUSIONS

Changes in thermal efficiency, second law efficiency and irreversibility versus of recipient temperature changes for different environmental factors have been investigated. Some of the results are shown in Fig. 2 until Fig. 9, which is discussed below.

It can be seen of Fig.2, the thermal efficiency of the cycle is increased with using of an organic working fluid n – octane.

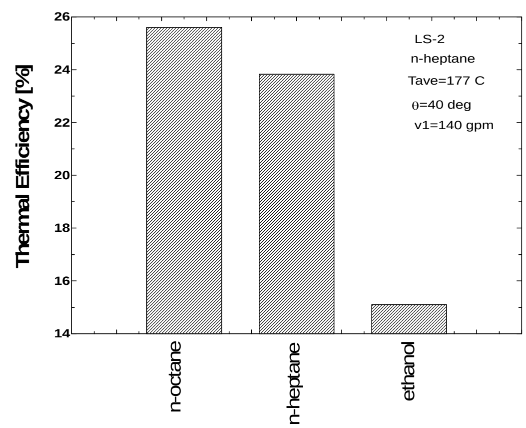

Fig. 2 The value of organic Rankine cycle efficiency for different working fluids

The value of irreversibility of each component of the cycle is shown in Fig.3. It can be seen of Fig. 3, the irreversibility of the other components of the cycle is negligible in compare to the irreversibility of the evaporator and collector.

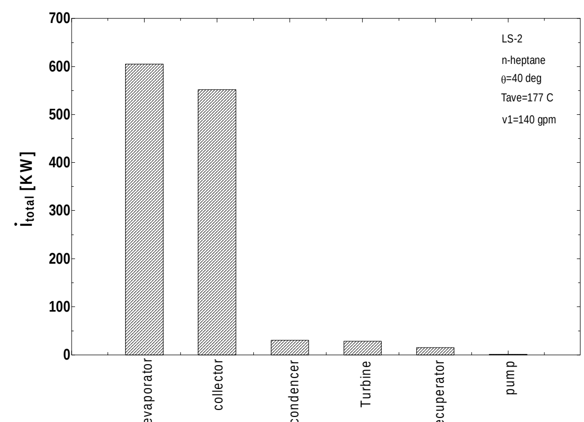

Fig. 3 The value of irreversibility of each component of the cycle

Irreversibility changes with recipient temperature as function of solar radiation angle, solar radiation intensity, wind speed, temperature and flow rate of carrier fluid in the receiver, respectively are shown in Fig.4 until Fig.8. According to Fig. 4, 5 and 7 the rate of irreversibility is increased with reduction of solar radiation angle and also increasing in the radiation intensity and environment temperature. Fig. 6 and 8 shows that the variations of wind speed and flow of carrier fluid in the receiver have no effects on the irreversibility. Fig. 4 until Fig. 8 shows that for all the cases the irreversibility rate is decreased with increasing in the temperature of recipients.

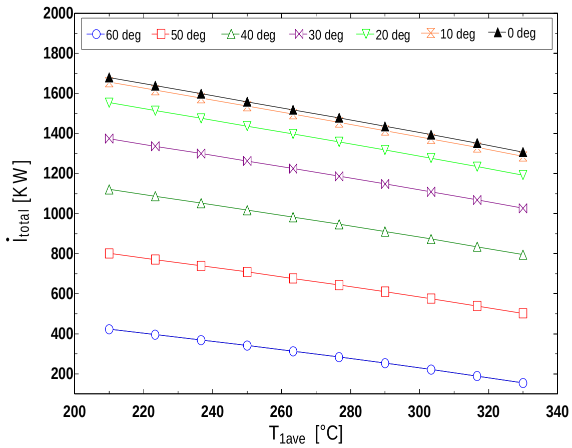

Fig. 4 Irreversibility changes in terms of recipient temperature per solar irradiation angle

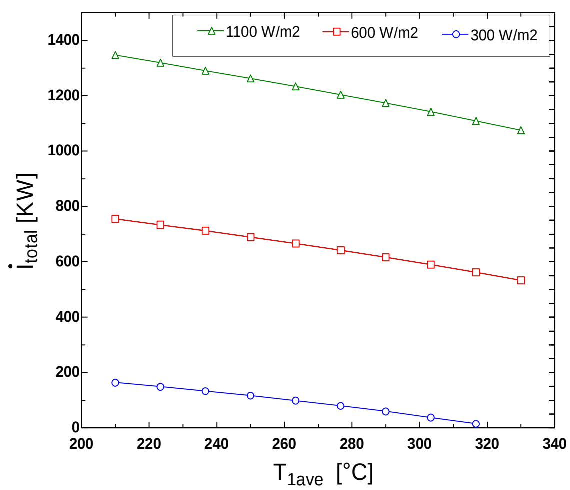

Fig.5 Irreversibility changes in terms of recipient temperature per solar irradiation intensity

Fig. 9 shows the recipient efficiency changes with recipient temperature per solar radiation intensity. This figure shows that the efficiency is reduced by increasing in the temperature of the heat transfer carrier fluid. And also will result in the increase of the thermal efficiency, increase in the solar radiation intensity. Mago [13], suggests that in the organic Rankine cycle with increasing of organic fluid boiling point, thermal efficiency of the cycle will increase. This is valid in our research. Namely the highest thermal efficiency of organic Rankine cycle for the working fluid n-octane was obtained which has higher boiling point than n - heptanes and ethanol.

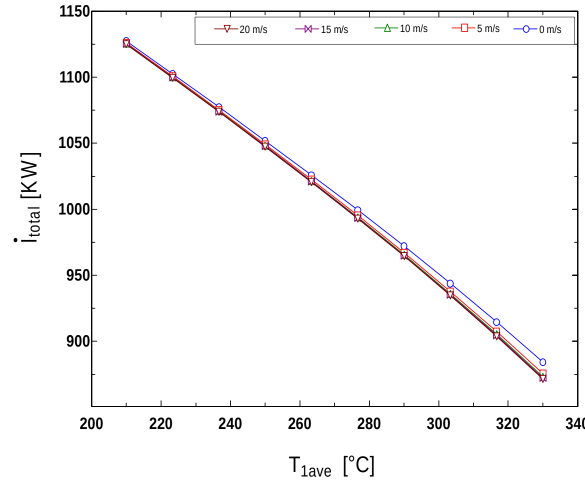

Fig. 6 Irreversibility changes with recipient temperature per wind speed

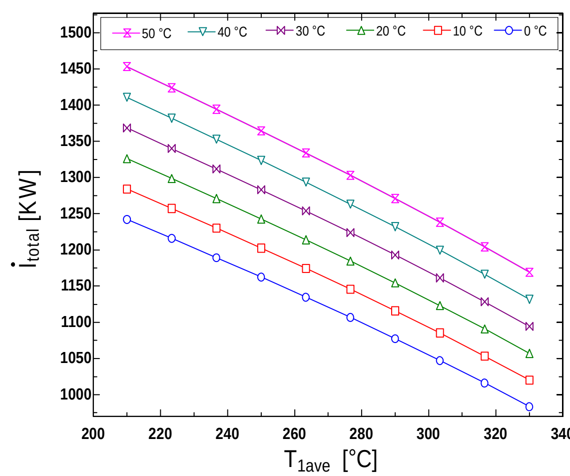

Fig. 7 Irreversibility changes with recipient temperature per environment temperature

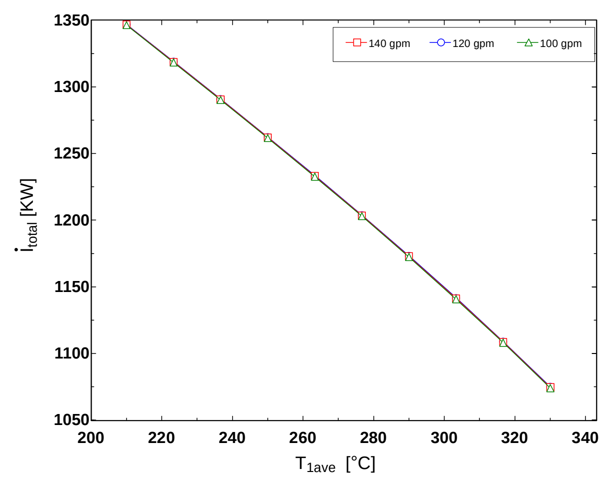

Fig. 8 Irreversibility changes with recipient temperature per carrier liquid flow.

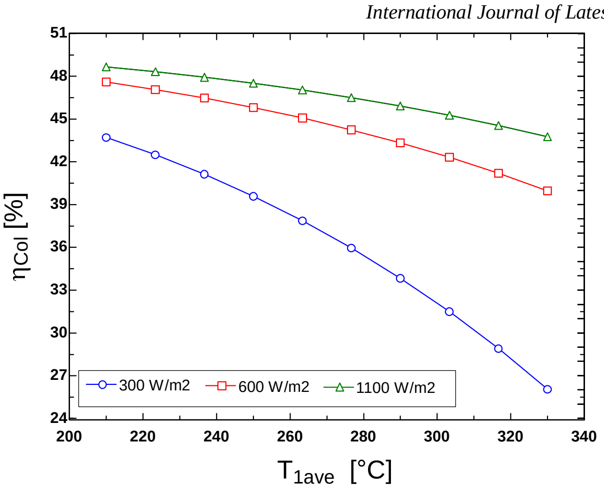

Fig. 9 The recipient efficiency changes with recipient temperature per solar radiation intensity

IV. CONCLUSION

As it was seen, environmental factors have important role in the cycle performance and directly effect on the rate of heat loss and thus effect on the recipient efficiency. A point to be noted is that the role of some factors such as heat carrier fluid flow in the recipient and wind speed is minor, but some other such as solar intensity the angle of solar irradiation and environment temperature of solar radiation have major roles. It is crucial that all these parameters will be optimized toward the improvement of the recipient efficiency and reduction of the irreversibility and losses.

As was observed, most of the value of irreversibility in the evaporator and the recipient happens that this more clarifies the importance of thermodynamic optimization of the evaporator and the receiver. In fact one of the most important roles of exergy analysis is to identify the amount and location of exergy destruction in the cycle.

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