Comparative Study of Solar Assisted ORC by Using R600 & R245fa from View Point of Energy and Exergy

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Abstract-*In order to find the best organic fluid for Organic Rankine Cycle (ORC), a comparison between R600 and R245fa as working fluid is carried out in this paper. A solar assisted ORC is proposed and its thermodynamic performance is evaluated with view point of energy and exergy. It is observed that R600 offer higher energy and exergy efficiency as compared to R245fa at same operating conditions. The energy efficiency 10.63% and exergy efficiency 11.39% with R600 & energy efficiency 9.004% and exergy efficiency 9.64% with R245fa is observed at turbine inlet pressure (1.98MPa), turbine back pressure (0.22MPa) and condenser temperature (290C).*

Keywords-R245fa, R600, Solar heat, DNI, Energetic & Exergetic efficiency

I. INTRODUCTION

As we know human population is increasing day by day, it increases dependencies on energy simultaneously. Demand for electricity is prime need for human kind. We also know that our nonrenewable energy (fossil fuels) are finite, so for the electricity generation we need burning of fossil fuel which place a significant stress on the environment. Therefore it has become an essential need for conservation of efficiency. In order to optimally exploit different potential of available energy resources, in which Organic Rankine Cycle place a vital role. It is almost much identical to the classical steam Rankine cycle. It (ORC) can convert heat at very low temperature to electricity with the help of selection of alternative working fluid. Use of ORC cycle and its benefits includes not only low maintenance but also favorable operating pressure with autonomous operation. It (ORC) has become a matured technology to be efficiently used in the field of energy conversion. ORC also have different benefits associated [1].

The second law effectiveness (efficiency of exergy) can be expressed as the ratio of total exergy output by exergy input. It (exergy) may be described as the maximum potential work for the components or system at given state in a specified surrounding. Its (exergy) efficiency is considered as one of vaary important tool to be used for investigating and comparing of different working fluids with each order. We know that the importance of exergy efficiency realize on its ability to give a clear view about different losses of the system, as well as also describe s about the potential and performance of system [2].

Wang et al. [3] reviewed about regenerative ORC for utilizing of solar energy over a low temperature rang using for solar collector which in a shape of flat plate. They also conducted various parametric analyses for the examination of various effects on turbine inlet pressure, temperature and condensation temperature with the help of use of different working fluids. There always indicates that by increasing inlet pressure and temperature or decreasing the back pressure of turbine could improve the performance of system. They also found that almost various working fluids R123 and R245fa where the best suitable working fluid used for the system due to its high performance and low operative pressure.

Xu et al. [4] studied that thermal efficiency are correlated with the critically temperatures and refrigerant such as R245fa, can be used over a wide temperature of heat source. Tchantce et al. [5] studied that the solar ORC cycle require low temperature analysis with the help of thermodynamics and theoretical performance as well as properties of fluid for the comparatively assessment. For the comparison of 20 working fluids various parameters for refrigerant and their properties has been used, such as toxicity, mass flow rate, volume flow rate, GWP, and ODP. Amongst all the fluids are R600 appeared as one of the most suitable refrigerant for small scale solar application. 134a, R290, R600a, R152a offers vary attractive performance but also need certain safety precaution.

Wei et al. [6] studied that effects of parameters such as exhaust mass flow rate, exhaust inlet temperature, air mass flow rate and ambient temperature on the net power output, system efficiency and irreversibility of ORC for waste heat recovery. They obtained that choosing appropriate nominal state was a good idea to improve the system net power output and efficiency. Roy and Misra [7] conducted thermodynamic parametric study of an ORC using R123 by considering intermediate heat source temperature. They found that the best thermodynamic performance of the cycle can be obtained at a turbine inlet pressure of 2.7 MPa.

II. WORKING & DESCRIPTION OF ORC CYCLE

The solar operated Organic Rankine Cycle (ORC) system consists of various components such as solar energy collecting sub-system with Organic Rankine Cycle (ORC) sub-system. Fig 1 the schematic diagram of the ORC system. The Organic Rankine Cycle (ORC) sub-system consists of four main components, namely: heat recovery vapour generator (HRVG), a turbine, a condenser and a pump. Solar radiation falls on the heliostat plates and being reflected on the central receiver's aperture area which has been located at the top of the tower. The concentrated waves which falls on the central receiver (CR) makes the temperature of the central receiver high, which is result heat the Duratherm oil. This heated oil flows through the pipes which transfer its thermal energy from central receiver (CR) to the HRVG. The superheated refrigerant vapour is expanded in the turbine for power generation, the turbine exhaust is condensed in the condenser. Now the saturated liquid has been pumped to HRVG of Rankine Cycle.

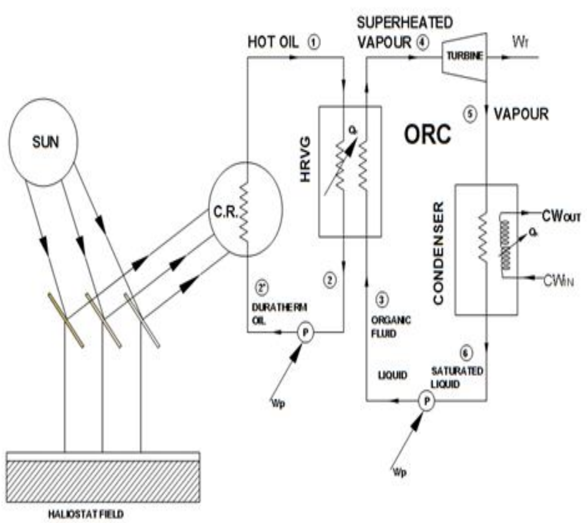

Fig. 1 Schematic Diagram of ORC

ASSUMPTIONS

1. The system runs at steady state process.
2. Pressure drop and heat loss in pipeline should be neglected.
3. The working fluid at the condenser outlet (pump inlet) is saturated liquid.
4. Kinetic energy, potential energy and exergy all are ignored.
5. Chemical exergy of materials is neglected.

III. ENERGY EQUATION FOR ORC SUB-SYSTEM

The Organic Rankine Cycle subsystem is modeled based on the laws of mass and energy conservation.

In the HRVG, the heat addition into the power cycle is given by: $Q_{HRVG} = m_f (h_4 - h_3)$

In the condenser, heat rejected is expressed as:

$$Q_c = m_f (h_5 - h_6)$$

For the turbine, the isentropic efficiency is expressed as:

$$\eta_T = \frac{h_4 - h_5}{h_4 - h_{5S}}$$

The power output of the turbine is given by:

$$W_T = m_f (h_4 - h_5)$$

For the pump, the isentropic efficiency can be expressed as:

$$\eta_P = \frac{h_{3S} - h_6}{h_3 - h_6}$$

The ORC pump power consumption is defined as:

$$W_P = m_f (h_3 - h_6)$$

The net power generated by the solar driven ORC is defined as:

$$W_{net} = (W_T)_{actual} - (W_P)_{actual}$$

EXERGY EQUATIONS FOR ORC SUB-SYSTEM

Exergy destruction in HRVG

$$E_{xdHRVG} = m_{oil}*(h_1-h_2)-T0*(T1+273)/T2+273)+mf*(h_3-h_4)-T0*(S_3-S_4)$$

Exergy destruction in Turbine

$$E_{xd\,Turbine} = (h_4 - T_o * S_4) - (h_5 - T_o * S_5) - (h_4 - h_5)$$

Exergy destruction in condenser

$$E_{xd,cond.} = (h_5 - T_o * S_5) - (h_6 - T_o * S_6)$$

Exergy destruction in pump

$$E_{xd,pump} = (h_6 - T_o * S_6) - (h_3 - T_o * S_3) + (h_3 - h_6)$$

$E_{x,input} = Q_s^*[1-T_0/(T_4+273)]+W$

$E_{xd\ total} = E_{xd\ HRVG} + E_{xd\ turbine} + E_{xd\ cond.} + E_{xd\ pump}$

Exergetic efficiency:

$$\eta_{ex} = 1 - \frac{E_{xd,\,total}}{E_{x,\,input}}$$

$E_{x,input} = Q_S*[1-T_o/(T_2+273)]+W$

$W_{net} = W_T - W_P$

$$\eta_{ex} = \left(\frac{W_{net}}{E_{x,\,input}} \right) \times 100\%$$

IV. RESULTS & DISCUSSION

Fig. 1 shows the effect of turbine inlet pressure (TIP) on exergy destruction (irreversibility) in various components of ORC. It is evident from the fig.1.that the exergy destruction rate in HRVG using R245fa as working fluid is higher and increases with increase in turbine inlet pressure. It is observed that at a given turbine inlet pressure of 1.98 MPa, the total irreversibility in components of HRVG, turbine, pump and condenser is 23.26 kW with refrigerant R245fa which is much higher than the total irreversibility of 18.43 kW with R600. Hence it is better to the R600 as compared to R245fa to obtain higher exergy efficiency.

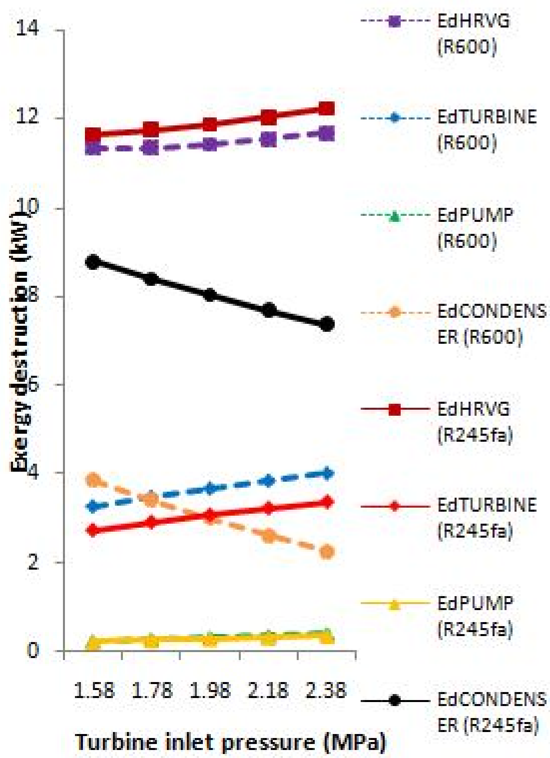

Fig.1 Effect of turbine inlet pressure on exergy destruction in component of ORC

Fig. 2 clearly indicate that the use of R600 as working fluid, the energetic efficiency and exergetic efficiency obtained are higher than R245fa and increases with increase in turbine inlet pressure. At pressure of 1.98 MPa, the energetic efficiency and exergetic efficiency are 10.63% and 11.39% with R600 as working fluid.

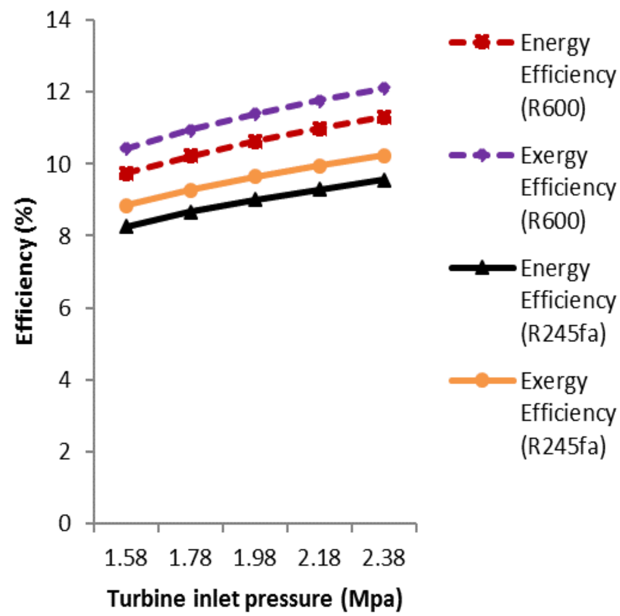

Fig.2 Effect of turbine inlet pressure on energy and exergy efficiency

Fig. 3 indicates that with variation on turbine back pressure, there is no effect on exergy destruction (Ed) in HRVG and pump. But exergy destruction (Ed) in condenser increases significantly with increase in turbine back pressure. It has been observed that total Ed in all components of ORC increases with increase in turbine back pressure.

Fig. 4 shows that energy and exergy efficiency decreases with increase turbine back pressure. At turbine back pressure (Pbp) of 0.22 MPa efficiency of energetic 10.63% and efficiency of exergetic 11.39% is obtained with R600 as working fluid.

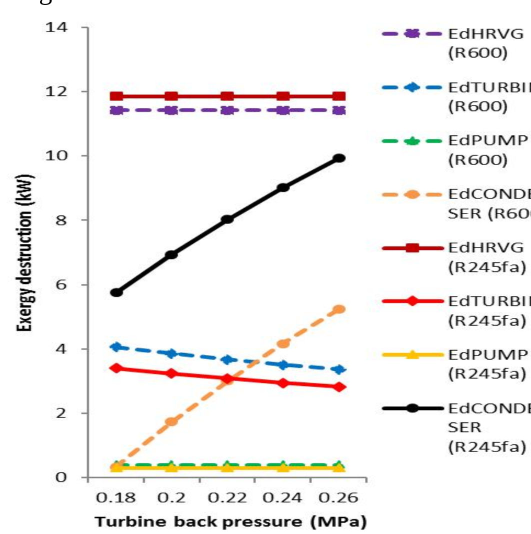

Fig.3 Effect of turbine back pressure on exergy destruction in component of ORC

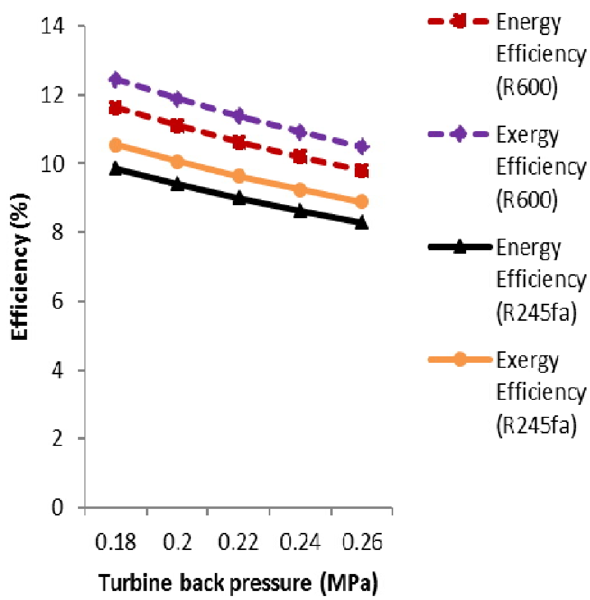

Fig.4 Effect of turbine back pressure on energy and exergy efficiency

Fig. 5 clearly indicates the effect of condenser temperature on exergy destruction (Ed) in components of turbine, condenser, pump and HRVG of Organic Rankine Cycle.

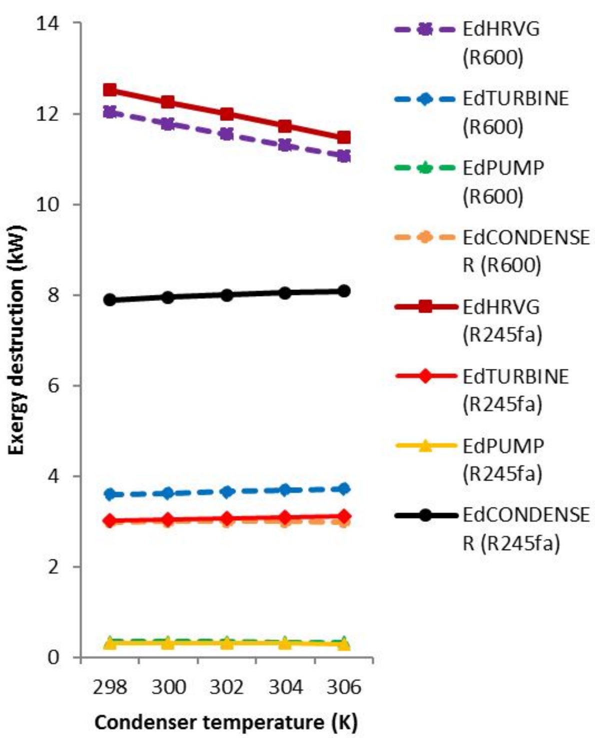

Fig.5 Effect of condenser temperature on exergy destruction in component of ORC

The effect of condenser temperature on energetic efficiency and exergetic efficiency of ORC is depicted in figure 6. It is clearly mention that at condenser temperature of 29 0C, the energy and exergy efficiency are 10.59% & 11.34% with R600 which is higher than R245fa as working fluid.

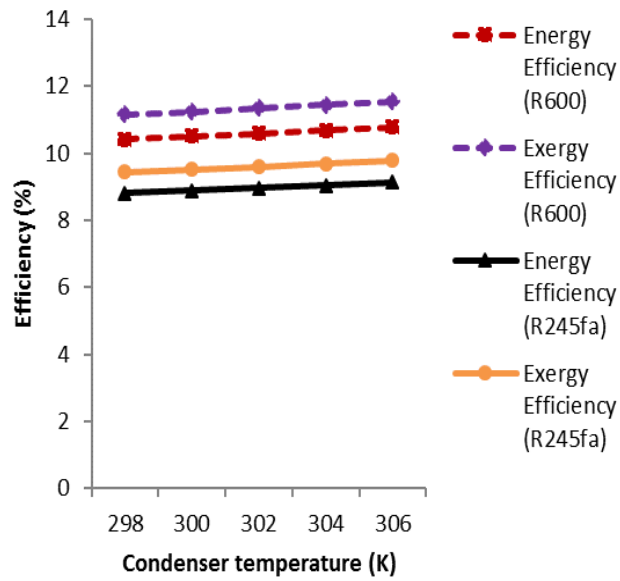

Fig.6 Effect of condenser temperature on energy and exergy efficiency

V. CONCLUSIONS

The major conclusions during theatrical performance analysis are as follow:

- R600 better performance as compared to R245fa.
- The ODP of R600 is very less as compared to R245fa.
- The energy efficiency 10.63% and Exergy efficiency is 11.39% of R600 which is greater than R245fa.
- With increase in turbine inlet pressure (TIP) of refrigerant R600, irreversibility (E_D) in HRVG, turbine and pump increases and in condenser decreases.
- With increase in turbine back pressure (P_{BP}) of R600, the major exergy destruction (E_D) increases in condenser.
- With increases in condenser temperature of R600, the effect of all ORC components is very less.

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