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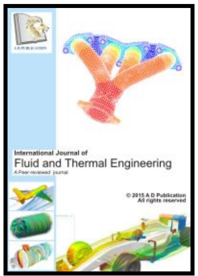

Energy, Exergy and Parametric Analysis of Solar Operated Organic Rankine Cycle with R245fa as working fluid

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ABSTRACT: In this paper parametric analysis is carried out to find the realistic performance of Organic Rankine Cycle by using first and second law approach. The effect of various operating parameters such as turbine inlet pressure, turbine back pressure, & condenser temperature on energy and exergy efficiency along with exergy destruction in components of HRVG, turbine, condenser, & pump are analysed. It was observed that with increase in turbine inlet pressure, energy efficiency increases from 8.75 % to 10.75 % and exergy efficiency also increases from 9.38 % to 11.46 %. With increase in turbine back pressure the energy and exergy efficiency decreases and with increase in condenser temperature, energy efficiency increases from 9.72 % to 10.14 % and exergy efficiency also increases from 10.47 % to 10.86 %.

Keywords: Energy efficiency, Exergy efficiency, ORC, R245fa, Solar heat

1. Introduction

In today's world energy usually plays a vital role in the development of a nation. We know that with the gradual depletion of conveniently available fossil fuel reserves, people are seeking alternative energy resources which are long lasting as well as eco- friendly i.e renewable energy sources. There are various renewable energy sources which are used nowadays such as wind, solar, geothermal, biomass and hydro. [1]. When moderate temperature steam is used for production of electricity in conventional Rankine cycle it is not considered as good choice economically and technologically .The system known as Organic Rankine Cycle (ORC) which has a promising technology used for conversion of low-grade heat into electricity has been introduced. The basic difference in Organic Rankine Cycle (ORC) cycle is use of an organic working fluid with lower boiling temperature in the expander (turbine) instead of water. The ORC exhibits great flexibility in utilization of moderate temperature in heat source [2]. Guo et al. [3] The thermodynamic analysis of a waste heat power generation system have proposed two approaches to analyze and improve ORC performance; first is to improve availability of heat source and the second is to enhance the heat-work conversion of the system.

Donghong Wei [4] represented optimization and performance analysis of an organic Rankine cycle (ORC) system in which HFC-245fa has been used as a working fluid which is driven by exhaust heat. In ORC system the thermodynamic performances under various disturbances have been analyzed. Mago [5] Many dry organic working fluids are selected for investigation such as R113, R245ca, R123, and Isobutane, with boiling points ranging from 12 C to 48 C. The performance have been evaluated on various parameters using a combined first and second law analysis by varying certain system operating parameters at various reference temperatures and pressures. In another study, the performance of an ORC system has been investigated, evaluating various

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working fluids with a genetic algorithm to optimize the system [6]. Roy et al. [7] have presented a parametric optimization of a non-regenerative Organic Rankine Cycle, using different working fluids. Touaibi [8] have presented the energy and exergy analyses of single-effect water-lithium bromide absorption cooling system driven by solar heat with cooling capacity of 10 kW. Khaliq et al. [9] presented an industrial waste heat recovery system based on cogeneration cycle for production of refrigeration and power. They observed the various effects of operating parameters on efficiency of energy and exergy. Dai et al. [10] carried out exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle.

Nomenclature

E_{xd}	Exergy destruction rate (KW)
$E_{x.in}$	Inlet exergy into the system (KW)
ORC	Organic Rankine Cycle
Q_{HRVG}	Heat added to the heat recovery vapour generator (HRVG) (KW)
Q_{cond}	Heat rejected by the condenser (KW)
Q_{solar}	Solar heat input (KW)
T	Temperature (K)
W_{net}	Net power output (KW)
$E_{x,\ solar}$	Incoming exergy associated with solar radiation (KW).
η_{energy}	Energy efficiency of heliostat field
η_{exergy}	Energy efficiency of central receiver
η_{T}	Isentropic efficiency of the turbine
η_{P}	Isentropic efficiency of the pump

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2. System Description

The solar assisted Organic Rankine Cycle consists of solar energy collecting sub-system and Organic Rankine Cycle sub-system. Figure 1 illustrates the schematic diagram of the entire system. The Organic Rankine Cycle sub-system consists of four main components, namely: a heat recovery vapour generator (HRVG), a turbine, a condenser and a pump. Solar radiation falls on the heliostat field and it is reflected on the aperture area of central receiver, aperture area which is located at the top of the tower.

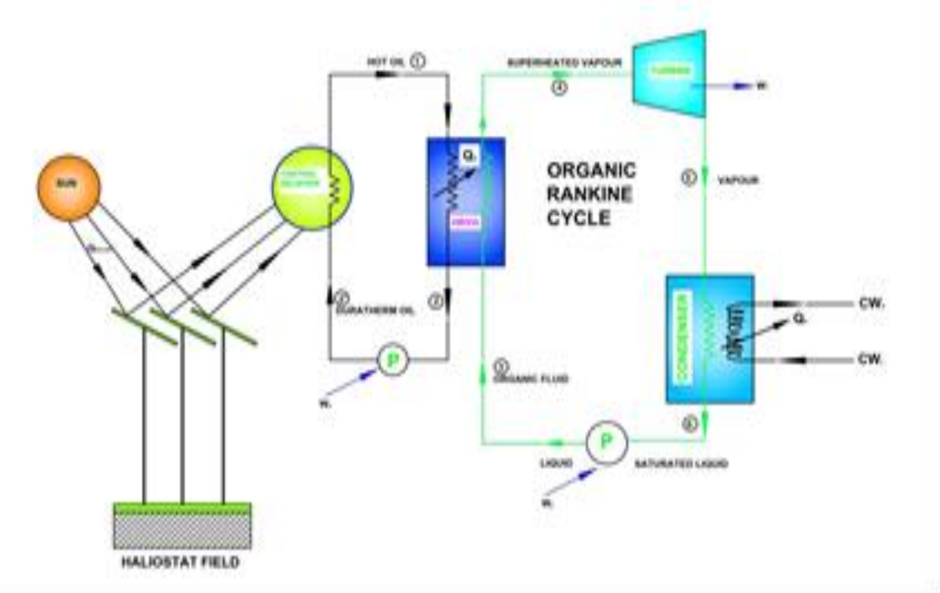

Fig: 1 Schematic diagram of solar assisted Organic Rankine Cycle

The concentrated rays which falls on to the central receiver results in higher temperature of the central receiver, which is used to heat the oil (Duratherm oil 600). The heated oil flows through the pipes which transfers thermal energy from central receiver to the R245fa flowing in the HRVG. The superheated refrigerant vapour of R245fa expanded in the turbine to produce power, the turbine exhaust is condensed in the condenser. The saturated liquid is pumped by pump to the HRVG (Boiler) of Organic Rankine Cycle.

3. Assumptions

The solar driven ORC for power generation is mathematically modeled using energy and exergy balanced on each component as well as on the whole system. To simplify the theoretical analysis, some assumptions are made as follows:

1. The system runs at steady state process.
2. Pressure drop and heat loss in pipelines are all neglected.
3. The working fluid at the condenser outlet is saturated liquid.
4. Kinetic and potential energy and exergy are ignored.
5. Pressure drops of R245fa in the HRVG and condenser is neglected.

4. Energy Equations

4.1. Energy equations for Organic Rankine Cycle sub-system

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

In the HRVG, the heat addition into the power cycle is given by:

$$Q_{HRVG} = m_f (h_4 - h_3) \qquad (1)$$

In the condenser, heat rejected is expressed as:

$$Q_{cond.} = m_f (h_5 - h_6) \qquad (2)$$

For the turbine, the isentropic efficiency is expressed as:

$$\eta_T = \frac{h_4 - h_5}{h_4 - h_{5S}} \qquad (3)$$

The power output of the turbine is given by:

$$W_T = m_f (h_4 - h_5) \qquad (4)$$

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

$$\eta_P = \frac{h_{3S} - h_6}{h_3 - h_6} \qquad (5)$$

The ORC pump power consumption is defined as:

$$W_P = m_f (h_3 - h_6) \quad (6)$$

$$W_{net} = (W_T) - (W_P) \quad (7)$$

$$\eta_{energy} = \frac{W_{net}}{Q_{solar}} \quad (8)$$

5. Exergy Equations

5.1. Exergy equations for Organic Rankine Cycle sub-system

Exergy destruction in HRVG:-

$$E_{xd\,HRVG} = \mathrm{moil} * (\mathrm{h}_1 - \mathrm{h}_2) - \mathrm{T0} * (2.4 * \ln(\mathrm{T1} + 273)/\mathrm{T2} + 273) + \mathrm{mf} * (\mathrm{h}_3 - \mathrm{h}_4) - \mathrm{T0} * (\mathrm{s}_3 - \mathrm{s}_4)$$

Exergy destruction in Turbine:

$$E_{xd\,Turbine} = (h_4 - T_o * S_4) - (h_5 - T_o * S_5) - (h_4 - h_5) \quad (9)$$

Exergy destruction in condenser:

$$E_{xd,cond.} = (h_5 - T_o * S_5) - (h_6 - T_o * S_6) \quad (10)$$

Exergy destruction in pump:

$$E_{xd,pump} = (h_6 - T_o * S_6) - (h_3 - T_o * S_3) + (h_3 - h_6) \quad (11)$$

$$E_{x,input} = Q_s^*[1 - T_0/(T_4 + 273)] + W \quad (12)$$

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

Table 1 Percentage (%) of Sun's energy / exergy distribution in ORC

Energy / Exergy input and output	**Sun's energy / exergy distribution R245fa**	
	KW	%
Energy input from Sun into system	231	100 %
Energy efficiency		9.95 %
Exergy associated with solar heat input	215.7	100 %
Exergy efficiency		10.66 %

6. Results and Discussion

The parametric analysis has been carried out with the help of EES software (Version 9.2) in order to find the effect of various operating parameters on energy and exergy efficiency along with exergy destruction in the components of ORC.

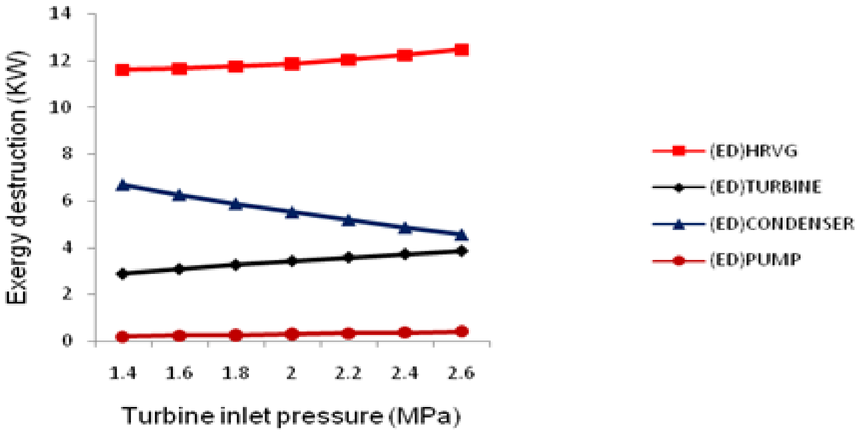

Fig.1. Effect of turbine inlet pressure on exergy destruction rate in various components of ORC

Figure 1 shows the effect of variation of turbine inlet pressure on exergy destruction in components of ORC. With increase in turbine inlet pressure, exergy destruction in HRVG, turbine and pump increases where as exergy destruction in condenser decreases. Therefore it is observed that with increase in turbine inlet pressure, the exergy destruction in condenser decreases from 6.6 KW to 4.5 KW.

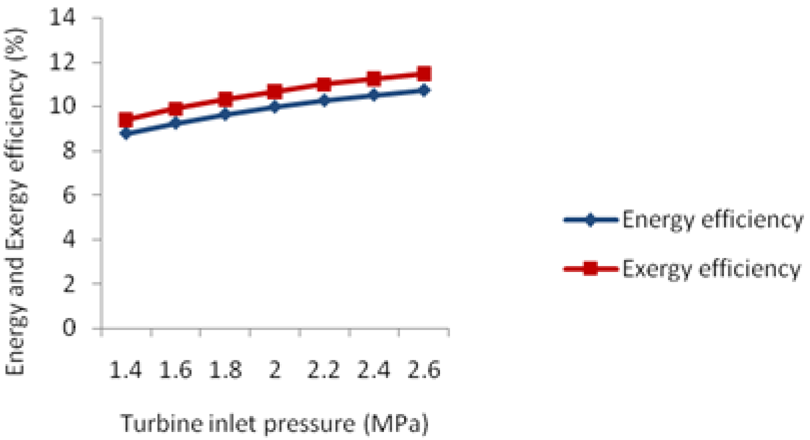

Fig. 2. Effect of Turbine inlet pressure on energy and exergy efficiency

Figure 2 shows the effect of turbine inlet pressure on energy and exergy efficiency. With increase in turbine inlet pressure, energy and exergy efficiency also increases. The energy efficiency of increases from 8.75% to 10.76% and exergy efficiency also increases from 9.38% to 11.46%.

Figure 3 shows the effect of turbine back pressure on exergy destruction rate in various components of ORC. With increase in turbine back pressure, no effect has been monitored on exergy destruction in HRVG, and pump where as we can notice that major increase in exergy destruction in condenser from 1.78 KW to 8.34 KW has been notice. Therefore increase in turbine back pressure, increases the total exergy destruction.

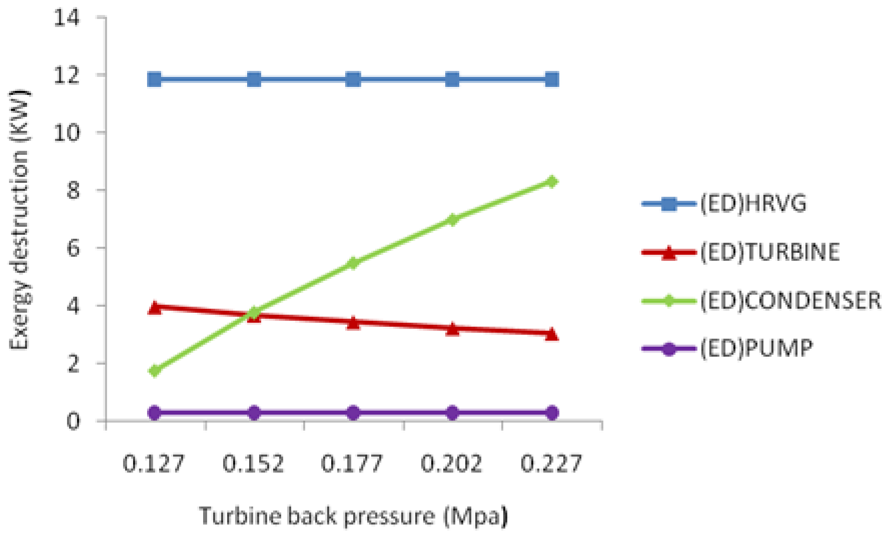

Fig.3. Effect of turbine back pressure on exergy destruction rate in various components of ORC

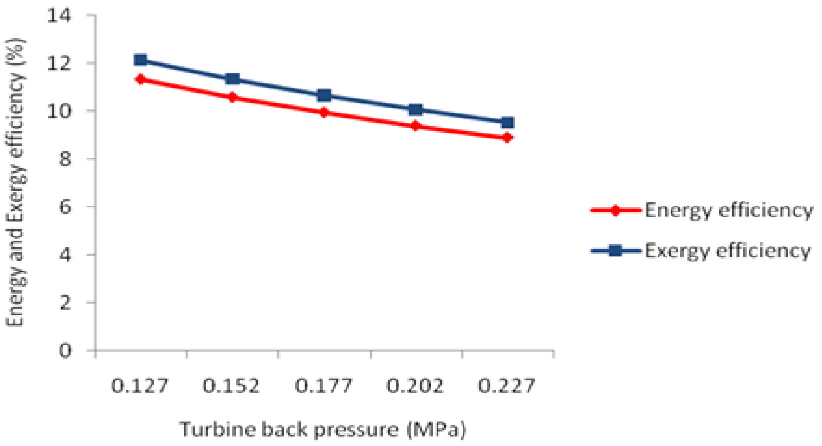

Fig.4. Effect of Turbine back pressure on energy and exergy efficiency

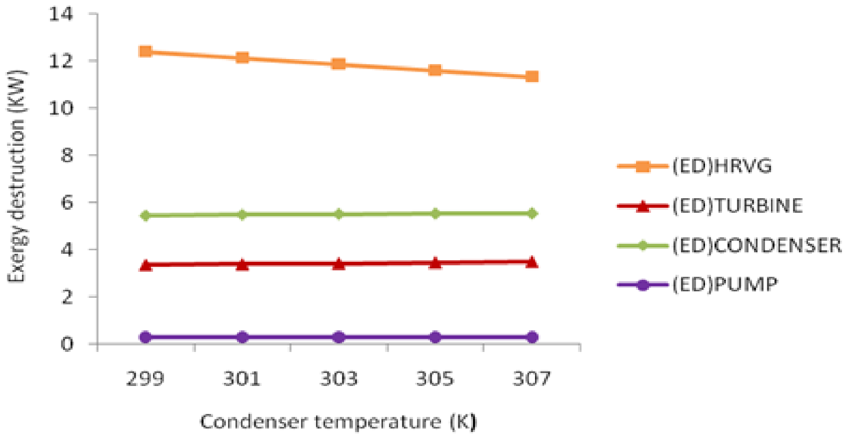

Fig.5. Effect of condenser temperature on exergy destruction rate in various components of ORC

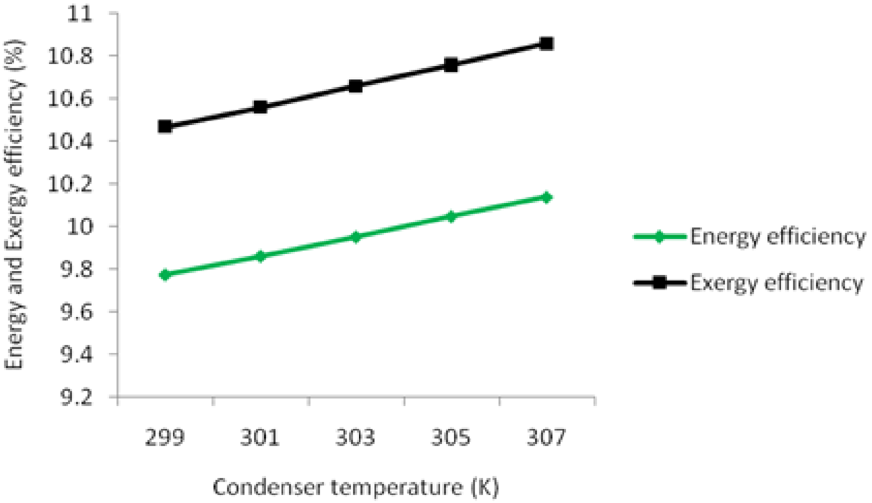

Fig.6. Effect of condenser temperature on energy and exergy efficiency

Figure 4 shows the effect of turbine back pressure on energy and exergy efficiency. With increase in turbine back pressure, the energy and exergy efficiency decreases.

Figure 5 shows the effect of condenser temperature on exergy destruction rate in various components of ORC. With increase in condenser temperature, exergy destruction in HRVG and pump decreases where as exergy destruction turbine and condenser increases. Therefore we conclude that with increase in condenser temperature, total exergy destruction deceases from 21.54 KW to 20.60 KW.

Figure 6 shows the effect of condenser temperature on energy and exergy efficiency. With increase in condenser temperature, energy efficiency increases from 9.72% to 10.14% and exergy efficiency also increases from 10.47% to 10.90%.

Conclusion

The major conclusions during parametric analysis of Organic Rankine Cycle by using first and second law approach are as follow:

- With increase in turbine inlet pressure, energy and exergy efficiency both increases.
- With increase in turbine back pressure, energy and exergy efficiency both decreases.
- With increase in condenser temperature, energy and exergy efficiency both increases.

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