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Exergetic analysis of Solar Operated Power and Cooling Cycle

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Abstract—*A combined cycle is proposed for the production of power and cooling. Exergetic analysis has been done to observe the effect of turbine inlet temperature on the performance of the combined cycle. The variation of turbine inlet temperature on the performance of the cycle has significant effects on the net power output, cooling, energy efficiency and exergetic efficiency. It is also observed that the maximum percentage exergy destruction occurs in the heat recovery vapor generator followed in the ejector, and turbine components of the cycle.*

Keywords: *Exergy destruction, extraction ratio, ejector, energy efficiency, exergetic efficiency, entrainment ratio.*

1. INTRODUCTION

Many researchers have studied the ejector refrigeration cycle because it has many advantages like less movable parts, less maintenance and possibility to use wide variety of refrigerants. The COP of the ejector refrigeration cycle is relatively low (Yapici, R., 2007; Li et al., 2005; Pianthong et al., 2007; Sankarlal and Mani, 2007).

Recently, an energy and exergy analyses of combined power and ejector refrigeration cycles was reported by (Wang et al., 2008; Yapici and Yetisen, 2007; Dai et al., 2009; Wang et al., 2009; Gupta et al., 2014) which shows that the maximum irreversibility/exergy loss occurs in heat addition process followed by the ejector and turbine.

2. SYSTEM DESCRIPTION

Fig. 1 shows the simplified combined Rankine and ejector cooling cycle. The proposed system consists of Rankine cycle (RC), ejector cooling cycle (ECC), with only solar heat source. The oil transfers the thermal energy from central receiver to the refrigerant passing through the HRVG. Superheated refrigerant vapor (4) is expanded in a turbine to generate work. The working fluid at low pressure and temperature from the throttle valve is vaporized in the evaporator (12-13) to produce cooling effect.

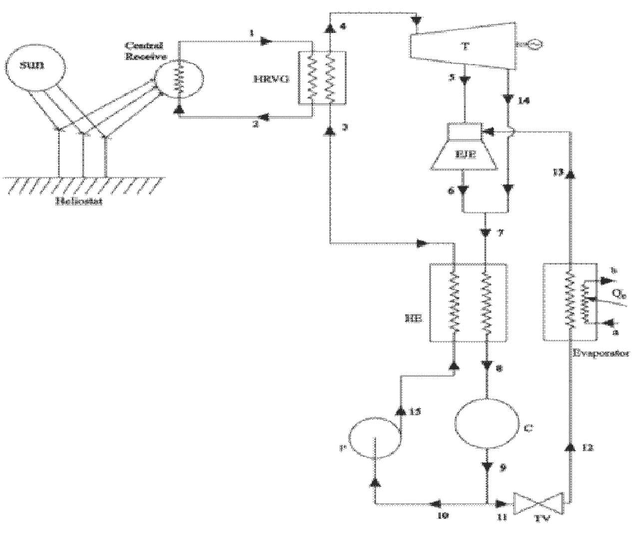

Fig. 1 Schematic diagram of solar operated combined Rankine and ejector refrigeration cycle

For the analysis, the specifications of the combined Rankine and ejector refrigeration cycle are given inTable 1.

Table 1: Main parameters considered for the analysis

Atmospheric Temperature (K)	298
Atmospheric pressure (MPa)	0.10135
Turbine inlet pressure (MPa)	0.650
Turbine inlet Temperature (K)	393-453
Extraction ratio	0.3
Extraction pressure ratio	2.5
Turbine isentropic efficiency (%)	85
Pump isentropic efficiency (%)	80
Condenser temperature (K)	293
Evaporator temperature (K)	268
Solar radiation received per unit area (kWm-2)	0.85
Apparent Sun temperature (K)	4500
Heliostat aperture area (m2)	3000
Oil temperature inlet to CR (oC)	373
Oil temperature inlet to HRVG (oC)	433

HRVG efficiency (%)	100
Pinch point temperature difference (oC)	10.0
Nozzle efficiency (%)	90
Mixing chamber efficiency (%)	85
Diffuser efficiency (%)	85
First law efficiency of heliostat field (%)	75
First law efficiency of central receiver (%)	90
Second law efficiency of heliostat field (%)	75
Second law efficiency of central receiver (%)	30

3. THERMODYNAMIC ANALYSIS

A thermodynamic analysis considering both the energy and the exergy provides an opportunity to evaluate the theoretical performance of the proposed cycle. Exergy analysis determines the system performance based on exergy, which is defined as the maximum possible reversible work obtainable in bringing the state of the system to equilibrium with that of the environment. Mathematically,

$$\dot{E} = \dot{m}[(h - h_0) - T_0(s - s_0)] \quad (1)$$

Entropy generation over a control volume is given by

$$\dot{S}_{gen} = \frac{dS}{dt} - \sum_{i=0}^{n} \frac{\dot{Q}_i}{T_i} - \sum_{in} \dot{m}s + \sum_{out} \dot{m}s \geq 0 \quad (2)$$

According to Gouy-Stodola theorem, the exergy destruction and entropy generation are related as

$$\dot{E}_D = T_0 \dot{S}_{gen} \quad (3)$$

3.1 First law efficiency (η_I)

The first law efficiency of the combined cycle is given by

$$\eta_I = \frac{\dot{W}_{net} + \dot{Q}_E}{\dot{Q}_{Solar}} \quad (4)$$

$$\dot{Q}_{Solar} = AI \quad (5)$$

$$\dot{W}_T = \dot{m}_f(h_4 - h_5) + \dot{m}_f(1 - E_r)(h_5 - h_{14}) \quad (6)$$

$$\dot{W}_p = \dot{m}_f(h_{15} - h_{10}) \quad (7)$$

$$\dot{W}_{net} = \dot{W}_T - \dot{W}_p \quad (8)$$

$$\dot{Q}_E = \dot{m}_f E_r \mu (h_{13} - h_{12}) = \dot{m}_w(h_a - h_b) \quad (9)$$

3.2 Second law Efficiency (η_{II})

The second law efficiency of combined cycle may be reported as

$$\eta_{II} = \frac{\dot{W}_{net} + \dot{E}_E}{\dot{E}_{Solar}} \quad (10)$$

$$\dot{E}_E = \dot{m}_{sf}[(h_{12} - h_{13}) - T_0(s_{12} - s_{13})] \quad (11)$$

$$\dot{E}_{Solar} = \dot{Q}_{Solar}\left(1 - \frac{T_0}{T_{Solar}}\right) \quad (12)$$

4. RESULTS AND DISCUSSION

An exergetic analysis has been carried out to find out to the variation of turbine inlet temperature on the performance of the combined power and cooling cycle. Exergy balance approach is applied to find out the exergy destruction in each component of the system. The exergy destruction in each component has been determined with the variation of turbine inlet temperature is shown in table 2.

Table 2: The exergy destruction in each component with the variation of turbine inlet temperature

Turbine inlet tempera ture	Exergy destruction (%)						
	Conde nser	Eject or	Genera tor	Heat exchan ger	Pu mp	Turbi ne	Throt tle Valve
120	22.16	22.82	25.98	0.82	2.30	20.16	0.44
130	21.07	22.07	28.69	1.20	2.19	19.23	0.43
140	20.11	21.46	30.92	1.67	2.08	18.41	0.41
150	19.25	20.96	32.72	2.21	1.99	17.67	0.40
160	18.49	20.54	34.18	2.81	1.91	17.00	0.39
170	17.81	20.21	35.37	3.46	1.84	16.39	0.38
180	17.18	19.94	36.31	4.15	1.77	15.84	0.37

Fig. 2 shows the effect of variation of turbine inlet temperature on the energy and exergetic efficiency of the proposed cycle. As the turbine inlet temperature increases the energy and exergetic efficiencies increases.

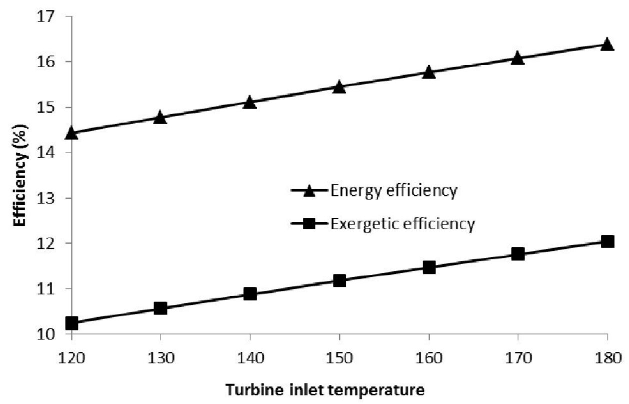

Fig. 2 Effect of turbine inlet temperature on energy and exergetic efficiency

Fig. 3: Shows the effect of variation of turbine inlet temperature on the net power output and cooling of the proposed cycle. As the turbine inlet temperature increases the net power output and cooling increases.

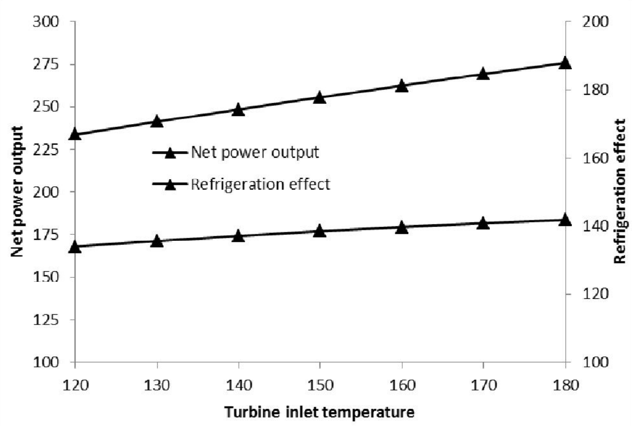

Fig. 3 Effect of turbine inlet temperature on net power output and refrigeration effect

5. CONCLUSION

A solar operated combined Rankine and ejector cooling cycle is proposed for the production of power and cooling output. Exergetic analysis has been done to identify the effects of variation of turbine inlet temperature on the performance of the proposed cycle. The conclusions of the present analysis can be summarized as follows:

- As the turbine inlet temperature increases the energy and exergetic efficiencies increases.
- As the turbine inlet temperature increases the net power output and cooling effect increases.
- The percentage of exergy loss is biggest in the heat recovery vapour generator followed in the ejector, and turbine components of the cycle.

Results obtained in the present study may be utilized by the engineers and scientists for a suitable thermodynamic design of solar operated combined Rankine and ejector cooling cycle.

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