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Parametric Study of a Combined Power and Ejector Cooling Cycle using Low Temperature Heat Source

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Abstract: *A parametric study is carried out to analyze the performance of a combined power and ejector cooling cycle using low temperature heat source. The performance of different working fluids (R290, R152a, R134a, and R717) is investigated using first and second law thermodynamics.The effect of most influenced parameters such as driving pressure ratio, and compression pressure ratio on the entrainment ratio, net power output, refrigeration output, first law and second law efficiency of the proposed cycle for various environmentally benign fluids (R290, R152a, R134a, and R717) have been studied. The performance of the proposed cycle shows that the R290 gives better first law efficiency and refrigeration output while R134a gives better net power output and second law efficiency at high driving pressure ratio.*

Keywords: *Solar energy; driving pressure ratio; ejector; compression ratio; ecofriendly refrigerants; entrainment ratio.*

1. INTRODUCTION

Flue gases release from industrial plants contain low temperature energy goes waste to the atmosphere which caused the depletion of Ozone layer and global warming in recent years. For the past decades, the organic Rankine cycle (ORC) and the power generating system using binary mixture as a working fluid have attracted much attention as they are proven to be the most feasible methods to achieve high efficiency in converting the low temperature energy to more useful forms of energy [1-8]. For efficient utilization of low temperature energy, a combined power and refrigeration cycle has been analysed to improve the overall efficiency of the system. Many researchers have studied combined heating and power (CHP) systems [9, 10]which make complete use of the energy contained in these sources.

Demirkaya et al. [11] analysed a combined power and cooling cycle using heat source as low-grade energy. This can be done by combining a power cycle with either absorption or ejector cooling cycle. Dai et al. [12] proposed a combined power and refrigeration cycle, which combines the Rankine cycle and the ejector refrigeration cycle. This combined cycle produces both power output and refrigeration output simultaneously and it can be driven by the solar energy, geothermal energy and industrial waste heats. Li et al. [13] proposed an organic Rankine cycle with ejector (EORC) for the purpose of increasing the power output capacity and its efficiency. Habibzadeh et al. [14] investigated the effects of the system parameters including the turbine inlet temperature and pressure on the performance of the combined power and ejector cooling cycle using first and second law of thermodynamics.

Recently, an energy and exergy analyses of combined power and ejector refrigeration cycles was reported by Gupta et al. [15] which shows that the maximum irreversibility/exergy loss occurs in heat addition process followed by the ejector and turbine.

Present study shows the parametric analysis of a combined power and ejector cooling cycle with ecofriendly refrigerants as working substance using low temperature heat source. The effect of most influenced parameters such as driving pressure ratio (ε), and compression pressure ratio (λ) has been observed on the performance (entrainment ratio, net power output, refrigeration output, first law and second law efficiency) of the proposed cycle.

2. SYSTEM DESCRIPTION

Fig.1 shows the combined power and ejector cooling system. It consists of a pump, heat exchanger (HE), heat recovery vapor generator (HRVG), an extraction turbine (ET), condenser (C), an ejector (EJE), evaporator (E), and throttle valve (TV). Low temperature heat source is used to heat the high pressure refrigerant in the HRVG. Superheated refrigerant vapor expands in the turbine. Extracted vapor from the turbine enters the ejector nozzle and entrains secondary vapor from the evaporator mixes in mixing chamber of the ejector. The ejector exit stream mixes with the extraction turbine exhaust and is flow into the heat exchanger, and then enters into the condenser. Saturated liquid from condenser then enters into throttle valve and pump. The high pressure liquid delivered by the pump flows into the heat exchanger and then converted into superheated vapor in the HRVG. The part of the saturated liquid expands to the evaporator pressure in the throttle valve and vaporized in the evaporator to produce cooling effect.

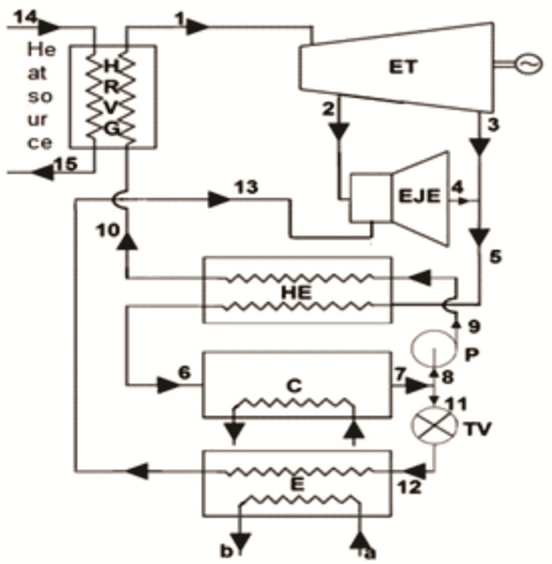

Fig. 1. Combined ejector cycle

For the analysis, the parameters used of the combined power and ejector refrigeration cycle are given in Table 1

TABLE 1: Main parameters considered for the analysis

Atmospheric Temperature (K)	298
Atmospheric pressure (MPa)	0.10135
Turbine inlet Temperature (K) Extraction ratio Turbine isentropic efficiency (%) Pump isentropic efficiency (%) Condenser temperature (K) Evaporator temperature (K) Water temperature inlet to evaporator (K) Water temperature outlet to evaporator (K)	393 0.5 85 70 303 273 299 283
HRVG efficiency (%)	100
Pinch point temperature difference (°C)	10.0
Nozzle efficiency (%)	90
Mixing chamber efficiency (%)	85
Diffuser efficiency (%) Source temp inlet to HRVG (K) Source temp outlet to HRVG (K)	85 403 363

3. THERMODYNAMIC ANALYSIS

The entrainment ratio on the bases of mass, momentum and energy equations is developed by Dai et al. (2009) and may be written as

$$\mu = \sqrt{\eta_n \eta_m \eta_d \left(h_{pf,n1} - h_{pf,2s}\right)/\left(h_{mf,ds} - h_{mf,m}\right)} - 1 \quad (1)$$

The efficiencies of various components of the ejector such as nozzle, mixing chamber, and diffuser are given in Table 1 and the enthalpy and entropy values at salient state points of the proposed cycle for ecofriendly refrigerants are taken from NIST Standard Reference Database 23, REFPROP 6.01(1998).

A parametric analysis provides an opportunity to evaluate the theoretical performance of the combined power and ejector cooling cycle. It determines the system performance based on exergy, which may be defined as the maximum possible reversible work obtainable in bringing the state of the system to equilibrium with that of the environment Bejan, A. [17]. Mathematically,

$$\dot{E} = \dot{m}[(h - h_0) - T_0(s - s_0)] \quad (2)$$

3.1. FIRST LAW EFFICIENCY (η_I):

First law efficiency is defined as the ratio of the sum of the net power output ($\dot{W}_{net}$) and refrigeration output in the evaporator ($\dot{Q}_E$) to the energy input ($\dot{Q}_{in}$).

The first law efficiency of the combined cycle is given by

$$\eta_I = \frac{\dot{W}_{net}+\dot{Q}_E}{\dot{Q}_{in}} = \frac{(\dot{W}_T-\dot{W}_p)+\dot{Q}_E}{\dot{m}_g(h_{14}-h_{15})} \quad (3)$$

Where

$$\dot{Q}_E = \dot{m}_f E_r \mu (h_{13} - h_{12}) = \dot{m}_w (h_a - h_b) \quad (4)$$

$$\dot{W}_T = \dot{m}_f (h_1 - h_2) + \dot{m}_f (1 - E_r)(h_2 - h_3) \quad (5)$$

$$\dot{m}_f = \dot{m}_{pf} + (1 - E_r)\dot{m}_f \quad (6)$$

$$\dot{W}_p = \dot{m}_f (h_9 - h_8) \quad (7)$$

Extraction ratio:

$$E_r = \frac{\dot{m}_{pf}}{\dot{m}_f} = \frac{\dot{m}_2}{\dot{m}_1} \quad (8)$$

Entrainment ratio:

$$\mu = \frac{\dot{m}_{13}}{\dot{m}_2} = \frac{\dot{m}_{sf}}{\dot{m}_{pf}} \quad (9)$$

Driving pressure ratio:

$$\varepsilon = \frac{P_{Ext}}{P_C} = \frac{\text{Turbine pressure}}{\text{Condeser pressure}} \quad (10)$$

3.2. SECOND LAW EFFICIENCY (η_{II}):

The second law efficiency of cycle may be reported as

$\eta_{II} = \frac{\dot{W}_{net}+\dot{E}_E}{\dot{E}_{in}}$ Where, $\dot{E}_{in}$ is incoming exergy associate with heat source, $\dot{E}_E$ is the exergy of refrigeration output in the evaporator,

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

$$\dot{E}_{in} = \dot{Q}_{in}\left(1 - \frac{T_0}{T_{14}}\right) \quad (11b)$$

4. RESULTS AND DISCUSSION

A Parametric study has been carried out to analyses the effect of some influenced parameters on the performance of the solar driven combined power and ejector cooling cycle.

Fig. 2, 3 and 4 show the effect of driving pressure ratio (ε) for constant turbine inlet pressure, condenser pressure , and evaporator pressure on first law efficiency and second law efficiency, entrainment ratio, net power output and refrigeration output for various eco-friendly refrigerants (R290, R152a, R134a, and R717). As driving pressure ratio increases (or extraction pressure increases) net power output decreases. Due to higher driving pressure ratio, the ejector suck more secondary refrigerant from the evaporator at constant evaporator pressure resulting in increase in entrainment ratio, refrigeration output and exergy of refrigeration. Increase in the refrigeration output is more than the decrease in net power output resulting in increase in first law efficiency and decrease in second law efficiency.

It is also observed that among the various ecofriendly refrigerant, R290 gives better first law efficiency and refrigeration output while R134a gives better net power output and second law efficiency at high driving pressure ratio.

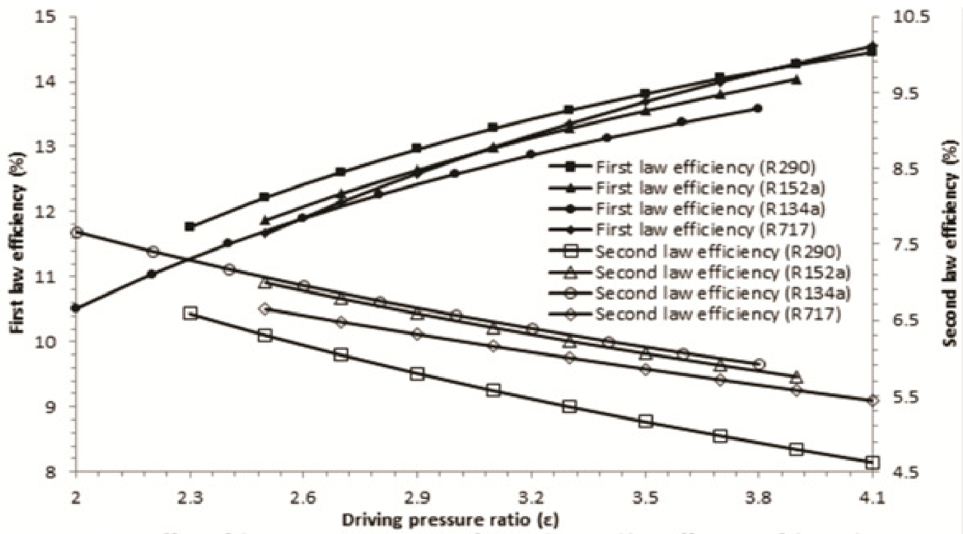

Fig. 2. Effect of driving pressure ratio on first and second law efficiency of the cycle

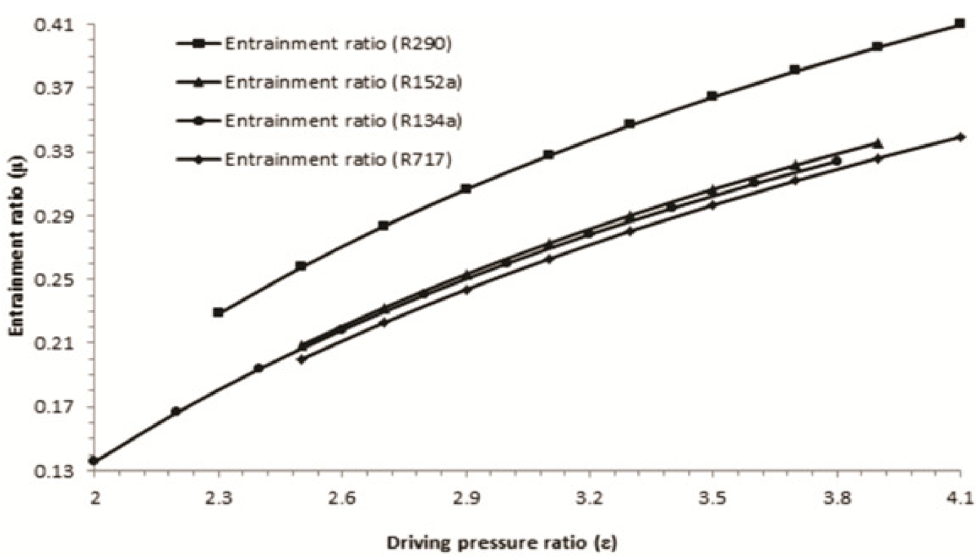

Fig. 3. Effect of driving pressure ratio on entrainment ratio

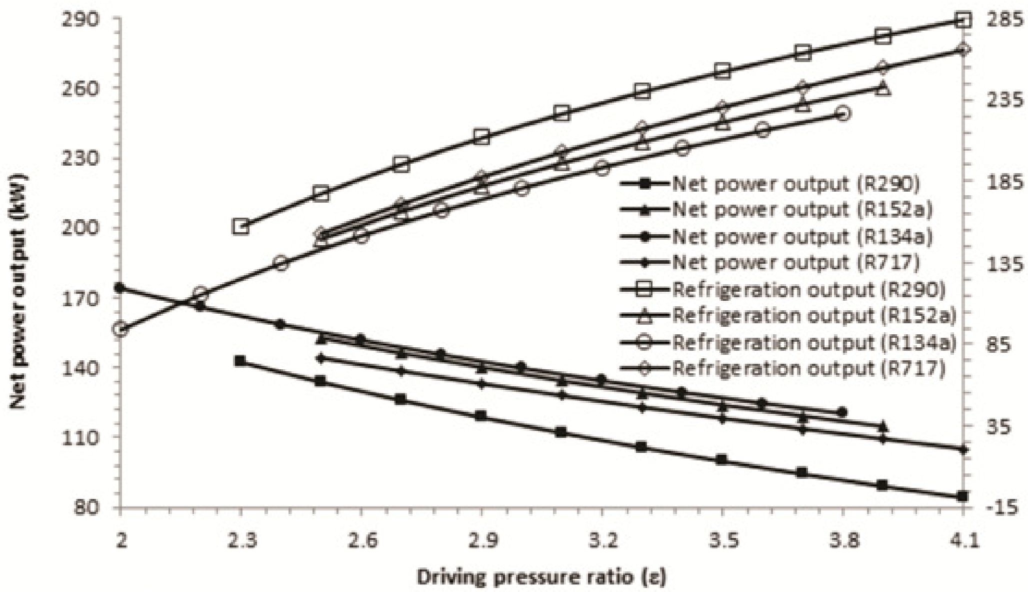

Fig. 4. Effect of driving pressure ratio on net power output and refrigeration output of the cycle

5. CONCLUSIONS

Present study deals with the solar operated combined power and an ejector refrigeration cycle with ecofriendly refrigerants as working fluid. The effect of most influenced parameters such as driving pressure ratio has been observed on the performance (first law efficiency and second law efficiency, entrainment ratio, net power output and refrigeration output) of the proposed cycle.

- From the above discussion, it can be concluded that
- As the driving pressure ratio (ε) increases, entrainment ratio, refrigeration output, and first law efficiency increases while second law efficiency and net power output decreases.
- At high driving pressure ratio (ε) R290 and R134a gives better performance.

Results obtained may be utilized by the engineers and scientists for design a combined power and ejector cooling cycle.

REFERENCES

[1] Hung, T.C.; Shai, T.Y.; Wang, S.K. A review of organic Rankine cycles (ORCs) for the recovery of low-grade waste heat. Energy, 1997, 22, 661-667.

[2] Gu, W.; Weng, Y.; Wang, Y.; Zheng, B. Theoretical and experimental investigation of an organic Rankine cycle for a waste heat recovery system. Proc IMECHE – Part A: J Power Energy, 2009, 223(5), 523–533.

[3] Lai, N.A.; Wendland, M.; Fisher, J. Working fluids for high temperature organic Rankine cycle. Energy, 2011, 36, 199-211.

[4] Wei, D.; Lu, X.; Lu, Z.; Gu, J. Performance analysis and optimization of organic Rankine cycle (ORC) for waste heat recovery. Energy Conversion Management, 2007, 48(4), 1113–1119.

[5] Kim, K.H.; Han, C.H.; Kim, K. Effects of ammonia concentration on the thermodynamic performances of ammonia-water based power cycles. ThermochimicaActa, 2012, 530, 7-16.

[6] Chen, H.; Goswami D.Y.; Stefanakos E.K. A review of thermodynamic cycles and working fluids for the conversion of low-grade heat. Renewable and Sustainable Energy Reviews, 2010, 14, 3059–3067.

[7] Kim, K.H.; Han, C.H.; Kim, K. Comparative exergy analysis of ammonia-water based Rankine cycles with and without regeneration. Int. J. Exergy, 2013, 16, 344-361.

[8] Roy, P.; Désilets, M.; Galanis, N.; Nesreddine, H.; Cayer, E. Thermodynamic analysis of a power cycle using a low-temperature source and a binary NH3–H2O mixture as working fluid. Int. J. Thermal Sciences, 2010, 49, 48–58.

[9] Guo, T.; Wang, H.X.; Zhang S.J. Selection of working fluids for a novel low temperature geothermally-powered ORC based cogeneration system. Energy Conversion Management, 2011, 52, 2384–2391.

[10] Heberle, F.; Brüggemann, D. Exergy based fluid selection for a geothermal organic Rankine cycle for combined heat and power generation. Appl. Therm. Eng. 2010, 30, 1326–1332.

[11] Demirkaya, G.; Padilla, R.V.; Goswami, D.Y.; Stefanakos, E.; Rahman, M.M. Analysis of a combined power and cooling cycle for low-grade

heat sources. Int. J. Energy Res., 2011, 35, 1145-1157.

[12] Dai, Y.; Wang, J.; Gao, L. Exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle. Appl. Therm. Eng., 2009, 28, 335-340.

[13] Li, X.; Zhao, C.; Hu, X. Thermodynamic analysis of organic Rankine cycle with ejector. Energy, 2012, 42, 342-349.

[14] Habibzadeh, A.; Rashidi, M.M.; Galanis, N. Analysis of a combined power and ejector-refrigeration cycle using low temperature heat. Energy Conversion Management.2013, 65, 381-391.

[15] Gupta, D.K.; Kumar, R.; Kumar, N. First and second law analysis of solar operated combined Rankine and ejector refrigeration cycle. Applied Solar Energy, 2014, 50(2), 113–121.

[16] NIST Standard Reference Database 23, (1998). NIST Thermodynamic and transport properties of refrigerants and refrigerants mixtures REFPROP, Version 6.01.

[17] Bejan, A. Fundamentals of exergy analysis, entropy generation minimization and the generation of flow architecture. International Journal of Energy Research, 2002, 26, 545-565.