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Cascade Utilization of Energy and Exergy for the Performance Analysis of a Solar Powered Cogeneration Cycle

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Abstract : Present study focuses on the first and second law analyses of a solar based cogeneration system which could simultaneously produce the electric power and refrigeration. An investigation is carried out to ascertain the effect of varying the direct normal irradiation (DNI) and turbine back pressure on the first law efficiency, cooling to power ratio and second law efficiency of the cogeneration system. The results obtained indicate that variation in DNI and turbine back pressure have a considerable impact on the second law performance of the cogeneration system while its first law performance is least affected.

Keywords : direct normal irradiation, turbine

Nomenclature

E Rate of exergy [W]
Q Rate of heat transfer [W]
W Rate of work output [W]
$R_{C/P}$ Cooling to power ratio
q Solar radiation received per unit area [W/m^2]

Subscript

s Sun
R Refrigeration
El Electrical
c/p Cooling to power
ex exergy

1. Introduction

In order to utilize the solar thermal energy for its potential in reducing fossil fuel consumption and alleviating environmental problems, the cogeneration cycles for combined production power and cooling have been explored for improving the overall energy conversion efficiency. In this context, a new combined power and cooling thermodynamic cycle was proposed by Goswami [2002]. This was a combined cycle because it produces both power and cooling simultaneously with only one heat source, using ammonia-water mixture as the working fluid. Other researchers [Dai et al.(2009), Khaliq et al.(2012), Zhang and Li ( )] have also investigated this new cycle from both energy and exergy point of view where latter provides a clearer assessment of various losses occurring in energy systems both quantitatively and qualitatively and thereby shows the possibilities where improvements in efficiency could be made. Hasan et al [ ] presented the first and second law analysis of the combined power and cooling cycle that could use low temperature heat sources below 200^{o}C as a primary energy input and ammonia-water mixture as a working fluid. Li et al (2013) investigated the organic Rankine cycle with ejector from first and second law point of view and emphasized on its thermo-organic performance at the maximum net power output of the cycle. Habibzadeh (2013) conducted a thermodynamic study on organic Rankine cycle with ejector and evaluated its first and second law performance for different working fluids. They obtained the optimum values of the turbine and pump inlet pressures which minimize the total thermal conductance of the system for working fluids under consideration.

From the foregoing literature review, it is noted that the majority of the previous research is focused on the solar assisted cogeneration cycle which combines the organic Rankine cycle with an ejector and utilized R-134a, R-113, R-123, R141b, R-117, and R-609 etc. as the working fluids which have the advantages of zero ozone depletion potential, but they have higher global warming potential and safety problems as well as they produces lower power output because of their smaller latent heat of vaporization. In order to overcome with the aforementioned disadvantages, a new cogeneration cycle was introduced which combines the conventional Rankine power cycle with a steam ejector. This cycle used extraction steam from steam turbine in conventional Rankine cycle to heat the working fluid of the steam ejector refrigeration cycle. Since water is used as a working fluid for both power and cooling production which has a zero-ozone depletion potential and zero global warming potential as well as have very good thermal properties, therefore, this cycle could be considered as one of the most suitable options for harnessing the solar thermal potential of the hot areas. The performance characteristics of solar based cogeneration cycle using the solar power tower technology are not well reported in the literature. Therefore, the objective of the present work is to investigate the performance of a proposed cogeneration cycle using a combined first and second law approach. A parametric analysis is performed to examine the effects of some influencing parameters on the energy and exergy efficiency of the cogeneration cycle. Numerical results are graphed and commented upon.

2. Theoretical Analysis

Energy and exergy analyses of a solar powered cogeneration system involve the application of the principle of conservation of mass and conservation of energy along with the second law of thermodynamics and can identifies and quantifies the sources of losses and hence provides guidance for performance improvement.

The relevant parameters required to evaluate the energetic and exergetic performance of the proposed cogeneration cycle may be considered as follows:

2.1 Energy Utilization Factor (EUF)

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The energy utilization factor is the energy measure of efficiency and is simply a ratio of useful output energy to input energy. For cogeneration of electrical power and cooling the energy utilization factor can be defined as the ratio of all the useful energy extracted from the system to the primary energy input to the cycle, and may be expressed as:

$$\text{EUF} = \frac{\dot{W}_{el}+\dot{Q}_E}{\dot{Q}_{in}} = \frac{\dot{W}_{el}+\dot{Q}_R}{\dot{Q}_{solar}}$$

where, $\dot{Q}_{solar}$ is the rate of thermal energy received by the heliostat and may be given as

$$\dot{Q}_{solar} = A_H q$$

2.2 Cooling to power ratio $R_{C/P}$

The effectiveness of the proposed cogeneration system is directly related to the amount of power it can generate for a given amount of refrigeration produced. Therefore, $R_{C/P}$ which is the cooling to power ratio could be one of the important parameter to assess the thermodynamic performance of a given cogeneration system.

It is defined as:

$$R_{C/P} = \frac{\dot{Q}_R}{\dot{W}_{el}}$$

In both energy utilization efficiency and power to cold ratio, power and refrigeration are treated as equal from the first-law of thermodynamic point of view. This reflects that parameters based on first-law are concerned with the quantity of energy, not its quality. Thus, EUF and $R_{P/C}$ are also known as first-law efficiencies.

2.3 Exergy efficiency (η_{ex}):

Exergy, or availability, which deals with the quality of energy along with its quantity, can be defined as the maximum amount of work produced during the reversible transition of a stream of a matter from its given thermodynamic state to its dead state where it is supposed to be in thermodynamic equilibrium with the environment. Exergy efficiency is the exergy output divided by the exergy input to the cycle. It may be further defined as:

$$\eta_{ex} = \frac{\dot{W}_{el}+\dot{E}_R}{\dot{E}_{solar}}$$

where, $\dot{W}_{el}$ is the exergy of electrical power output and may be given as $\dot{W}_{el} = \eta_g \dot{W}_T$

where, $\dot{W}_{el}$ is the exergy of electrical power output $\dot{E}_R$ is the exergy associated with the rate of refrigeration produced, and $\dot{Q}_{solar}$ is the rate of exergy associated with the solar radiations falling on heliostat field and may be given as

$$\dot{E}_{solar} - \dot{Q}_{solar} \left(1 - \frac{T_o}{T_s}\right)$$

where T_s is the apparent Sun temperature which may be taken as 4500 K.

$$\dot{E}_R = \dot{Q}_R \left(\frac{T_o - T_E}{T_E}\right)$$

It is defined as the refrigerator capacity divided by the COP of a Carnot refrigeration cycle operating between $T_E - T_o$.

Environment Temperature(^{0}C)	27^{0}C
Turbine inlet pressure (MPa)	8
Molten salt outlet temperature range (^{0}C)	567-644
Molten salt inlet temperature (^{0}C)	290
Area of the heliostat, AH (m^2)	10000
Turbine isentropic efficiency (%)	85
Generated efficiency (%)	95
Evaporator temperature, T_E (^{0}C)	7

3. Results and Discussion

The effects of DNI and turbine back pressure is observed on the energyic and exergetic performance of the proposed solar based cogeneration. Numerical results are graphed and comment upon and may be reported below.

The effect of change in DNI on first law efficiency and cooling to power ratio of the cogeneration is shown in fig. 2. It is observed that the first law efficiency increases with the increase in DNI while cooling to power ration decreases insignificantly with the increase in DNI. This is because higher DNI causes a greater turbine output and hence a higher efficiency. Increase in turbine output is greater than the increase in cooling output, therefore, the cooling to power ratio increases marginally with the increase in DNI. In order to gain further insight into the performance of the system, the effect of DNI is also observed on the second law efficiency and the exergetic cooling to power ratio of the cogeneration which is shown in fig. 3. Both second law efficiency and the exergetic cooling to power ratio were found to be increased considerably with the increase in DNI. This is because increase in DNI as a higher temperature source causes a greater exergy output of the system. It is further noticed that amount of exergy associated with the cooling capacity is considerably less than the energy and turbine power output gives 100%contribution to exergy, therefore, the exergetic cooling to power ration also a considerable increasing trend parallel to second law efficiency.

The effect of change in turbine back pressure is also investigated and is shown in fig. 4. It is found that both first law efficiency and cooling to power ration of the cogeneration are significantly increased with the increase in turbine back pressure. This is due to the fact that as turbine back pressure increases, the pressure ratio across the turbine decreases which decreases the turbine power, but there is an increase in motive steam pressure which
increases the refrigeration capacity. Since the increase in refrigeration capacity is greater
than the decrease in turbine power output,

therefore, both first law efficiency and cooling to power ratio are increased considerably with the increase in turbine back pressure. The second law efficiency and the exergetic cooling to power ratio shows the opposite trend with the increase in turbine back pressure. This is because the turbine power output which gives 100% contribution to exergy decreases while the exergy of the refrigeration which is much less than the refrigeration capacity decreases with the increase in turbine back pressure. Therefore, exergy output which is the sum of turbine power and the exergy of the refrigeration decreases while exergetic cooling to power ratio increases.

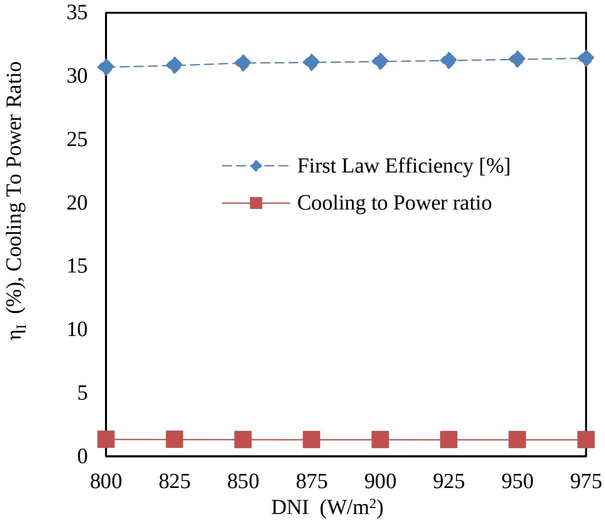

Figure 2

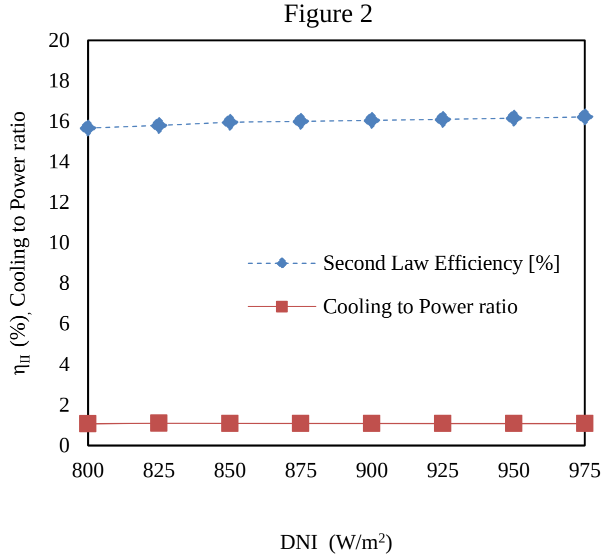

Figure 3

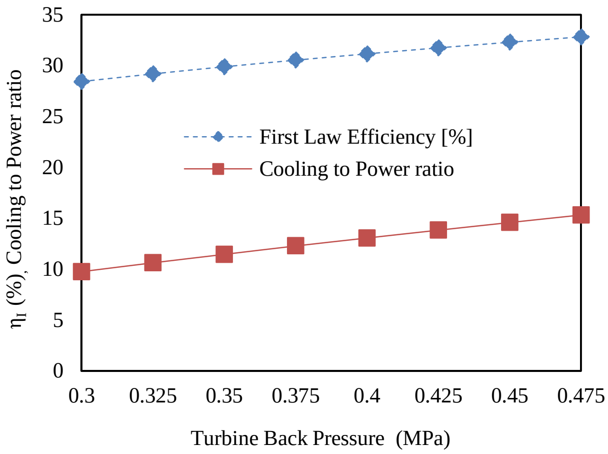

Figure 4

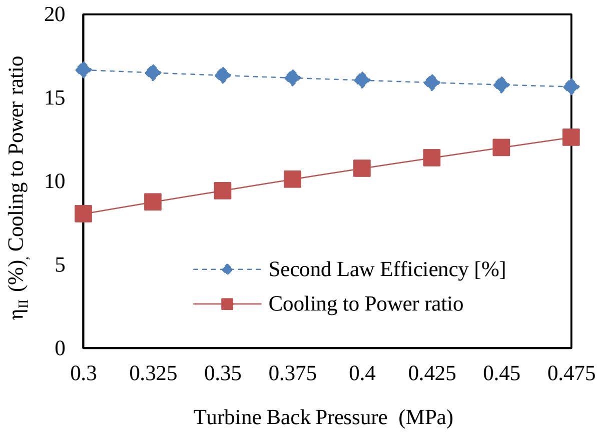

Figure 5

Conclusion : In this paper, an analysis based on combined first and second laws of thermodynamic was performed for the solar based cogeneration system which could produce both power and cooling simultaneously. It was found that by employing an ejector between the turbine and condenser, thermodynamic performance of the system increased. Results obtained after the parametric investigation show that the variation in DNI and the turbine back pressure have a greater impact on the second law performance of the cogeneration than its first law performance. It is noted that second law analysis provides an insight into the system performance which first law analysis alone cannot. The model presented for the analysis in this paper can be used to assess the thermodynamic performance of other kind of cogeneration system.

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REFERENCES

i. Xu F., Goswami D. Y., and Bhagwa S. S., A combined power/cooling cycle. Energy, 25 (3), 2002, pp. 233-246.

ii. Dia Y., Wang J., and Gao L., Exergy analysis, parametric analysis and optimization for a novel combined power and ejector refrigeration cycle. Applied Thermal engg. 29, 2009, pp. 1983-1990.

iii. Khaliq A., Agrawal B., and Kumar R., First and second law investigation of waste heat based on combined power and ejector–absorption refrigeration cycle. International Journal of Refrigeration, 35, 2012, pp. 88-97.

iv. Zhang N., and Lior N., Development of novel combined absorption cycle for power generation and refrigeration. ASME Trans. Energy Resources Technology, 129, 2007, pp. 254-265.

v. Hasan A. A., Goswami D. Y., and Vijayaraghavan S., First and second law analysis of a new power and refrigeration thermodynamic cycle using solar heat source. Solar Energy, 73 (5), 2002, pp. 385-393.

vi. Xinguo L., Xiajie L., and Zhang Q., The first and second law analysis on an organic Rankine cycle with ejector, Solar Energy, 93, 2013, pp. 100-108.

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

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

ix. Xu C., Wang Z., Li X., and Sun F., Energy and exergy analysis of solar power tower plants. Applied Thermal Engineering, 31, 2011, 3904-3913.