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Thermodynamic and Exergy Economic Analysis Combined Heat Power and Cooling in a Combined Cycle with Ejector Using Solar Energy

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ABSTRACT: Combined heat and power systems are used for renewable energies and reducing fossil fuels. This work, investigated energy efficiency, exergy, and exergy economic a Brayton cycle and refrigeration cycle with an ejector that used solar energy as a heat source. Inlet pressure turbine, outlet pressure turbine, inlet temperature turbine, and temperature of the evaporator are variable parameters, when one of the parameters changes, the other parameters are kept constant so that the thermodynamic analysis focuses on important parameters. Results showed that inlet pressure of initial flow in ejector and outlet velocity of flow on ejector are increased with increasing outlet pressure of turbine. The storage tank had the most exergy destruction rate among all components for the high-temperature difference that it's almost 29% from all of the exergy destruction rates. Also, the highest cost per unit of power is related to the combined heat and power cycle that it's about 53% of the total cost.

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1- Introduction

In Combined Cooling, Heating and Power (CCHP) systems can be generated simultaneously three different forms of energy such as cooling, heating, and power. It's including various technologies, provide an alternative for the world to meet and solve energy-related problems, such as energy shortages, energy supply security, emission control, the economy and conservation of energy, etc [1]. the knowledge of CCHP back more than 100 years ago but, its development has been very slow, and it is limited to absorption chiller on large scale. Initial energy sources of CCHP are oil products, natural gas, coal, biomass, and hydrogen and useful energy production are heat, cooling, and power that mechanical power energy is often used to start a generator [2]. A slight difference between CCHP and CHP is that thermal or electrical/mechanical energy is further utilized to provide space or process cooling capacity in a CCHP application. In some literature, CCHP systems are also referred to as trigeneration and Building Cooling Heating and Power (BCHP) systems. This research investigated a thermodynamic and exergy economic analysis combined heat power and cooling in a combined cycle with Ejector using solar energy. It studied a new cycle for generating power, heat, and cooling simultaneously based on solar energy as an energy source. Using solar energy is one of the methods for decreasing electricity consumption. It's added a heat storage tank when there is no solar energy for decreasing pollution. This system used an organic Rankin cycle as primary stimulus and used hollow cylindrical collectors as solar energy collectors.

2- Geometry and Mathematical Equation

A Diagram of the solar system with a power cycle has been shown in Fig. 1. It's investigated a control volume for each component of the cycle and all of the parameters are achieved by conservations mass, momentum, and energy laws. Working fluids are water and carbon dioxide in the solar cycle and combine cycle respectively. The inlet flow rate to collectors is 10 Kg/s. Table 1 showed the value of temperature and pressure on each component of the cycle. The first law of thermodynamic, conservation mass law, and rate of useful heat rate received from the collector are achieved as follows [3]:

$$\Delta_{out}^{in}\left(\sum_i \dot{m}_i . h_i\right)+\Delta_{out}^{in}\left(\sum_j Q_j\right)+\Delta_{out}^{in}\left(\sum_k W_k\right)=0 \quad (1)$$

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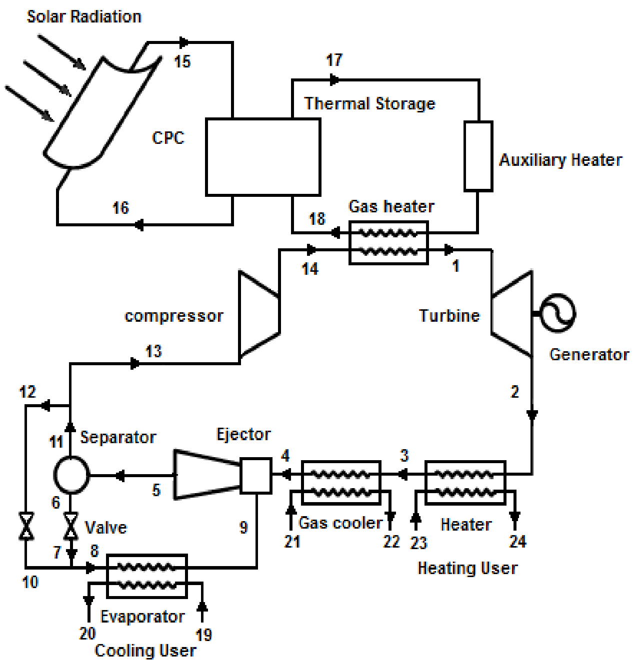

Fig. 1. Diagram of the solar system with the power cycle

$$\Delta_{out}^{in}\left(\sum_{i}\dot{m}_i\right)=0 \quad (2)$$

$$Q_u = F_R W L[S - \frac{U_{lo}}{C}(T_{fi} - T_0)] \quad (3)$$

3- Area Heat Transfer

For calculating heat transfer area used experimental equations. Pressure drop in the heat exchanger is considered as one of the convergence conditions for calculating heat transfer area. Physical properties of heat exchanger and specification of the stream are required for achieving heat exchanger area overall heat transfer coefficient. This study used a parabolic collector due to its high efficiency. In gas heater and gas cooler cycle used a single-phase flow regime and in the evaporator is used two-phase flow regime for modeling and achieving heat transfer coefficient and heat transfer area. Overall heat transfer is achieved as follows [4]:

$$Q_s = U_s A_s \Delta t_m \quad (4)$$

Where U_s overall heat transfer coefficient, A_s heat transfer area, and Δt_m logarithmic difference temperature between the hot and cold surface. Overall heat transfer coefficient is achieved follows:

Table 1. Comparing results this work with Ref. [3]

	This work	Ref.[3]
Heat of collector (kW)	135.02	135.27
Power of Turbine (kW)	25	25.182
Power of compressor (kW)	24.71	25.07
Power of cooling (kW)	7.69	7.96
Power of Heating (kW)	63.3	63.54
Heating efficiency (%)	53.62	53
Exergy efficiency (%)	29.41	28.8
Cost on time ($/MJ)	139.8	

$$\frac{1}{U_s} = \frac{1}{h_h} + \frac{\delta}{\lambda_m} + \frac{1}{h_c} \quad (5)$$

h_h and h_c convection heat transfer coefficient hot and cold respectively. Nusselt number is given as follow in the heat exchanger

$$Nu = 0.724(\frac{6\beta}{\pi})^{0.646}\,\mathrm{Re}^{0.583}\,\mathrm{Pr}^{1/3} \quad (6)$$

4- Results and Discussion

For validation of the thermodynamic model, thermal and exergy efficiency this study has been compared with Wang [3] and shown in Table 1.

Fig. 2 showed the effect of ejector back pressure on thermal and exergy efficiency. The drop of enthalpy is decreased with an increase in the outlet pressure of the turbine. To keep the constant condition of the inlet and outlet compressor, it’s assumed that the work of the compressor is constant. The temperature of the outlet turbine is increased with increasing outlet pressure of turbine, therefore, the heat of heater is increased. The pressure of initial inlet flow to jet pump is increased with increasing outlet pressure of turbine, also, the mass flow of inlet saturated steam is decreased that quality of carbon dioxide input to the evaporator is decreased too. Therefore, a difference of enthalpy is increased in the evaporator. It makes that cooling in the evaporator, thermal and exergy efficiency are increased. Fig. 3 showed the effect of turbine inlet pressure on the area. The Sum of the heat transfer area is increased with increasing turbine inlet pressure. Also, the mass flow of carbon dioxide is increased with increasing temperature. In other words, the temperature of the fluid is increased with increasing pressure. Therefore, for increasing heat transfer is required bigger heat transfer area for all of the heat exchangers in the cycle.

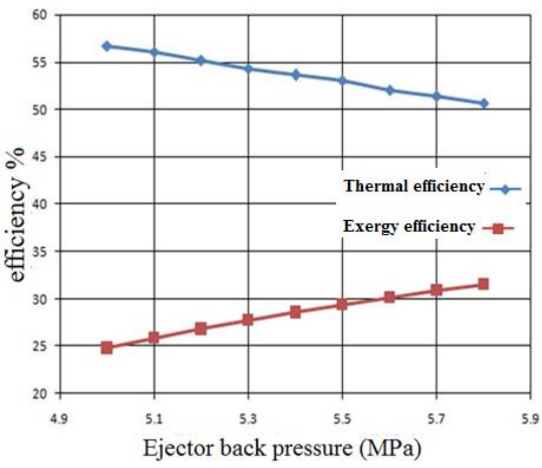

Fig. 2. Effect of ejector back pressure on efficiency

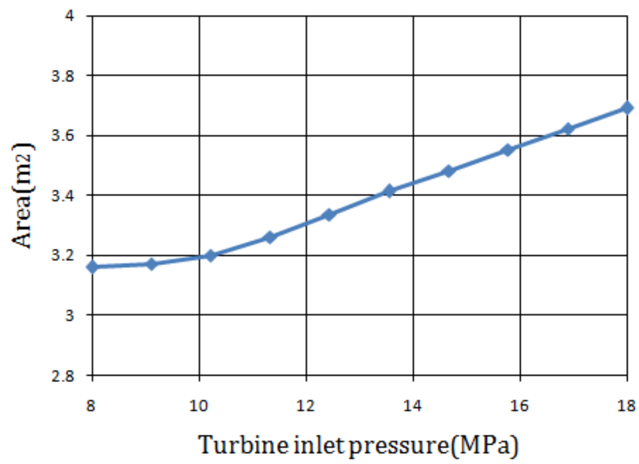

Fig. 3. Effect of the area on turbine inlet pressure

5- Conclusion

This study investigated a Brayton cycle and critical passage of carbon dioxide with a jet pump using solar energy as a heat source. The pressure of the initial stream to the jet pump and velocity of stream in the outlet of the nozzle is increased with increasing outlet pressure of turbine. For high temperature difference, the reserve tank had most rate of exergy destruction in all of the component. Increasing temperature of evaporator had very little effect on thermal and exergy efficiency. The highest cost on power is related to outlet cooling form combined cycle that it's almost 53% of all of the costs.

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