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Multiobjective Optimization of a Tri-Generation Organic Rankine Cycle for Power, Freshwater and Heat: Suitable Mixture of Three Fluid

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ABSTRACT: Improving the performance of a tri-generation organic Rankine cycle for the production of power, fresh water and heat using solar energy to respond to the needs in remote areas is very important. One of the effective factors in the performance of such a cycle is the thermodynamic behavior of its working fluid. Finding a suitable working fluid that has a good behavior on power generation, freshwater production and heat are of particular importance. This study aims to find an appropriate working fluid by analyzing, simulating, and optimizing a tri-generation Rankine cycle powered by solar parabolic trough collectors for simultaneous production of power, fresh water, and heat. The performance of this cycle is investigated with various mixtures of organic fluids R152a, R600a, and R1234yf which are categorized as wet, dry, and isotropic fluids, respectively. Therefore, first, a parametric study is conducted and followed by a multi-objective optimization for which power, fresh water, and heat are the objective functions. While the various mixture of these three working fluids are considered to be optimized. The results show that three-component mixture is more suitable for achieving three goals simultaneously, while if one of the objectives is considered, only one of these fluids should be used.

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1- Introduction

Thermodynamic characteristics and behavior of organic working fluids (dry, wet and isentropic) have a great influence on the performance of the organic Rankine cycles. On the other hand, none of the organic fluids alone have all the characteristics of the working fluid that are suitable for different types of these cogeneration cycles, and therefore the appropriate working fluid should be selected according to the desired cycle and the amount of demand for each of the generation. Tchanche et al. [1], by comparing different working fluids in an Organic Rankine Cycle (ORC) that is operated with solar energy, showed that R134a and R600a have the best performance. Yang and Ye [2], investigated six working fluids in the organic Rankine cycle and observed that R600a, R1234ze, and R1234yf have the best performance. Satanphol et al. [3], optimized the types of organic fluids and their mixtures in an ORC to maximize the net power production. Georgousopoulos et al. [4], showed that the best thermodynamic and economic performance happened for a mixture of R600a and R1234yf with mass fractions of 0.4 and 0.6, respectively. In this study, at first, the effects of three working fluids R152a, R600a, and R1234yf, which are wet, dry, and isentropic, respectively, on the performance of an ORC trigeneration have been studied. Then the effects of the mixture of these three working on the production of power, fresh water, and heat, on two days, 25 June and 25 December in Zahedan city in the optimum tilt angle of parabolic solar collector have been investigated.

2- System Description and Governing Equations

The considered tri-generation system is presented in Fig. 1, this system consists of a solar cycle, a main ORC power cycle, and a single-stage flash water desalination unit.

The amount of absorbed energy by the solar collector is calculated from Eq. (1) [5].

$$\dot{Q}_u = \left[K_4 \dot{Q}_S - K_5 \left(T_1^4 - T_{amb}{}^4 \right) \right] \tag{1}$$

Net power output, freshwater production, condenser heat output, and the overall energy efficiency of the tri-generation cycle are calculated from Eqs. (2) to (5), respectively.

$$\dot{W}_{Net} = \left(\eta_{Tur,mec} \eta_{Tur,gen} \dot{W}_{Tur} \right) - \left(\frac{\dot{W}_{pump1}}{\eta_{pump1,mec}} \right) - \left(\frac{\dot{W}_{pump2}}{\eta_{pump2,mec}} \right) \tag{2}$$

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$$\dot{m}_{dis} = \dot{m}_7 = \frac{\dot{m}_5 c_{p,W} \left(T_5 - T_{Sat}\right)}{h_{fg@Sat}} \quad (3)$$

$$\dot{Q}_{Cond} = \dot{m}_{20} h_{20} - \dot{m}_9 h_9 \quad (4)$$

$$\eta_{Overall} = \frac{\dot{W}_{Net} + \dot{Q}_{Cond} + \dot{m}_{dis} h_{fg@Sat}}{\dot{Q}_S} \quad (5)$$

3- Results and Discussion

To find the optimum mass fraction of each component of the mixture multi-objective optimization using the genetic algorithm method is adopted. In this algorithm, the mass fractions of fluids R152a, R1234yf, and R600a are defined as variables, and the net power, the mass flow rate of fresh water, and the heat generated in the condenser are selected as objective functions. Different optimum scenarios have been obtained by using the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method. Table 1 briefly shows the performance of the ORC trigeneration system using either one of the three working fluids or an optimum mixture of these three working fluids.

4- Conclusions

The main results of this research are summarized as follows:

For both selected days, if the goal is only freshwater production, fluid R600a is suitable. If the only heat output is considered, fluid R1234yf is suitable, and if the objective is only the output of electrical power, mixture fluid R152a and R600a are suitable with mass fractions, respectively. 0.815, and 0.185.

The optimization results show that to provide the desired conditions, the acceptable mass fractions for fluid R152a are between 0 and 0.355, for fluid R1234yf, 0 to 0.74, and for fluid R600a, between 0.25 and 0.865.

Optimal scenarios are determined according to the user's needs. For example, in Scenario 2 of this study, on 25 June, for mass fractions of 0.2, 0.068, and 0.732 in a three-component mixture for fluids R152a, R1234yf, and R600a, the amount of produced net power, the flow of produced fresh water, the produced heat in the condenser and the overall energy efficiency of the cycle are 1325.3 W, 27.37 kg/h, 17698 W and 66.75%, respectively. Whereas on 25 December, these values were 947.2 W, 19.31 kg/h, 12613 W, and 65.32%, respectively, in which case the mass fractions in the three-component mixture for fluids R152a, R1234yf, and R600a, respectively, are 0.105, 0.514 and 0.381.

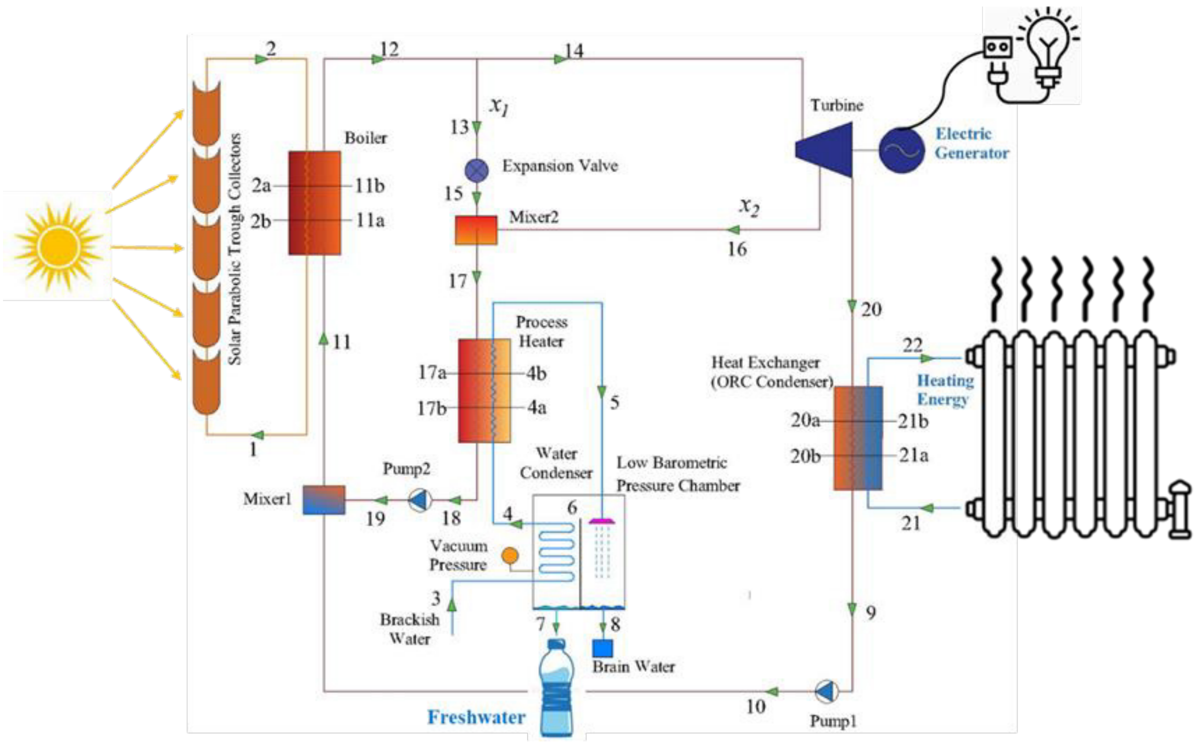

Fig. 1. The schematic design of the tri-generation cycle.

Table 1. Comparison of objective functions, overall energy efficiency, and temperature of the water entering the heating system for pure fluids and three-component mixture optimized in two days, 25 June and 25 December

date	fluids	$\dot{W}_{Net}$(W)	$\dot{m}_{dis}$(kg/h)	$\dot{Q}_{Cond}$(W)	$\eta_{Overall}$(%)	T_{22}(K)
25 June	R152a	1471.2	27.34	17568	66.74	312.1
	R1234yf	1407.2	26.73	18076	66.8	308.6
	R600a	1213	27.55	17693	66.75	339.1
	R152a/R1234yf/R600a (0.2/0.068/0.732)	1325.3	27.37	17698	66.75	329.05
25 December	R152a	1043.1	19.39	12456	65.29	312.1
	R1234yf	997.7	18.95	12816	65.36	308.6
	R600a	860	19.54	12545	65.3	339.1
	R152a/R1234yf/R600a (0.105/0.514/0.381)	947.2	19.31	12613	65.32	323.75

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