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Research Article

Optimal Organic Working Fluid for the Rankine Cycle Operating by Parabolic Trough Solar Collector

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Abstract:

Abstract: This paper investigates finding the best working fluid to improve the giving of the solar organic Rankine cycle. A parabolic trough solar complex was designed to focus the sun rays on a vicious cylinder to produce sufficient steam to operate the ORC. The steam is collected in an isolated tank filled with molten salt called an evaporator. The heat gained in this evaporator is transferred to feed the power generation turbine. Ten different working fluids of R123, R143a, R433A, R290, R40, R22, R600a, R601, RC318 and R1270 were tested at a boiling temperature from 100°C to 360°C. The results showed that using R601 as a working fluid for ORC gave the highest thermal efficiency compared to other organic liquids tested at temperatures from 180 to 330 °C. R601 gives a gain in cycle thermal efficiency by about 24.6% relative using R600a. While R 290 gave an improvement in the power produced by the turbine estimated at 10% higher than that used at higher temperatures above 240° C.

Key words: vacuum tube; parabolic trough; solar collector; evaporator; organic fluids; organic rankine cycle

1.Introduction

Increasing the Rankine cycle's efficiency requires using an aqueous working fluid with high energy sources [1- 4]. But if the cycle uses organic matter as a working fluid, it is called the organic Rankine cycle and works at low energy sources of solar heat or waste heat [5-12]. This cycle is simple in construction, easy tomaintain, and highly reliable [13-21]. Delgado and Garcia [22], carried out a theoretical analysis of ORC coupled to solar collectors for desalination applications. Quilon et al. [23] analyze an ORC powered by a solar capacitor. Mahmoudi et al. [24] studied the effect of system performance by changing the operating fluid. Villarini et al. [25], reviewed some ORC applications powered by solar thermal energy. ORC is applied in cogeneration plants, industrial processes, fermentation of organic products, cement kilns, flue gas condensation, gas turbines exhaust gases, and power cycle condensers [26-37]. Although ORC is appropriate for medium/low-temperature heat sources, reliable, and less complex than water Rankine cycles [38, 39]. Lee [40] stated that ORCs are an excellent technology for producing electricity from low and medium-temperature sources. The theoretical basis for ORCs has been described by [41, 42], Yang et al. [43], and Geville et al. [44] made comparisons to determine the difference between using water as a working fluid in the traditional thermalcycles and organic liquids with organic. They concluded that the organic working fluids evaporate at low temperatures, and thus it is possible to take advantage of the thermal energy wasted in factories and solar energy. Also, choosing the operating liquid is significant in improving the efficiency of ORCs [45-49].Simulation of ORCs requires a numerical analysis in which mass-energy balance equations, heat transfer, pressure drop, and thermodynamic properties of organic liquids are implemented [50–57].

2.Components and alternative of ORC working fluids

The components of the ORC system (Fig. 1) are a parabolic solar collector with a length of 11.8 m, centrallength of 2.6 m, edge angle of 85 degrees, hollow cylinder diameter of 7 cm, and automatic orientation. The ORC scheme consists of two closed loops. The first loop captures the energy of solar radiation through the parabolic trough and transfers it to the organic working fluid in a heat exchanger. The second loop consists of a heat exchanger (evaporator), that interacts with the ORC loop and a pump to move the working fluid to the turbine. Molten salt at a concentration of 1% AG was used as an effective nanomaterial to increase the efficiency of heat absorption and storage that powers the organic Rankine cycle even in the absence of sunlight.The solar system is designed based on the location of Jazan city, KSA, and all-weather information of the temperatures. And to obtain the highest thermal energy, the values of the temperature between 15ºC to 37ºC

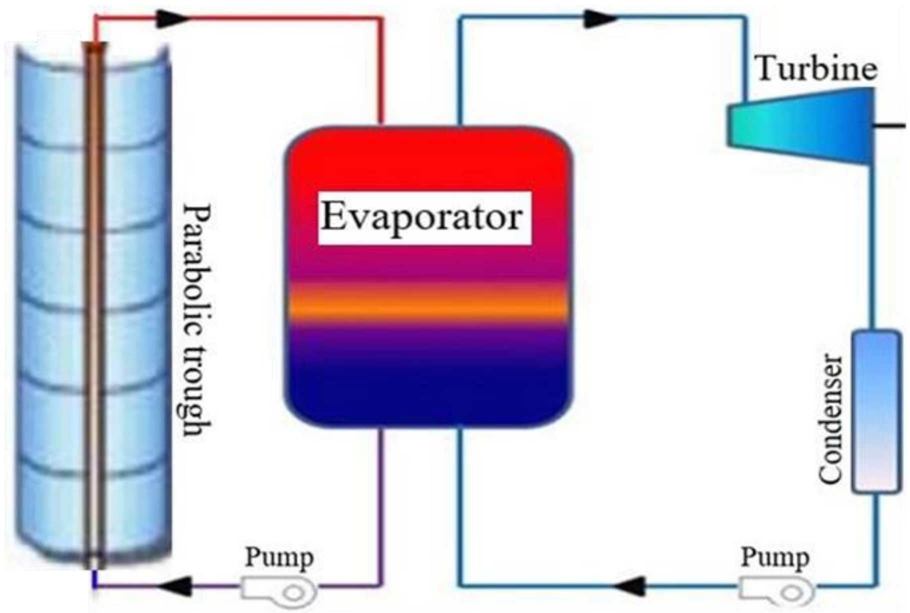

Figure 1: system layout

workingfluid	Triplepoint Temp. °C	Normal boiling point, °C	Critical Temp. °C	Critical pressure, MPa	Molecular Weight, (g/mole)
R123	-107.15	27.823	183.681	3.6618	152.931
R143a	-111.81	-47.241	72.7070	3.761	84.041
R433a	-	-	94.2298	4.342957	43.47086
R290	-187.62	-42.114	96.74	4.2512	44.09562
R40	-98.15	-23.977	143.15	6.6773	50.48752
R22	-157.42	-40.81	96.145	4.99	86.468
R600a	-159.42	-11.749	134.66	3.629	58.1222
R601	-129.68	36.06	196.55	3.37	72.14878
Rc318	-39.8	-5.9749	115.23	2.7775	200.0312
R1270	-185.197	-47.619	91.061	4.555	42.07974

Table 1: Organic fluids general properties

4.Data calibration and calculation of transmission characteristics

NET, J2EE, COM platform, dynamic link library (DLL), static linking, and application program interfacewere used in this research. According to Fig.1, energy balances for apiece component of the ORC scheme is:

$$Q - W = m_e h_e - m_i h_i \quad (1)$$

Where Q,and W are the warmth rate and power, m flow rate, h specific enthalpy, and subscript i and einlet and outlet conditions, parabolic trough heat rate, q_H [58-63] is:

$$q_H = \alpha\tau I_g - (T_i - T_o)U_g A_C = mC_p(T_s - T_c) \quad (2)$$

And the irreversibility in cycle components using exergy analysis as:

$$Ex_i = Ex_e + Ex_d \quad (3)$$

Where Ex_e, and $\acute{E}x_i$ are heat and work exergy transfer, and Ex_d exergy destruction. The irreversibility as:

$$(m_i x_i + Ex_o)i = (m_e x_e + Ex_w + Ex_d)e \quad (4)$$

For a constant movement of flow, the rate of irreversibility is:

$$I = T_O dS/dt = T_O m_{ORC}[(S_e - S_i) + dS_{ORC}/dt + q_i/T_i] \quad (5)$$

And the turbine usentropic work is:

$$\dot{W}_{Ts} = \dot{m}(h_3 - h_{4s})\eta_{sT} \quad (6)$$

Where η_{sT} is the turbine efficiency and *s* isentropic, ORC power output is:

$$\dot{W}_{net} = \dot{W}_T - \dot{W}_P \quad (7)$$

Where $\dot{W}_T$, and $\dot{W}_P$, are the turbine and pump power respectively, and thermal efficiency of solar collector is:

$$\eta_{th-c} = C_f \square C A_b V(T_{fo} - T_{fi})/G_e A_a \quad (8)$$

Where C_f is coefficient of heat transfer, □ density, A_b, A_a collector and absorber areas respectively, G_e collectorheat gain. Using Equ. (8), ORC thermal efficiency is:

$$\eta_{th-ORC} = (W^{'}_{net} + Q_{eva})/(Q_{geo} + Q_{solar}) \quad (9)$$

5. Results and discussion

Figures 2 - 5 show that ORC output power and thermal efficiency increase with an increase in the temperature of the action liquid. The organic Rankine cycle gives different thermal consistent efficiencies with the various fluids. High power when using the working fluids of R601, R290, RcQ318, R1270, and R433, while lower output powers when using R123, R22, R40, R143, and R433. Some fluids work at low temperatures, such as R123, and some work at temperatures higher than 180 OC, such as R601, and some workat all temperatures, such as R290 and R143. The cycle gives the highest thermal efficiency and output power with the working fluid R601 and R290 concerning other liquids at different evaporator pressures and temperatures. It is clear from Fig. 9, which shows the effect of increasing the pressure of the liquid entering the turbine on the performance of the cycle with different working organic fluids. That is, the working fluid of R601 gives the highest thermal efficiency at different temperatures and steam pressures entering the turbine. The results indicate that using ORC to the working fluid of R601 gives the highest performance at different temperatures and steam pressures entering the turbine compared to all other fluids.

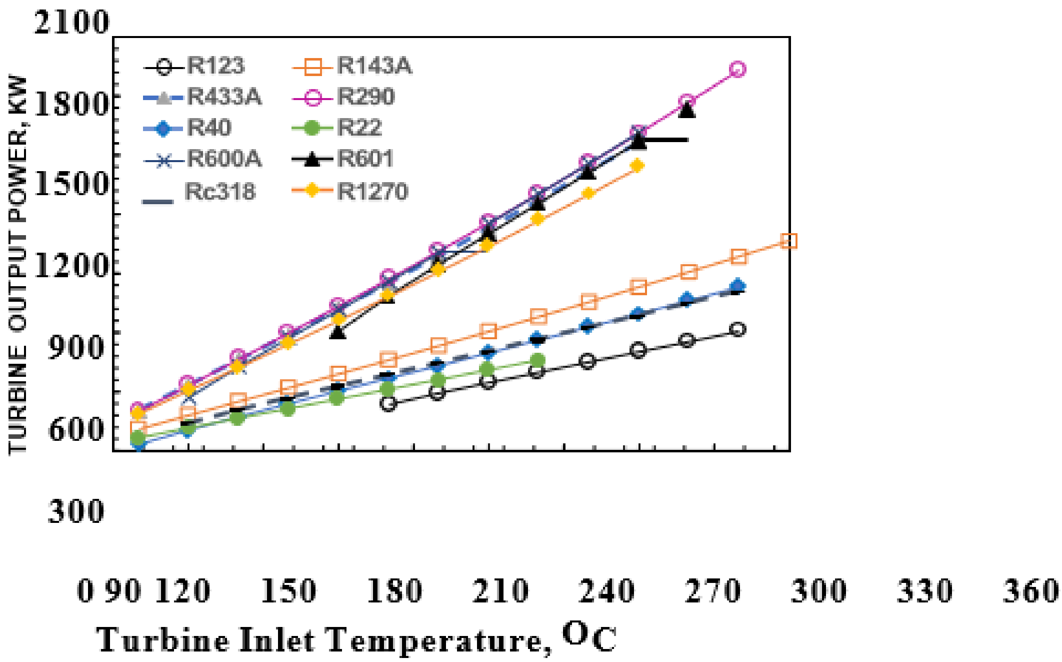

Figure 2: Effect of evaporator temperature on ORC output power at Pi =2 MPa

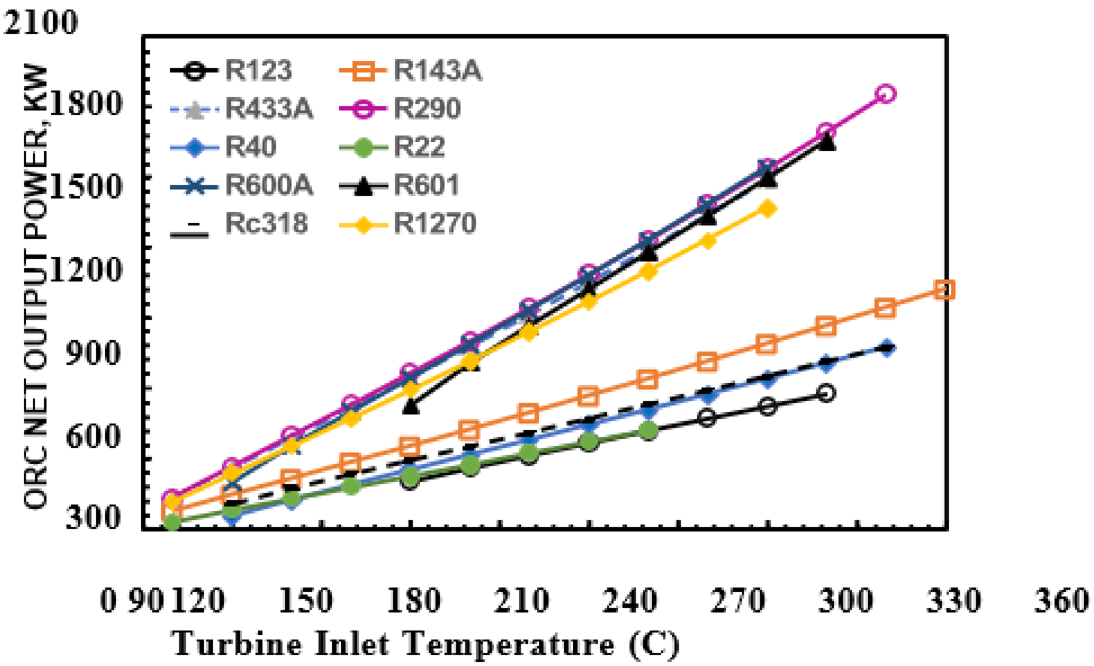

Figure 3: Effect of evaporator temperature on ORC output power at Pi =3 MPa

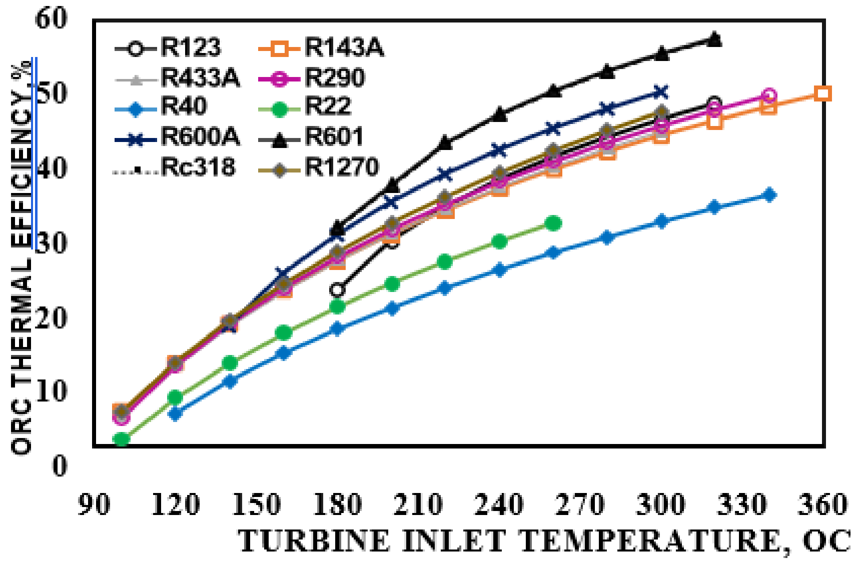

Figure 4: Effect of evaporator temperature on ORC efficiency, at Pi =2 MPa

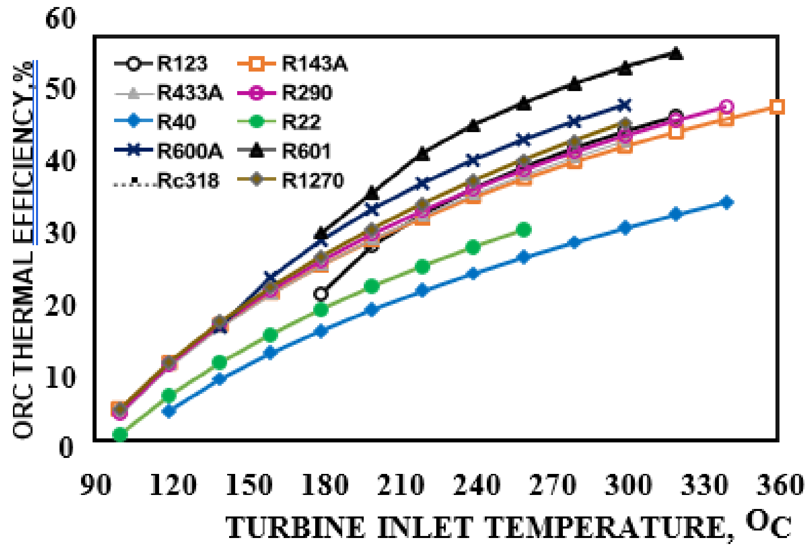

Figure 5: Effect of evaporator temperature on ORC efficiency at Pi =3 MPa

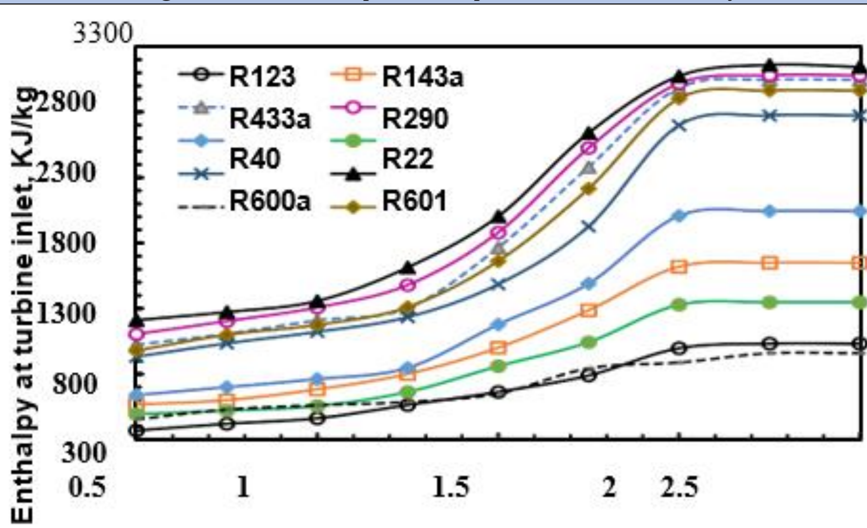

Figure 6: Effect of turbine inlet pressure on the enthalpy generation

Conclusion

Because of the high air temperature and environmental pollution, researchers have tended to use solar energy to power the organic Rankine cycle. Parabolic solar collector, molten salt (at 1% Ag) is designed and stored in a heat exchanger for ORC operation. ORC system performance was evaluated by calculating net output power, thermal efficiency, and evaporator temperature. Various organic liquids R123, R143a, R433a, R433a, R290, R40, R22, R600a, R601 (n-pentane), Rc318 and R1270 were tested at boiling temperature from 100 to 360 °C. RC.

The results showed that ORC using R601 gave the highest thermal performance compared to other organic liquids and an improvement of about 24% in the thermal efficiency of ORC. The lowest ORC performance when using R22. The higher the boiling point of the ORC's working fluid, the higher the overall thermal efficiency of the system. Significant improvement in ORC efficiency as the pressure and temperature of the fluid entering the turbine increases and decreases at the outlet. It is not necessary that the fluid that gives the highest output power from the turbine should be given the organic Rankine cycle with the highest thermal efficiency and that this fluid is the best.

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