Potential Utilization of Solar Energy using Organic Rankine Cycle In Hungary

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Abstract. The organic Rankine cycle (ORC) is a promising proposal for creating clean energy in distant regions at a low cost by utilizing solar energy in low-medium temperature systems. The ORC system may be powered by the quantity of solar energy available in Hungary. A parabolic through collector (PTC) solar collector is utilized in this study to transform solar thermal energy into a heat stream that is used to boil the R245fa working fluid, which was chosen as a good ORC working fluid because to its low boiling point, low ODP, and low GWP value. Many recent research have looked at solar-ORC from both a theoretical and experimental standpoint in a variety of disciplines, including design systems. The basic design that eliminates the requirement for solar-ORC will be extended in this study, which will include an energy analysis, system efficiency, and turboexpander characteristics utilizing different pinch temperatures (10 °C and 5 °C). For computations in the PTC solar collector, the weather data from June is used as the starting data input. When comparing the energy from the turbine and the thermal efficiency of the ORC system with 5 °C to the ORC system with 10 °C, the result shows that the ORC system with 5 °C has a better outcome.

Keywords: solar thermal, organic rankine cycle, performance analysis, power utilization

INTRODUCTION

Due to its widespread availability, solar energy has eclipsed wind and biomass as the most popular renewable energy source [1]. Solar energy is a form of energy that can be used to address key energy challenges like global warming, ozone depletion, and high power prices [2]. The organic Rankine cycle (ORC) is an exciting notion for creating sustainable energy in distant places by utilizing solar energy in low-medium temperature systems. ORC is widely regarded as the most cost-effective technique for converting any heat source into electricity, including geothermal brine or excess steam [3], industrial waste heat [4], biomass, municipal waste heat, and solar energy. ORC gets its heat from a low-boiling-point working fluid or refrigerant, similar to how a traditional Rankine cycle gets its heat from a water stream. Solar thermal is used as a heat source in this study, with a solar collector component boiling water from the tank. According to Solargis, Hungary receives between 1100 and 1350 kWh/m2 of yearly worldwide horizontal irradiation, making it a suitable location for solar thermal collectors paired with an ORC system [5].

Solar-ORC solutions for engineer supply, on the other hand, have been widely explored but rarely implemented, particularly in Hungary. However, because of the solar thermal potential described earlier, it is critical to investigate ORC generators that use solar thermal heat sources.

This research will present the best design for overcoming the need for solar-ORC, including an examination of the system's energy and efficiency, as well as turbo-expander characteristics utilizing various pinch temperatures.

MATERIAL AND METHODS

2.1 Solar-ORC concept

The ORC cycle, which consists of an evaporator, turboexpander, condenser, and pump, is seen in Fig. 1. Heat transfer occurs in the boiler between hot steam and working fluid or organic fluid with a low boiling temperature, allowing the working fluid to change phase into steam vapor with sufficient temperature and pressure to turn the turbo-expander, and the rotation to be converted into electricity by the generator. The first and second laws of thermodynamics should be used to evaluate the ORC's performance. The energy equilibrium equation can be used to calculate the quantity of work generated and the amount of heat required by the ORC. The following are the equations for each component [6].

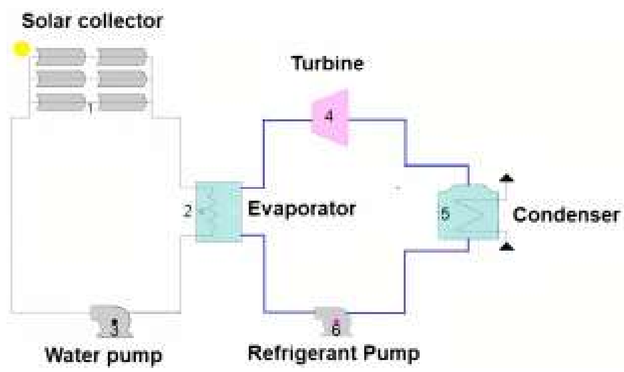

FIGURE 1. The schematic of solar-ORC

Process 1-2, turbine:

$$\dot{W}_{turbine} = \dot{m}(h_1 - h_2)\,\eta_{turbine}, \tag{1}$$

Process 2-3, condenser:

$$\dot{Q}_{out} = \dot{m}(h_2 - h_3), \tag{2}$$

Process 3-4, pump:

$$\dot{W}_{pump} = \frac{\dot{m}(h_4 - h_3)}{\eta_{pump}}, \tag{3}$$

Process 4-1, evaporator:

$$\dot{Q}_{in} = \dot{m}(h_1 - h_4), \tag{4}$$

The net power output of solar-ORC can be evaluated through the following equation:

$$\dot{W}_{net} = \dot{W}_{turbine} - \dot{W}_{pump} = (h_1 - h_2) - (h_4 - h_3), \tag{5}$$

meanwhile, the thermal efficiency is as follows:

$$\eta_{therm} = \frac{\dot{W}_{net}}{\dot{Q}_{in}} = \frac{\dot{W}_{turbine} - \dot{W}_{pump}}{\dot{Q}_{in}}, \tag{6}$$

In the equations *the* $W_{turbine}$, W_{pump} are work on turbine and pump respectively, while m˙ is mass flow rate (kg/s), h is specific enthalpy (kJ/kg), and Q_{in}, Q_{out} are the heat enters and exit from the system. The equations (1-6) are valid in the ideal condition (all the processes are isentropics), where all losses arisen are ignore. In actual conditions many losses occur including an increasing entropy in the compression and expansion process. In this study, the isentropic efficiency for turbine (*η_turbine)* is set at 75% and for pump (*η_pump*) is 90%.

Meanwhile, the solar collectors that will be used in this study is using parabolic tube collector (PTC) with area surface (ASC) around 1.7 m^2. The performance of the PTC will modelled using a steady-state efficiency equation (7) [7]:

$$\frac{\dot{Q}_u}{A_{sc}} = 0.761\, K_\theta\, G_b - 0.22\,(T_{c,out} - T_{c,in}) - 0{,}000503\,(T_{c,out} - T_{c,in})^2, \quad (7)$$

G_b and K_θ are the global solar irradiation (Wh/m^2) and incident angle of the solar collector, respectivelly. While the solar collector useful heating product (*Qu*) is found by using the following equation (8):

$$\dot{Q}_u = \dot{m}C_p(T_{c,out} - T_{c,in}). \quad (8)$$

2.1 Operation Parameter and working fluid

The author of this study set the temperature within the evaporator at between 10 and 5 degrees Celsius. The condenser, on the other hand, is around 5 °C. Because of its low ozone depletion potential (ODP) and global warming potential (GWP), R245fa was chosen as a working fluid [8]. R245fa is also suited for working fluids that can generate energy from a stream at temperatures below 100 °C [9]. The working fluid characteristics of R245fa are listed in Table 1.

TABLE 1. The properties of R245fa

Parameters	Unit	Value
$T_{critical}$	°C	154.01
$T_{boiling}$	°C	58.8
$P_{critical}$	MPa	3.651
Molar mass	g/mol	134
Liquid density	kg/m^3 (0 °C)	1338.54
Vapor density	kg/m^3 (25 °C)	8.55
Type	-	Isentropic
ODP	-	0
GWP	-	1030
ASHRAE class	-	B1
ATEL/ODEL	kg/m^3	0.19
Practical limit	Kg/m^3	0.19

Fig. 2 depicts the type of T-s cycle of R134a working fluid that is dependent on the pressure of the working fluid in the evaporator when heat is applied. If the working fluid pressure is less than the critical pressure (P1<Pcrit), during heat transfer in evaporator, the working fluid will evaporate from the liquid phase to gas phase by passing through the 2-phase region, this process is called a sub-critical cycle (process cycle: 1-2-3-4-1). Meanwhile, the detail of each parameter and some assumptions will be given in Table 2.

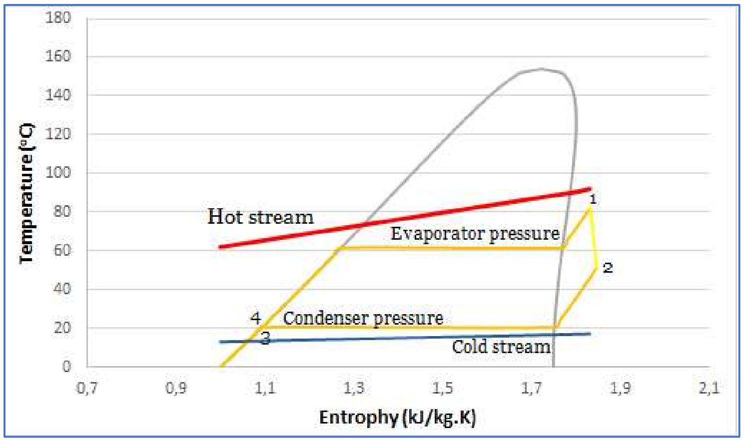

FIGURE 2. T-s diagram and operating state of R245fa

TABLE 2. Solar-ORC parameters of different pinch temperature

Parameters	Value (10 °C)	Value (5 °C)
$T_{evap,in}$ (°C)	92	92
$T_{evap,out}$ (°C)	62	62
T_1 (°C)	82.13	87.13
T_2 (°C)	50.63	52.095
T_3 (°C)	20	20
T_4 (°C)	20.4	20.4
$T_{cold,\ in}$ (°C)	15	15
$P_{evaporator}$ (Mpa)	0.495	0.569
$P_{condenser}$ (Mpa)	0.122	0.122
mdot (kg/s)	1.5	1.5

RESULT AND DISCUSSIONS

In this section, a report on the theoretical result of the preliminary design of solar-ORC parameters including the performance of the cycle and performance of the turboexpander will be presented.

3.1 Solar irradiation in Hungary

The incident angle modifier for the solar collector in this study is 45°, and the hourly average of global sun irradiation under summer circumstances (June) in Gödöll, Hungary is 142.3 Wh/m^2 (given in average values of direct normal irradiance), with the ambient temperature peaking at roughly 30 °C. Fig. 3 shows the heating product produced by a parabolic through collector over the course of a month. The highest Qu is obtained at the peak sun position, according to Eq (7). In addition, Eq. (8) can be used to compute the output temperature of the solar collector, which will be utilized to heat the ORC working fluid in the evaporator by converting it to a steam turbine. Based on Fig. 3, it can be seen that the PTC could reach the maximum output temperature 92 °C.

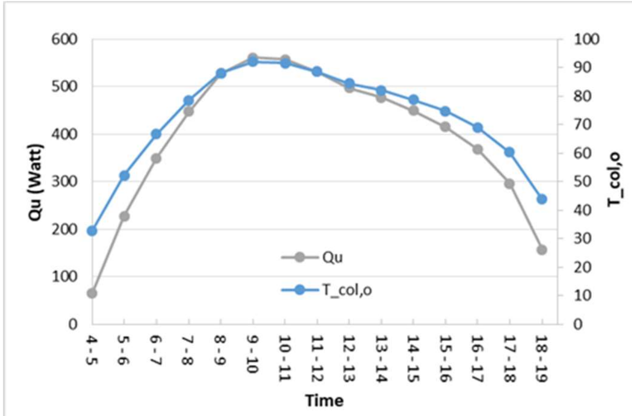

FIGURE 3. The heating product and outlet temperature of solar collector

3.2 Performance cycle

This section discusses the energy performance characteristics of the ORC using R245fa working fluids. The calculation results are presented in **Fig. 4**. Using two different pinch temperatures at the evaporator, Fig. 4 shows how much energy is produced by each component of R245fa. It can be noted that R245fa produces the most $W_{turbine}$ at 5 °C pinch temperature compared to 10 °C, with values of 28.9 kW and 26.1 kW, respectively. Furthermore, W_{nett} produces more power at a pinch temperature of 5°C than at a pinch temperature of 10°C, with values of 26.4 kW and 23.7 kW, respectively. Meanwhile, the ORC system that uses a pinch temperature of 10 °C has a thermal efficiency of 6.48 percent, which is somewhat less than the ORC system that uses a pinch temperature of 5 °C, which has a thermal efficiency of 7.13 percent.

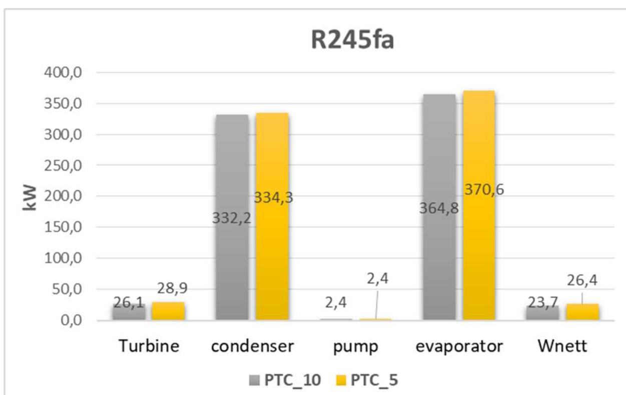

FIGURE 4. The energy generation by each components

3.2 Turboexpander performance

Fig. 5 depicts the properties of a turbo-expander-produced Wshaft at two different pinch temperatures, namely 5°C and 10°C. As seen in Fig. 5, input temperature entering the turbo-expander has a significant impact on both pinch temperature and W_{shaft}. W_{shaft} approximately 26.88 kW is created at an intake temperature of 87 °C for the pinch temperature 5 °C, while the highest of Wshaft, 23.84 kW, is produced at an inlet temperature of 82 °C for the pinch temperature 10 °C. The variation in evaporator pressure at each pinch temperature caused this circumstance to arise. The evaporator pressure at pinch temperature 10 °C is 0.495 MPa, while at pinch temperature 5 °C, the evaporator pressure is 0.569 MPa. The enthalpy inlet values will be affected by the evaporator pressure difference.

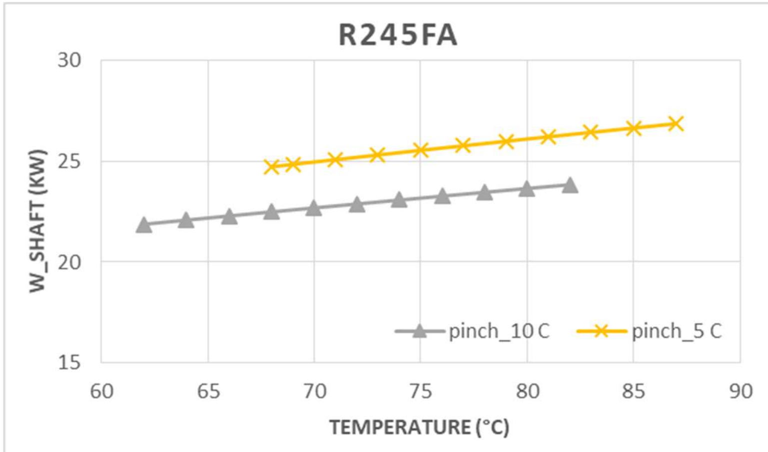

FIGURE 5. W_{shaft} vs temperature

CONCLUSION

The preliminary design and calculation basis for collecting energy from solar thermal usage via ORC have been completed. The design incorporates basic thermodynamic calculations, variations in pinch temperature (10°C and 5°C), and a PTC solar collector. The meteorological data from Godollo in June is used as a case study, with PTC outlet temperatures about 92°C and R245fa working fluid. The results demonstrate that when the evaporator pinch temperature is set to 5 °C, it produces more energy than when it is set to 10 °C, with values of 26.4 kW and 23.7 kW, respectively. Furthermore, the thermal efficiency of the system using 5 °C and 10 °C pinch temperatures was 7.13 and 6.48 percent, respectively.

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