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5th International Conference on Applied Engineering and Natural Sciences

July 10-12, 2023 : Konya, Turkey

https://www.icaens.com/

An Investigation of Organic Rankine Cycle (ORC) System Application for Energy Efficiency of Smart Agriculture

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Abstract—Organic rankine cycle (ORC) system application on smart agriculture is rather energy efficient in terms of waste heat recovery supplied by ORC. The recovered waste heat, such as from agricultural wastes, changes into the electrical energy produced by the generator of ORC cycle. This energy efficiency supplied by ORC system is crucial for smart agriculture as being not only efficient but also environment friendly which is good for green world and nature. In this study, biogas based regenerative ORC system design is explained as more efficient than simple ORC design due to its better regenerator efficiency.

Keywords-ORC; Smart Agriculture; Energy Efficiency; Waste Heat Recovery; Thermodynamic Cycle Analysis

I. INTRODUCTION

ORC is waste heat recovery system consisting of evaporator, condenser, pump, turbine and electrical energy producing generator which leads clean energy gaining. Thus, ORC systems are nature friendly and also low heat waste energy recovering which is fine for smart agriculture. Agricultural waste can be recycled with the help of ORC system [1,2,3].

Recently, growing population and technological progresses lead increasing fossil fuel depletion and environmental concerns. Moreover, swift increase in energy production and the demand for energy exigencies are anticipated due to the quickly switching standards of living in near future. However, still, a few amount of the energy depletion is supplied by sustainable energy resources like biogas. Thus, researches in this study field are concentrated on the fact that renewable energy resources are limitless, economical, efficient and also have slighter negative effect on environmental health. Among these type of other recovery cycles, ORC is attracted attention with its senior possessions like low maintenance cost, low installation cost, and the capability to easily recover from low-temperature heat sources, which has led to many studies about ORC systems, latterly [4,5,6].

ORC systems utilizes organic fluid which makes it differ from steam rankine cycle. Mostly, R245fa and R134 organic working fluids are applied when the previous studies regarding ORC systems are examined, because more energy and exergy efficiency is supplied with these basic organic fluids due to their valid fluid properties such as enthalpy, specific heat and mass flow rate [7,8]. Accordingly, Reference [9] investigated the supercritical and subcritical ORC using organic fluids and binary mixtures. System performance was examined based on the working fluids under optimum operating conditions, in view of simulations carrying out between 150 ˚C and 300 ˚C heat source temperatures. Also, some turbine size parameters related with working fluid were computed. It was monitored that the efficiency of the recommended system is influenced by the thermophysical properties of working fluids such as critical temperature. Consequently, finding outs were the exergy efficiency is varied from 15 % to 40 % between 150 ◦C and 300 ◦C heat source temperatures, and the most appropriate fluid above 170 ˚C is mixtures were decided [9].

II. SIMPLE ORC SYSTEM OVERVIEW

The general ORC system design consists of evaporator, condenser, pump, expander and electrical energy producing generator as seen in Figure 1 [2,10].

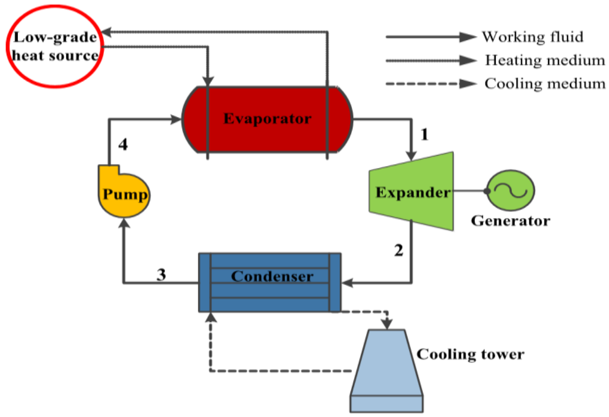


Figure 1.General simple ORC system

The flow process across ORC components as observed in Figure 1 is described below:

- 1–2: An expander transforms the heat energy of the working fluid into mechanical energy. Then, an alternator makes this mechanical energy to be transformed into electricity.
- 2–3: The steam fluid condenses into the liquid phase, which is the heat-refusing operation.
- 3–4: A feed pump make low pressure liquid organic working fluid pressurized.
- 4–1: The liquid working fluid takes thermal energy in and vaporizes to the steam phase then a new cycle begins [1,2,11].

The reciprocal temperature-entropy diagram of the simple ORC is demonstrated in Figure 2 [1,2].

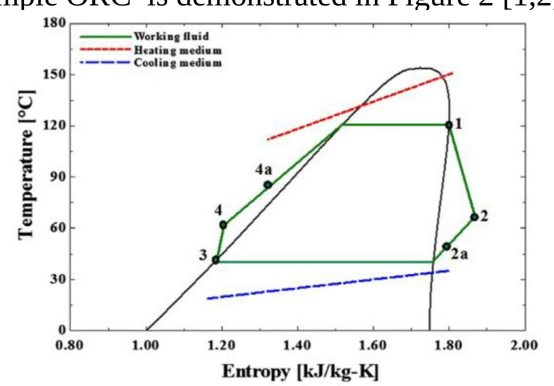


Figure 2. Temperature-entropy diagram of the simple ORC system

III. ORC SYSTEMS DESIGN FOR SMART AGRICULTURE

In terms of smart agricultural application, biomass and biogas system add in was observed. Accordingly, in Figure 3, an internal combustion engine connected both simple and regenerative ORC system design layout is observed [3,12].

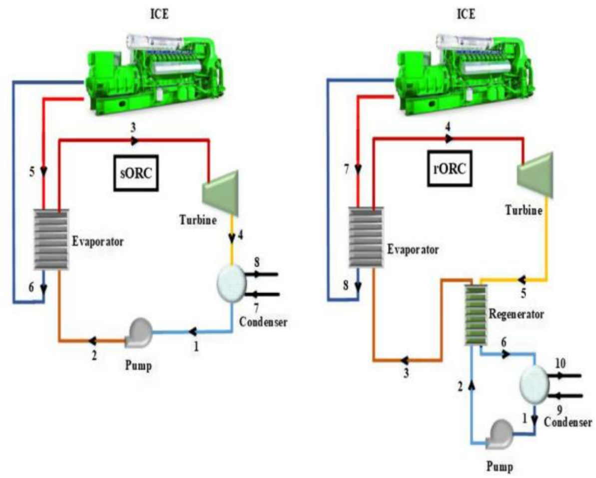


Figure 3. The simple and regenerative ORC layout designed for the waste heat recovery of jacket water

While the simple ORC design is composed of 4 components, the regenerative ORC contain 5 components as seen in Figure 3. The regenerator is used in the rORC, unlike sORC. In such manner, it is targeted to cause utilization of the low temperature waste heat to gain from the biogas based system as much as possible in conjuction with ascertaining the optimum temperature and pressure ranks where the regenerator has a beneficial effect on the ORC system efficiency as observed from Figure 4 for each components [3,13].

Domestic agricultural wastes led to the biogas plant are purified from inorganic wastes and the rest of the organic wastes are forwarded to the digestion wells. Biogas is generated by anaerobic digestion bacteria in the digestion well,. The biogas gathered from the top of the well is sent to desulphurizer firstly and then to the dehumidifier to refine [14]. The refined biogas consist of 55 % methane (CH4) and 45 % carbon dioxide (CO2). After the desulphurized and dehumidified pure biogas was saved inside the biogas tank, the stored biogas is directed to the internal combustion engine by blending it with air, and generated electricity. However, the jacket water is utilized to chill the engine, and then the waste heat transmited from internal combustion engines is let out to the atmosphere.

Energy and exergy balance equations are used for the calculations of ORC design. Some design parameters utilized in ORC design is in Table I. Additionally, the energy and exergy balance equations for the components of ORC cycle are in Table II [3,15].

Table I. Some of design parameters utilized in ORC design

Parameters	Value	Unit
$\eta_{p;ise}$	80	%
$\eta_{t;ise}$	88	%
$\eta_{gen;elec}$	98.5	%
Condenser pressure	2	*bar*
Condenser pressure drop (hot side)	0	*bar*
Condenser pressure drop (cold side)	0.5	*bar*
JW inlet temperature	86	°C
JW outlet temperature	79.505	°C
JW mass flow rate	12.5	*kg/s*
Cooling water temperature	25.008	°C

A design simulation software is rather useful for designing this system. The parameters like pressure and temperature can be obtained from the software. These thermodynamic parameters are fundamental parameters to acquire the best-performing cycle situation but not enough. Since the energy and exergy founded assessment of the ORC component as well as complete ORC system is also significant. In this situation, the energy and exergy based analysis of the ORC system is assigned by the way of the common equations of the first and second law of thermodynamics including the general mass, energy and exergy balance equations as seen in Table II [3,16].

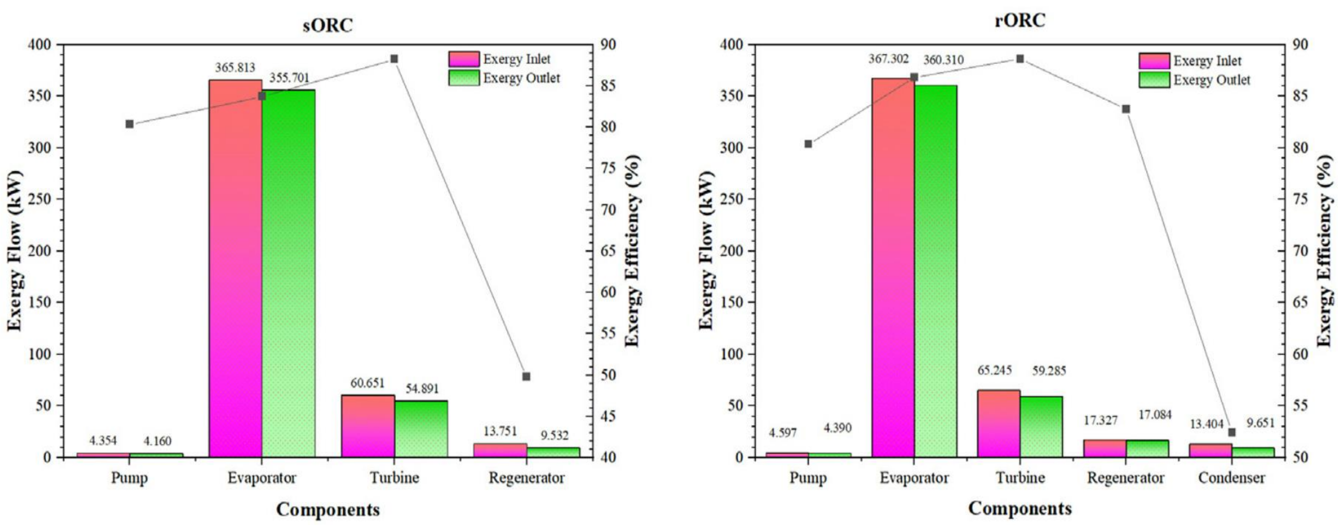
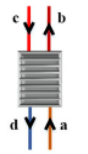
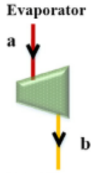
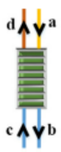
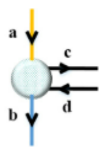


Figure 4. The exergy input, the exergy output and the exergy efficiency of the equipment in the components of the sORC and rORC cycles

Table II. Energy and exergy balance equations for ORC components

Components	Energy balance equations	Exergy balance equations
 Evaporator	$\dot{Q}_e = \dot{m}_{ORC}(h_b - h_a)$	$\dot{E}_{e,des} = \dot{m}_{JW}\left(\psi_c - \psi_d\right) - \dot{m}_{ORC}\left(\psi_b - \psi_a\right)$ $\varepsilon_e = \frac{\dot{m}_{ORC}(\psi_b - \psi_a)}{\dot{m}_{JW}(\psi_c - \psi_d)}$
 Turbine	$\dot{W}_t = \dot{m}_{ORC}(h_a - h_b)$ $\eta_t = \frac{(h_a - h_b)}{(h_a - h_{bs})}$	$\dot{W}_{t,rev} = \dot{m}_{ORC}(\psi_a - \psi_b)$ $\dot{E}_{t,des} = \dot{W}_{t,rev} - \dot{W}_t$ $\varepsilon_t = \frac{\dot{W}_t}{\dot{W}_{t,rev}}$
 Regenerator	$\dot{Q}_{reg} = \dot{m}_{ORC}(h_b - h_a)$	$\dot{E}_{reg,des} = \dot{m}_{ORC}\left(\psi_c - \psi_d\right) - \dot{m}_{ORC}\left(\psi_b - \psi_a\right)$ $\varepsilon_{reg} = \frac{\dot{m}_{ORC}(\psi_b - \psi_a)}{\dot{m}_{ORC}(\psi_c - \psi_d)}$
 Condenser	$\dot{Q}_c = \dot{m}_{ORC}(h_a - h_b)$	$\dot{E}_{c,des} = \dot{m}_{ORC}\left(\psi_a - \psi_b\right) - \dot{m}_{CW}\left(\psi_d - \psi_c\right)$ $\varepsilon_c = \frac{\dot{m}_{CW}(\psi_d - \psi_c)}{\dot{m}_{ORC}(\psi_a - \psi_b)}$
 Pump	$\dot{W}_p = \dot{m}_{ORC}(h_b - h_a)$ $\eta_p = \frac{(h_{bs} - h_a)}{(h_b - h_a)}$	$\dot{W}_{p,rev} = \dot{m}_{ORC}(\psi_b - \psi_a)$ $\dot{E}_{p,des} = \dot{W}_p - \dot{W}_{p,rev}$ $\varepsilon_p = \frac{\dot{W}_{p,rev}}{\dot{W}_p}$

As observed from Figure 4, the shortest exergy input and output of the components of the sORC and rORC acting under situations where the best performance attained, are accomplished in the pump. In both sORC and rORC, the biggest exergy input and output are executed in the evaporator as the black dashed line indicates the exergy efficiency of the components in Figure 4 [3,17].

IV. CONCLUSIONS

Although the thermal involvement of the rORC is higher than the sORC, the compensation period of the sORC is shorter than the rORC because of the capital investment and the operating and maintenance costs.

In this study, ORC system application for energy efficiency of smart agriculture is investigated. The general design criterias for an energy efficient biogas related ORC system are explained.

Furthermore, taking into account that the turbine cost is reduced beside higher isentropic efficiency, a crucial development in complete economic parameters will be accomplished. A big relative cost distinction and a small exergoeconomic factor imply that the performance of the components utilized might be developed by advancing their efficiencies. Thus, mainly condenser should be enhanced in both sORC and rORC systems. Moreover, the evaporator should be improved by advancing its efficiency as the evaporator in the sORC has big exergy destruction cost ratio. So, these are the future works of this study.

Accordingly, regenerative ORC design is more energy efficient than simple ORC design with the help of its regenerator component in terms of biogas waste heat recovery based for smart agriculture. Regenerator utilization raise the system efficiency with the turbine inlet utilization does not influence the specific work, temperature rising, however regenerator yet it bases on the mass flow rate of the working fluid.

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