SUSTAINABLE DEVELOPMENT CONFERENCE 2022

10-12 NOVEMBER 2022

BANGKOK, THAILAND

CONFERENCE PROCEEDINGS

Tomorrow People Organization

Dušana Vukasovića 73, Belgrade, Serbia

www.tomorrowpeople.org

Proceedings of international conference:

"SUSTAINABLE DEVELOPMENT CONFERENCE 2022"

Editors: Tomorrow People Organization
Dušana Vukasovića 73
11070 Belgrade, Serbia

Secretary: Vladimir Ilić

Producer: Tomorrow People Organization
Publisher: Tomorrow People Organization
Quantity: 200 copies

Table of Contents:

Waste to energy (WtE) from infectious medical waste and organic Rankine cycle

Chanansith Suvarnabol[a,b], Nattaporn Chaiyat*[a,b,c]

a School of Renewable Energy, Maejo University, Chiang Mai, Thailand
b Thermal Design and Technology Laboratory (TDeT Lab), Thailand
c Excellence Center on Environment Friendly Smart Agriculture and Renewable Energy Technology (ECoT), Thailand
* Corresponding author: Email address: benz178tii@hotmail.com

Abstract

This paper presents a simulation to determine the enhancement efficiency of an infectious medical waste treatment plant process based on the organic Rankine cycle (ORC). A treatment plant utilizing the steam sterilization process can be operated at 375 kg/cycle, with an operation cycle time of 55 min. The refrigerant fluid R-245fa generates the power in the ORC system. The system is driven by refuse-derived fuel type 3 (RDF-3). RDF-3 is produced from medical infectious waste at a low heating value of 26.92 MJ/kg. This is the main heat source for the hot water in the boiler of the ORC system. Infectious medical wastes are sterilized by using shredding and heating processes. The power consumption power of the machine is 23.24 kWh per operation day. The optimal systematic is evaluated by using the energy efficiency. The temperature of the hot water entering a boiler is found to vary in the range of 80-125 °C. From the simulation, the average energy efficiency of the ORC system is determined to be approximately 10.37%. The gross electricity power output in the expander varies in the range of 16.04-112.73 kW. The total average power output is approximately 413.82 kW.

Keywords: Waste to energy (WtE); infectious medical waste; organic Rankine cycle; refuse-derived fuel

1. Introduction

An issue arising from the coronavirus (COVID-19) pandemic is the collection and transport of infectious medical waste (IMW) to treatment centers. IMW remains a critical operational problem facing local authorities in all cities. The COVID-19 pandemic has led to the delivery of medical services for society all over the world. The COVID-19 pandemic is influencing waste management and especially medical waste management. According to the World Health Organization (W.H.O) [1], the total waste generated at hospitals is approximately 85% general waste and 15% hazardous material that can be toxic, infectious, or radioactive. The majority of infectious medical waste generators are laboratories, home isolations, mortuaries, blood banks, research centers, hospitals, and nursing homes. Medical waste contains potentially dangerous microorganisms. This waste may infect medical center patients, staff, the public, and the environment. Medical waste storage at health care centers and the transportation of these materials can be potentially harmful to

Nomenclature

Abbreviations and symbols

A	area, (m^2)
CHP	Combined heat and power
EP	electric power
ORC	organic Rankine cycle
P	pressure, (bar)
Q	heat rate, (kW)
RDF	refuse derived fuel
t	time, (s)
T	temperature, (°C)
W	work, (kW)

Subscript

A	absorber
AB	absorption system
AP	absorber pump
Amb	ambient
apm	air pressure motor
B	boiler
BW	blower
C	condenser
CDP	cooling draining pump
CF	cooling fan
CP	cooling pump
CW	cooling water
CT	cooling tower
DP	Decompression pump
e	electrical power
E	evaporator
EH	Exhaust stack
Exp	expander
H	high
HB	hot air blower
HF	hot fluid
HFT	hot fluid tank
HP	hot water pump
HW	hot water
HDP	Hydraulic darning pump
HOP	Hydraulic open pump
HTP	Hydraulic top pump
HS	heat source
HUP	Hydraulic under pump
HW	hot water
i	inlet
m	motor
o	outlet
OP	oil pump
op	operation time
P	refrigerant pump
P	pump
Ref	refrigerant
WF	working fluid
S	isentropic
SP	solution pump

Greek

η energy efficiency, (%)
ρ density, (kg/m^3)

treatment centers. These results indicate that the COVID-19 epidemic has led to an increase in waste generation of 102.2% on average in both private and public hospitals. In addition, the ratio of infectious waste in study hospitals has increased by an average of 9% in medical waste composition and 121% compared with that before the COVID-19 pandemic. Therefore, the disposal of infectious medical waste is a problem for all counties in the world. Therefore, this study aims to identify waste-to-energy solutions to solve this problem.

Waste-to-energy technology and collection transportation have been reported by various researchers. Nikzamir et al. [2] reported that waste management was a location-routing problem with the water-flow algorithm. Foroushani et al. [3] found that data waste management for energy drives the modeling of operational district energy networks. This showed that hourly thermal energy storage in a water tank can reduce the daily peak loads on boilers by as much as 20%. Taslimi et al. [4] considered transportation and storage risk with a decomposition-based heuristic. The model showed that Transport Risk & Occupational Risk has a risk value of 110.92 for a run time of 5 min 12 s and the transportation cost has risk value of 150.12 for a run time of 5 min 17 s. Valizadeh et al. [5] showed that energy can be produced from waste during the COVID-19 pandemic, and 34% of the total cost of collecting and transporting waste can be compensated. Govindan et al. [6] used a fuzzy mathematical programming model for medical waste management. The goal of the program was to approach the COVID-19 disease to determine the routing minimum cost and optimize the collection of infectious waste. Yatsunthea et al. [7] studied the energy process for municipal wastes based on the organic Rankine cycle. An incinerator system was used as a heat source from infectious medical waste mixed with municipal waste. A low heating value of 26.92 MJ/kg was obtained. The mixed fuel showed a disposal rate of approximately 92 kg/h. The energy efficiency was 31.66%, and the exergy efficiency was 4.05%. The ORC used an R-245fa-ORC refrigerant system to produce electricity at a gross power of 23.65 kW. Fredy Vélez et al. [8] reviewed the technical, economic, and market issues for organic Rankine cycles for the conversion of low-grade heat. At present, power generation is limited mainly to the range of 0.2-2 MWe with a cost of approximately 1 and 4×10^3 USD/kWe. Chaiyat [9] studied and analyzed the energy, economic, environmental (3E), and exergy (4E) impacts of infectious medical waste incinerators combined with an organic Rankine cycle. The ORC system used R-245fa as a working fluid to investigate the overall impacts. The system could manage a refuse-derived fuel type 3 (RDF-3) at 184.42 kg/h from infectious medical waste to produce 23.65 kWe. The power at energy efficiency was 0.91%, and the exergy efficiency was approximately 0.89%. The economic levelized energy cost was 0.153 USD/kWh. Intaniwet et al. [10] studied the levelized electricity cost per carbon dioxide intensity of an organic Rankine cycle. Water hyacinth and municipal solid waste were used at a ratio of 50:50%. Their heat source produced 20 kWe. The organic Rankine cycle has been evaluated in terms of energy, economic and environmental aspects (3E model). The levelized electricity cost from a water hyacinth-MSW-ORC (WMORC) system was determined to be 0.086 USD/kWh. The environmental impact, 0.172 kg CO_2-eq of greenhouse gas emissions, was estimated based on the utilization of 1 kg of the new fuel. The life cycle assessment for the WMORC system was 0.6078 kg CO_2-eq for an electrical energy generation of 1 kWh. The levelized electricity cost per carbon dioxide intensity was defined and found to be 0.052 USD·kg CO_2-eq/kWh^2, which is 20% lower compared to the value of 0.065 USD·kg CO_2-eq/kWh^2 obtained from a standard power plant in Thailand. Sengnavong et al. [11] studied the cost evaluation for medical infectious waste treatment and found a cost per unit of 0.099 USD/kW_{MCW}.

A literature review shows that many studies have reported collecting data on infectious waste and waste-to-energy technology, such as incinerators and bioenergy. A demonstrated prototype has not been presented; in particular, techniques to manage the volume transportation of infectious medical waste have not been reported. How much is the capacity of the treatment center? Many infectious medical wastes for the generation of electricity have not been reported in the recent literature. In particular, there has been no study of the transportation of volume infectious medical waste with software management. An interesting approach is novel design process management transportation of volume infectious medical waste appropriate for the organic Rankine cycle (ORC) and incinerator from a fuel composed of infectious medical waste. Through a combined heat and power (CHP) system. The experimental results of the advanced system are obtained to evaluate the gross electrical performance curves. This study aims to

1. Design the transportation process for a volume of infectious medical waste appropriate for the treatment process.

 ISBN: 978-86-87043-85-5

2. Simulate the heat capacity in an incinerator, with the produced gross power giving the energy efficiency of the ORC system.

2. System description

In this study, medical infectious wastes are treated by hybrid steaming sterilization. After the treatment process, medical infectious waste becomes refuel-derived fuel type-3 (RDF-3). They are the initial heat source appropriate for the incinerator investigated. A schematic diagram of the treatment process and CHP system is shown in Fig. 1. Infectious medical wastes are placed into treatment machines. The machine shreds and sterilizes infectious waste to reduce its volume. Then, all components are rendered unrecognizable in one fully enclosed chamber. The machine is an automated system. It combines shredding, direct steam sterilization, and high pressure to treat infectious waste materials. The processes use gravity. After shredding the material, it is dropped into a lower treatment chamber. Each particle is steam heated to 138 °C (280 F). The mixture is pressurized to 3-5 bar (51 psi) for 10 minutes. The operating and treatment conditions are continuously monitored and validated to achieve complete sterilization (microbial inactivation = 108 °C). After the cooling process, the final product is volume-reduced by up to 80%. The waste rendered unrecognizable is general waste and safe to recycle. This waste is used as a heat source for generating power in the ORC system. The duration of an average cycle process is 45 minutes, and is fully automated and monitored. The process generating the power system is shown in the side figure. Three main systems are combined to produce waste to energy: a hot fluid storage tank, incinerator, and ORC system. In the first point system, point R1, the appropriate value of RDF-3_{Dry}, is the initial heat source for combustion. This is selected for solid fuel transformation. In the second incinerator system, solid fuels are fed through a small chimney at the front side of the combustion chamber. Solid wastes RDF-3 are used as the combustion substrate. Then, heat is generated at (points 1–3 h). The storage tank is used to collect the heated fluid to supply the purified liquid fluid to the power unit. The combustion gas (exhaust) moves through the treatment unit. A hot air blower is used to force the exhaust gas into a double-absorber working set, in which all particulates and pollution are reduced by an absorption filter technique from spray water nozzles. These air pollutants are controlled under the standards set by the Pollution Control Department, Thailand [12]. Then, the reheat tube, cooling set, and vacuum filter are finally treated with the dioxin compound of dibenzofurans (PCDF) and polychlorinated dibenzo-p-dioxins (PCDD). Next, all clean gas is circulated into the environment by using the main exhaust stack. However, the bypass exhaust stack can be switched into operation in case of service and maintenance. The output products in the bottom ash are rejected below the combustion chamber.

The second system: the ORC system is used for heat-to-power technology. The hot fluids (points 4 h - 6 h) are pumped from the storage tank into the power unit (points 1–7). The ORC working fluid in the liquid phase is pumped to transfer heat to the ORC boiler. A dry type or an isentropic type of refrigerant is popular for use in a refrigerant loop (points 1–4 and 7). The superheated vapor is intently generated from the boiler component to efficiently drive the expander during the heat to thermal power process. Lubricant oil loops (points 4–6) are designed to reduce the friction loss in the reversed expander. Therefore, the refrigerant and lubricant oil are mixed in the expander and sent out to separate the mixed fluid at the oil and separator tank. The generator is situated in the work-to-power component that is mechanically connected to the expander. Then, the refrigerant at the vapor phase is divided from the oil and vapor separator and flows into the condenser. Heat is extracted from this working fluid and condensed by using a cooling loop (points

1c-3c), which is driven by the cooling pump and cooling tower. Next, the condensed working fluids are pumped to the boiler again, and a new ORC cycle starts.
The energy efficiency indicators for the incinerator, ORC, and cycles are determined as follows:

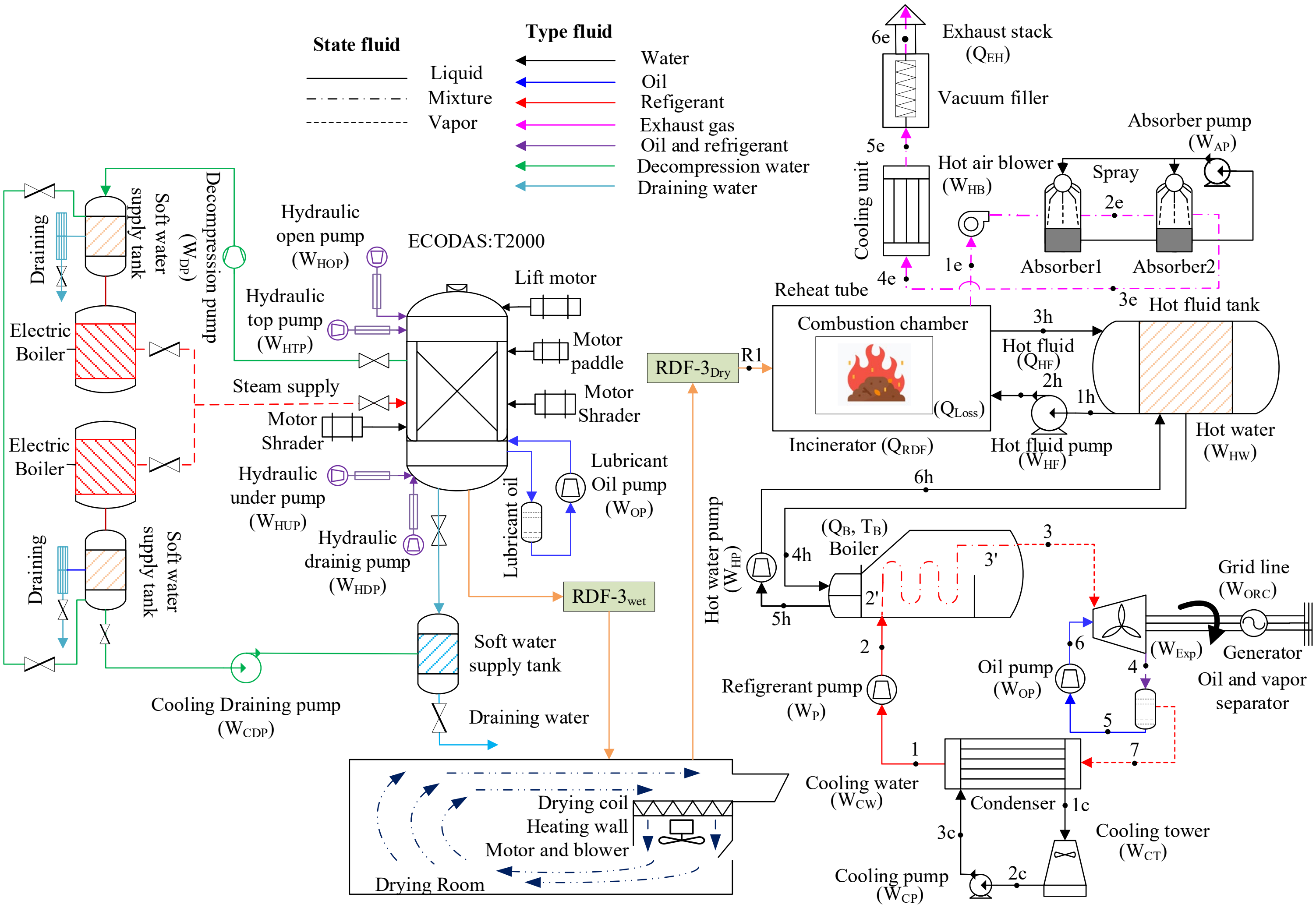

Fig. 1. Infectious medical waste treatment and Organic Rankine Cycle system.

3. Materials and Methods

The schematic shows how one can determine the volume of RDF-3 that is appropriate for the heat source for a suitable efficiency model of incinerator and power output ORC systems.

3.1 Mathematical modeling of the incinerator and ORC system

Mathematical modeling of the incinerator and the ORC system is used to analyze the volume of RDF-3 appropriate for the incinerator and ORC performance. The properties of the working fluid are referred to from the Refprop program [13]. The simulation steps for energy and efficiency are shown in Fig. 2. The given initial conditions for the system are as follows:

These mathematical models are solution process simulations to determine the waste-to-power performance and the efficiency of the treatment plant for the infectious medical waste process, incinerator, and ORC system. The next idea is to use these data to design and build a small power plant with medical infectious waste as the heat source.

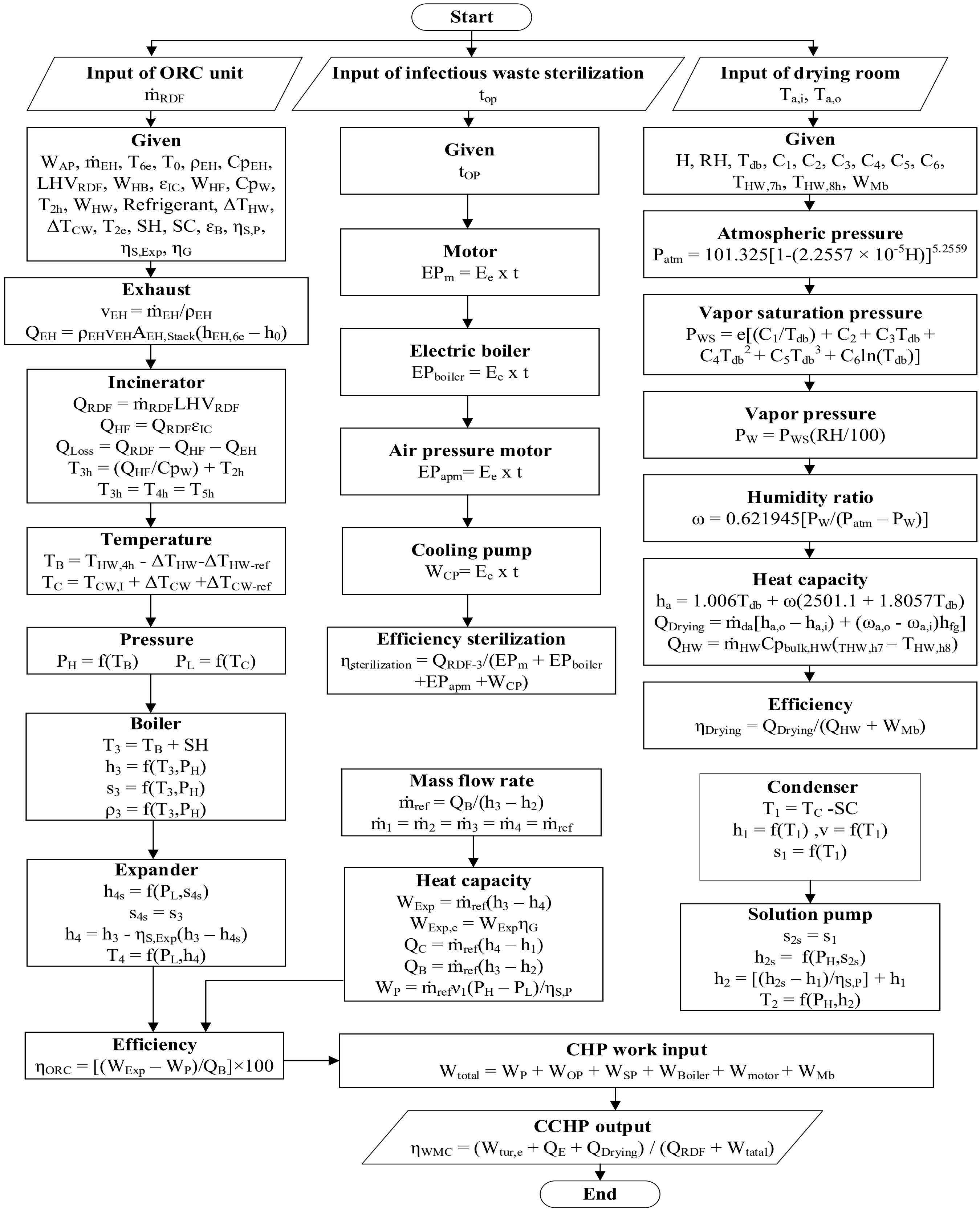

Fig. 2. Waste management center, incinerator, and ORC performance

4. Results and discussion

4.1 Thermal performance analysis of the ORC system

Fig. 3 shows the heat capacity in the incinerator at the combustion solid waste feed rate ($\dot{m}_{RDF}$) of 300-750 kg/h. The calculated results show that the RDF-3 heat capacity rate (Q_{RDF}) is 2,243.33-5,608.33 kW. The transformation system of solid fuels is processing. The heat of the hot fluid can produce a thermal capacity rate (Q_{HF}) of 1,906.43-4,767.08 kW. As the process continues, the heat capacity loss (Q_{Loss}) in the system is 203.84-708.59 kW. The data obtained for the heating capacity rate and thermal capacity rate are increasingly influenced by the effect of the combustion rate.

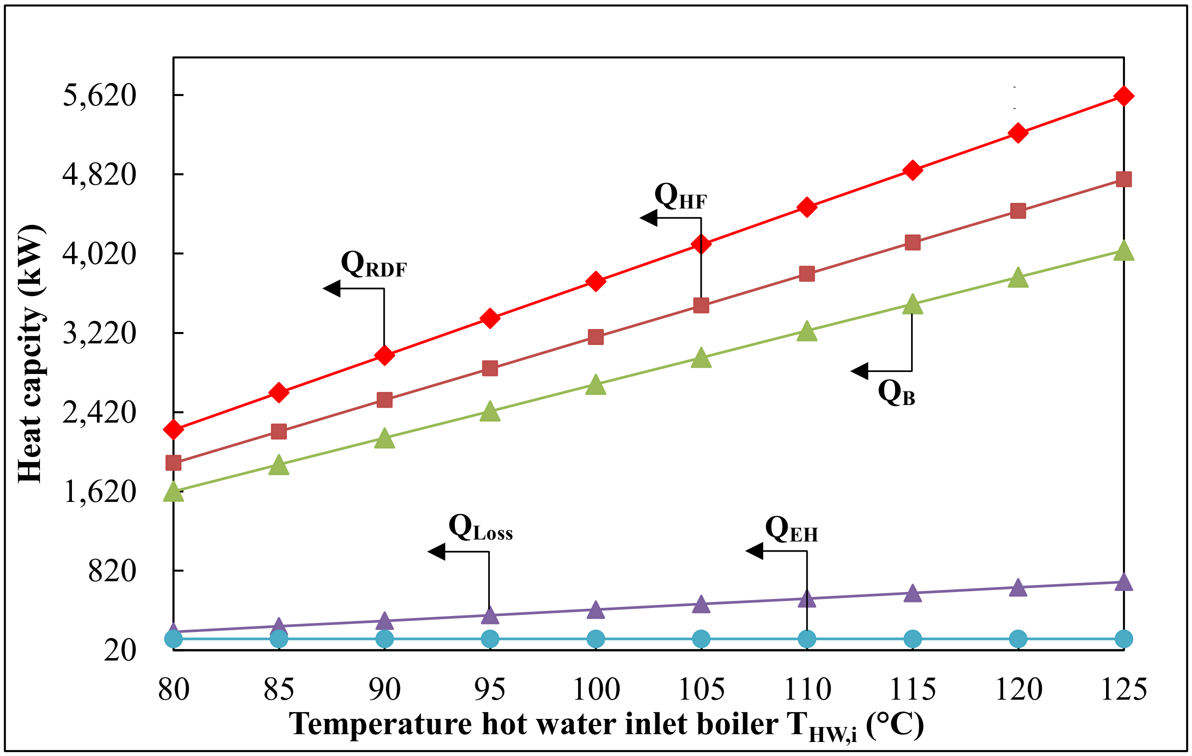

Fig. 1. Heat capacity of the incinerator and ORC system.

Fig. 4. Consider an ORC system with a thermal power output in the range of 97.40-413.82 kW. Therefore, for a boiler with a hot water inlet, the fluid is very hot. The heat of the boiler closely follows that shown in Fig. 5.

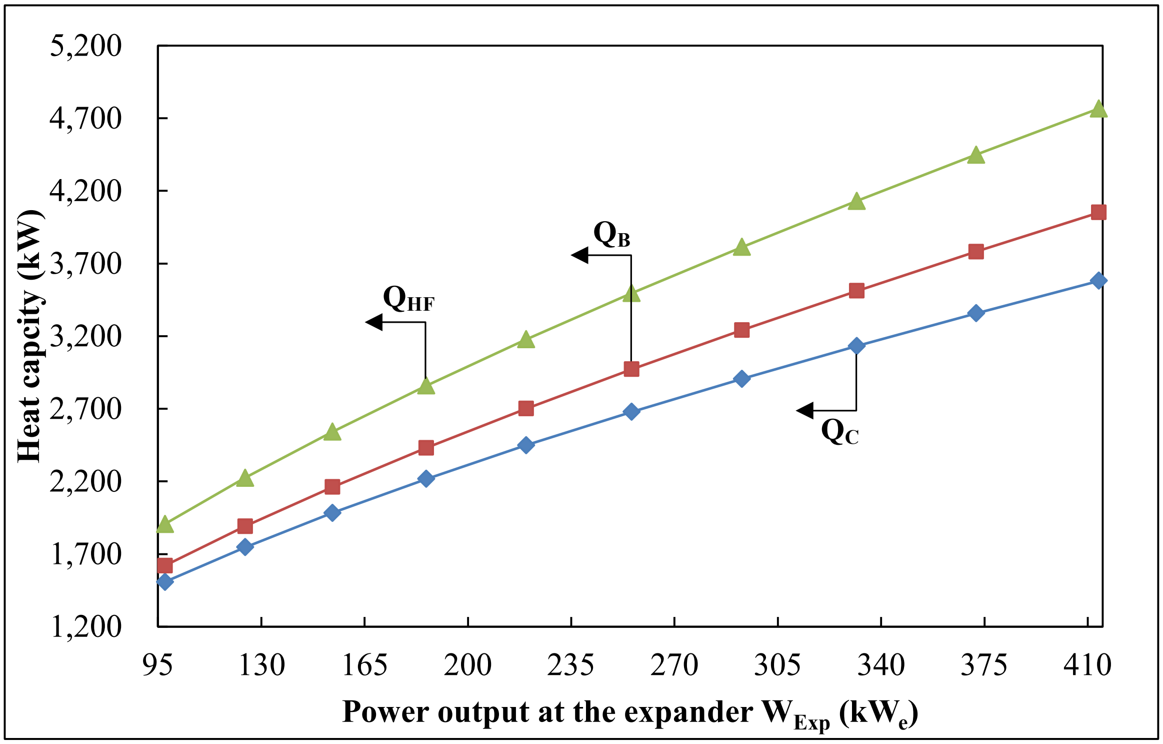

Fig. 2. Heat capacity of the hot water, boiler, and condenser in the ORC system.

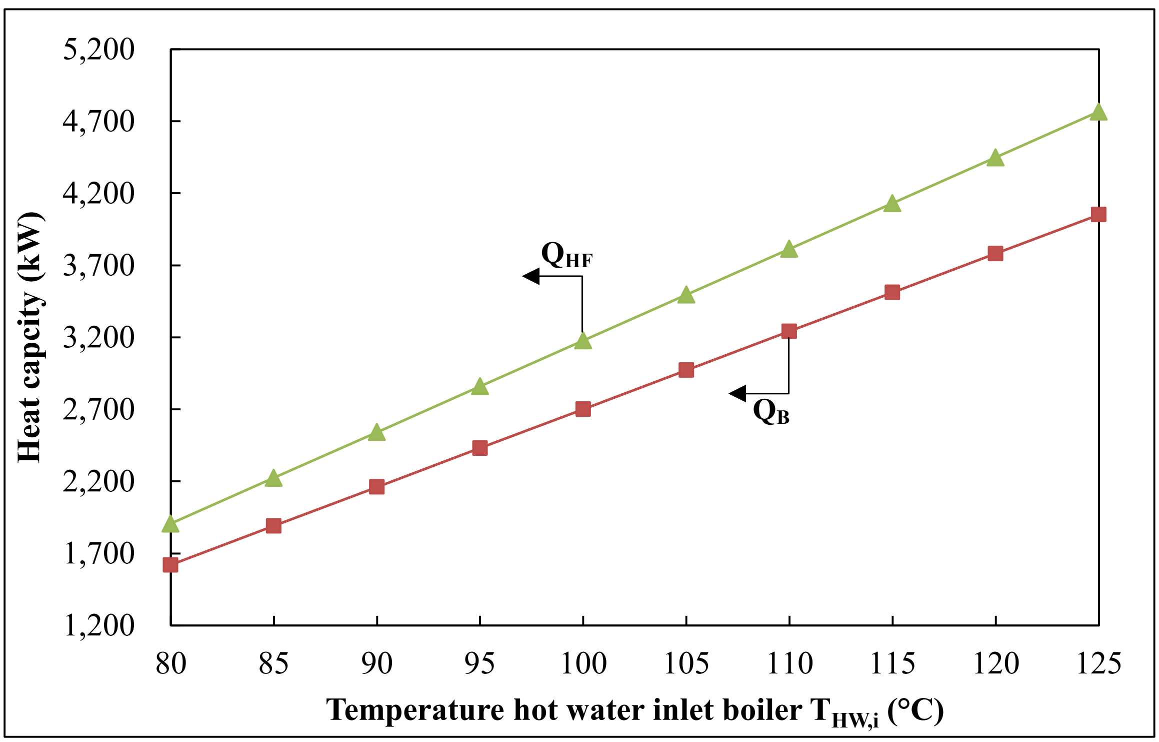

Fig. 3. Heat capacity of a hot water inlet boiler and the heat capacity at the boiler.

Fig. 6. shows that the working fluid temperature impacts the power output of the ORC and is slightly higher. The output work refrigerant pump feed-in boiler has a range of 0.26-3.14 kW. Furthermore, the working fluid temperatures leave the expender (T_4). This point fluid temperature

ISBN: 978-86-87043-85-5

is revealed to range from 56.63-117 °C. Then, the temperature point that is output from the boiler (T_3) is considered. If the temperature to the thigh is impacted, the gross power expander output is also impacted. The focused heat capacity of the boiler, condenser, and input heat is the working fluid. The heat of the boiler also closely follows the temperature as the working fluid is heated. The condenser heat leaving the expander decreases. This follows with working is refrigerant. The mass flow rate ($\dot{m}_{ref}$) in the system ranges from1.23-2.86 kg/s.

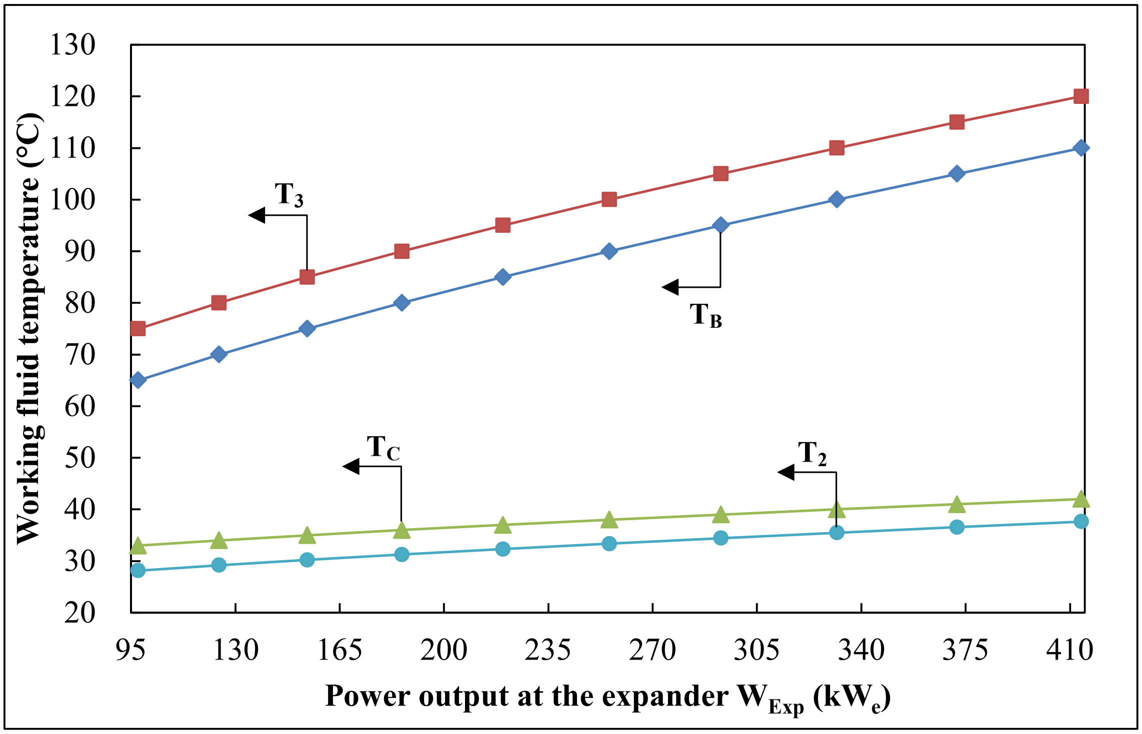

Fig. 4. Working fluid temperature in the ORC system.

Fig. 7. Furthermore, the working fluid temperature leaves the expender, which shows the effect of hot water entering the boiler. The operating temperature ranges from 80-125 °C. The ORC energy efficiencies and the heat input at the boiler for the case of the energy impact are very high. The increase in the power output of the turbine for electricity generation can be approximately 16.04-112.73 kW. The final results show that the energy efficiency is increased. The influence of the effect of the hot water temperature at the rage inlet boiler rung is 5.85-14.44%, as shown in Fig. 8.

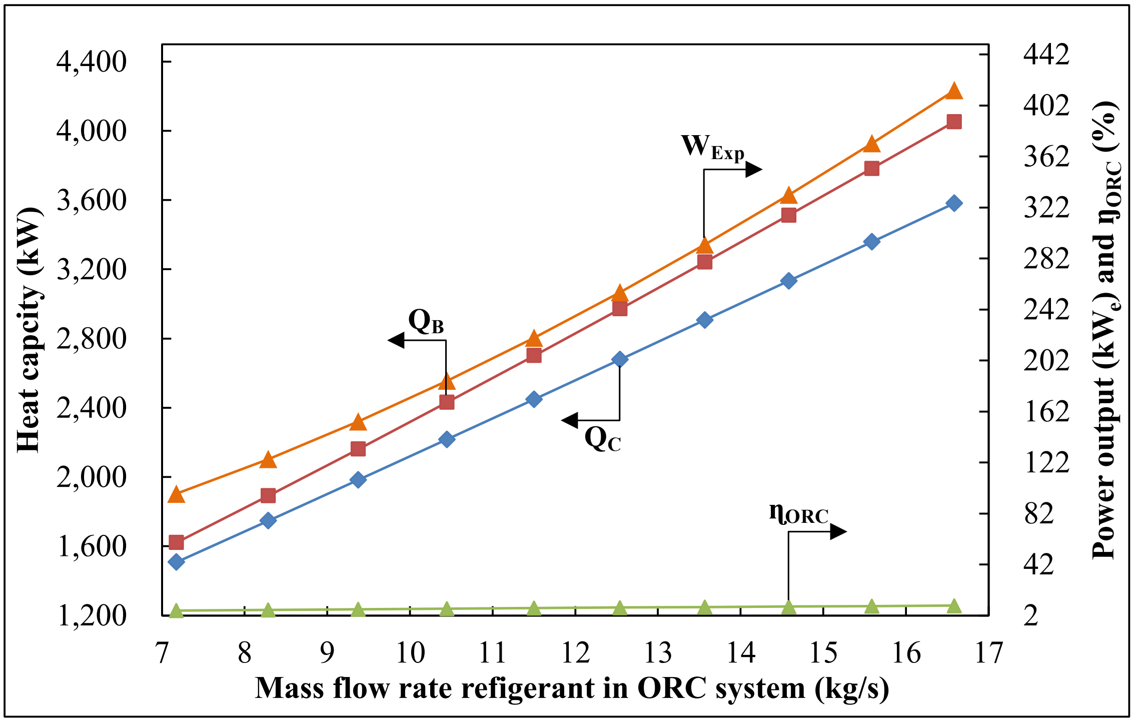

Fig. 5. The power output at the expander in heat capacity impact.

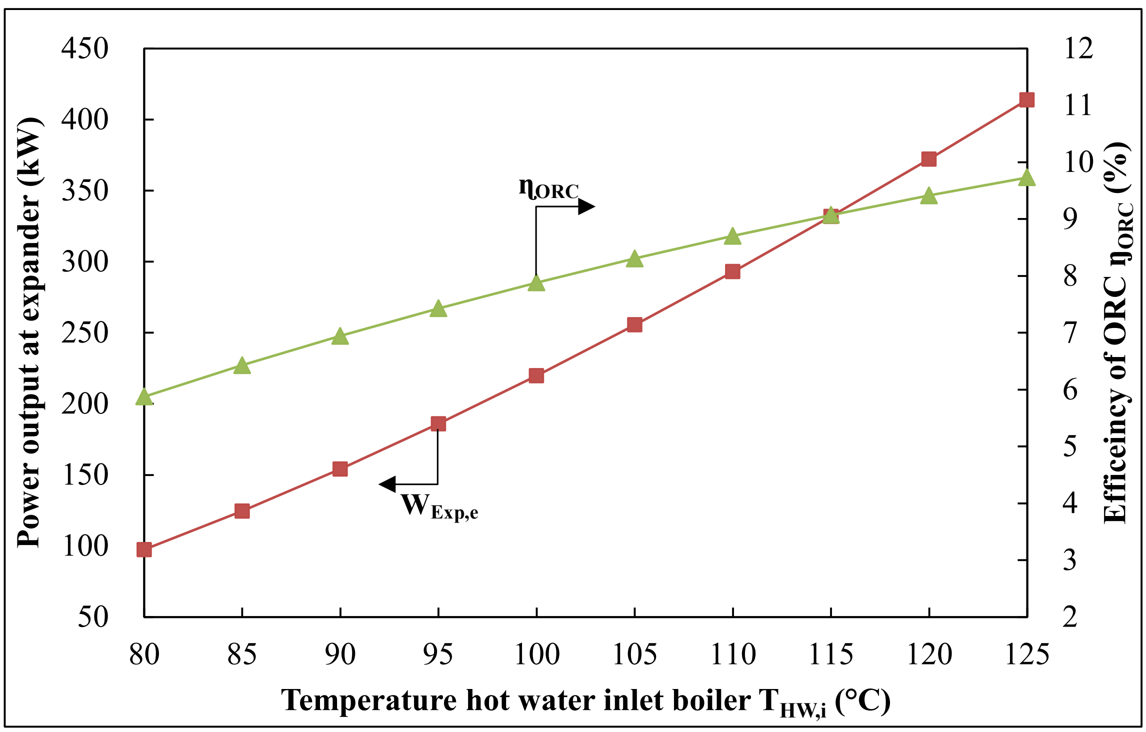

Fig. 6. Energy efficiency of the ORC system.

Fig. 9. A comparison of the input power for process sterilization and the consumption of power during operation. The system are operating operates in the range of 23.24-176.24 kWh.

The resulting power output in the expander system of the ORC ranges from 97.40-413.82 kW. The result shows that a high-value output efficiency is obtained during system operation and is worth investing in.

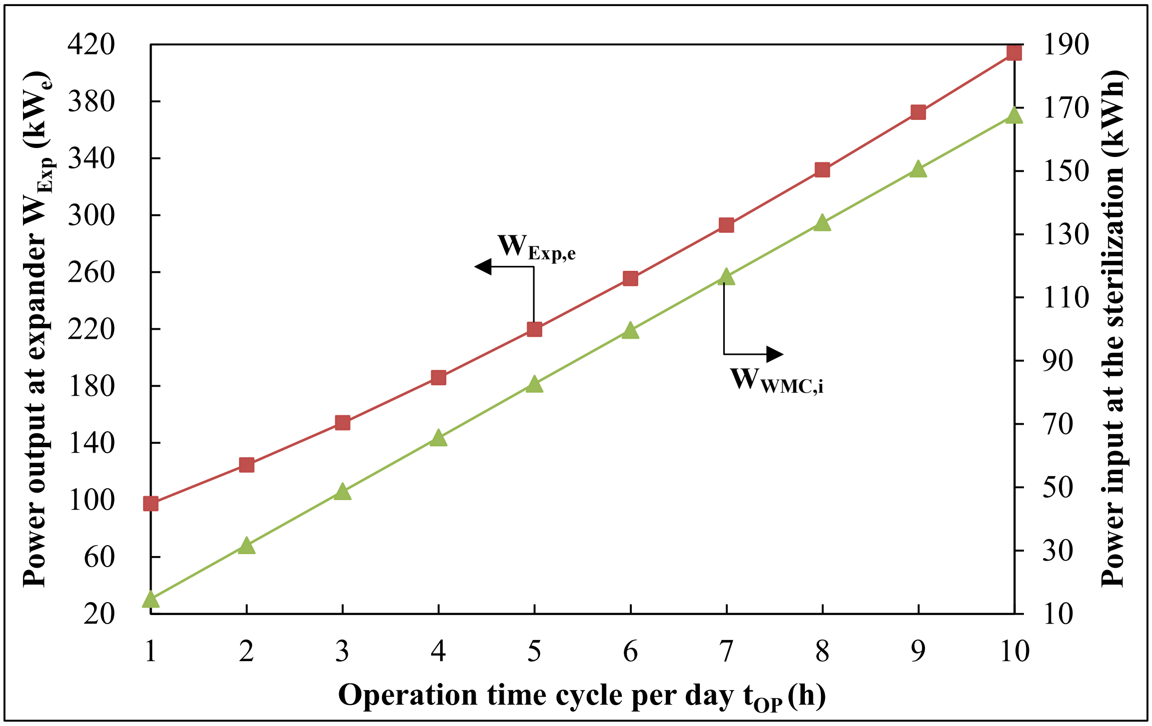

Fig. 7. Comparison of the input power for sterilization and the power output of the ORC

5. Conclusions

The conclusion from the schematics is that the use of RDF-3 is appropriate. The process for generating gross electric power output for an ORC system can be concluded as follows:

- The simulation results show a heat capacity at the incinerator combustion chamber RDF-3 (Q_{RDF}) in the range of 3,738.89-3,741.88 kW. The heat capacity of the hot water fluid (Q_{HF}) ranges from 317.09-892.70 kW. The heat capacity of the boiler (Q_B) ranges from 269.53-58.80 kW. The heat capacity at the condenser (Q_C) system varies in the range of 250.97-629.41 kW.
- The temperature in the ORC system is impacted by the heat capacity. The working fluid temperature follows the temperature at the boiler inlet (T_2) in the range of 35.13-35.60 °C. The boiler temperature (T_B) varies in the range of 62-107 °C. The temperature at the boiler output is superheated (T_3) in the range of 72-117 °C. The temperature of the leaf expander (T_4) ranges from 56.63 °C-71.75 °C. The temperature of the condenser (T_C) is stable at 40 °C.
- The work of the refrigerant pump is fed into the boiler (W_P) in the range of 0.26-3.14 kW.
- The gross electricity power output in the expander varies in the range of 16.04-12.73 kW.
- The average power output is 58.9 kW. The energy efficiency of the ORC system output varies in the range of 5.85-14.44%.

Acknowledgment

The author would like to thank the School of Renewable Energy, Maejo University for the project to produce and develop graduates in renewable energy ASEAN countries for graduate students (2021) and for supporting testing facilities and research budget.

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ISBN 978-86-87043-85-5
