SEE 2022

8th INTERNATIONAL CONFERENCE ON SUSTAINABLE ENERGY AND ENVIRONMENT

THE ROAD TO NET-ZERO: ENERGY TRANSITION CHALLENGES AND SOLUTIONS

7- 9 November 2022
The Knowledge Xchange (KX), Bangkok, Thailand

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Detailed programme

Date: 7 November 2022 **Starting time: 13.30**

Topic A: Future Energy Systems

Chairperson: Dr. Nakorn Worasuwannarak

TIME	ROOM X11.2 (11th Floor, KX)	
13.30-13.40	**Introduction of the session by the chairperson**	
13.40-14.00	**Development of novel highly efficient conversion methods of biomass waste and low-rank coals into electricity or useful products** *Ryuichi Ashida* (Invited speaker)	A-39
14.00-14.15	**Electricity price spike formation and LNG prices effect in Japan electric power exchange (JEPX)** *Samin Rassi, Takashi Kanamura*	A-04
14.15-14.30	**Performance analysis of a combined cooling heating and power (CCHP) system with an infectious waste incinerator** *Chindamanee Pokson, Nattaporn Chaiyat*	A-16
14.30-14.45	**Techno-economic of ammonia co-firing in low-rank coal-fired power plant** *Azaria Haykal Ahmad, Prihadi Setyo Darmanto, Firman Bagja Juangsa*	A-27

Topic B1: Bio-circular Economy: Energy

Chairperson: Dr. Suneerat Fukuda

TIME	ROOM X11.3 (11th Floor, KX)	
13.30-13.40	**Introduction of the session by the chairperson**	
13.40-14.00	**Catalytic conversion of biogas to biomethane** *Mirko Barz, Asnakech Laß-Seyoum, Steffen Kadow, Hartmut Wesenfeld, Jiawei He, Olga Ovsitser, Sascha Knist, Peter Geppert, Alexander Boitin, Daniel Hoffmann* (Invited speaker)	B1-01
14.00-14.15	**Improving enzyme activities and protein content of palm kernel cake residues using enzymatic hydrolysis prior to solid state fermentation** *Patsaporn Pongmalai, Apichaya Sae-Teng, Wairuj Dechmahitkul, Sunun Siriraksophon*	B1-02
14.15-14.30	**Metal modification on TiO_2 nanoparticles for enhanced photocatalytic conversion of lignin** *Surawut Chuangchote, Patiya Kemacheevakul, Puangphen Hongdilokkul, Kamonchanok Roongraung, Navadol Laosiripojana*	B1-31
14.30-14.45	**Hydrothermal synthesis of calcium methoxide nano-catalyst for palm oil based biolubricant production: Effect of hydrothermal synthesis time** *Natthawan Prasongthum, Amornrat Suemanotham, Wanchana Sisuthog, Neeranuch Duangwongsa, Lalita Attanatho, Chanatip Samart Yoothana Thanmongkhon*	B1-32
14.45-15.00	**Development of catalysts from biomass ash (bagasse) for hydrogen production via dry reforming of methane (DRM): A combined simulation and experimental study** *Ittichai Kanchanakul, Sanchai Kuboon, Thongchai Rohitatisha Srinophakun*	B1-33

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Performance analysis of a combined cooling heating and power (CCHP) system with an infectious waste incinerator

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Abstract:
This work presents the performance analysis of a combined cooling, heating, and power (CCHP) system with an infectious waste incinerator. Refuse-derived fuel type 3 (RDF-3) from infectious medical waste is the main heat source of the CCHP system. While the RDF-3 sterilized via shredding and heating processes is used to generate hot fluid with mass flow rate of 53.69 kg/h. The CCHP system comprises a 12.93-kW$_e$ *organic Rankine cycle (ORC), a 10-kW absorption unit, and a 22.14-kW centralized drying room. The CCHP can produce an energy output of 45.06 kW with energy efficiency of 10.95%. The energy cost of 0.158 USD/kWh. The environmental impact in terms of carbon dioxide emissions of 0.2567 kg* CO_2*-eq/kWh.*

Keywords: *Combined Cooling Heating and Power (CCHP); Energy Efficiency; Infectious Medical Waste; Refuse-derived Fuel; Waste-to- energy*

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1. Introduction

The outbreak of COVID-19 has led to an increase in infectious medical waste. Infectious medical waste can impact human health and can pollute the environment without proper management. Infectious medical waste, obtained as RDF-3 through a sterilization process, can be used for energy. This usage is in accordance with the Alternative Energy Development Plan 2018 (AEDP2018) to replace 30% of the final energy consumption by 2037 (EPPO, 2021).

Waste-to-energy (WtE) technology has been reported by various researchers, including Yatsunthea and Chaiyat (2020) presented the power generation process of municipal waste involving an organic Rankine cycle (ORC) with an incinerator. The main heat source of refuse-derived fuel type (RDF-3) from infectious and municipal waste was obtained after sterilization via shredding and heating processes at a low heating value of 26.92 MJ/kg. The contributions of electricity to the gross power and ORC efficiency reached 23.65 kWe and 8.05%, respectively. Ma et al. (2021) reported that the primary energy rate did not exceed 1% and that the difference in the primary energy saving rate was not more than 0.5%. This finding reflects the optimization performance of the CCHP system. Mehregan et al. (2022) proposed a CCHP system based on a trigeneration system driven with a gas engine and flat-plate solar collector. The overall efficiency of the trigeneration system was found to reach approximately 97%. Chaiyat et al. (2020) developed a microscale CCHP system with a hot spring as the main heat source. The net output energy reached 32.62 kWh at an average efficiency of 11.6%. Karim et al. (2021) proposed a CCHP system driven by evacuated tube solar collectors. The optimization results revealed a maximum exergy efficiency of 10.06%, and the minimum total cost rate reached 0.4835USD/h. Anvari et al. (2021) established a multigeneration system to produce power, heating/cooling, and desalinated water based on a gas turbine cycle as the prime mover. The results indicated that the cycle power, heating, cooling, and desalinated water production could reach 30.5 MW, 40.8 MW, 1 MW, and 0.168 kg/s, respectively. Xu et al. (2021) proposed a CCHP design based on acoustic impedance matching between thermoacoustic and alternator units. The system achieved an overall exergy efficiency of 24.1%, allowing 78.4 MWh. Nami and Moghaddam (2020) studied a CCHP system considering waste heat recovery at a cement plant. The results revealed exergy efficiency, energy utilization factor, and sustainability index values of 63.6%, 98.07, and 2.747, respectively. Jia et al. (2021) and Ai et al. (2022) conducted a CCHP thermodynamic analysis. The results demonstrated the potential for high efficiency and energy conservation. The CCHP system can be designed and operated to achieve energy savings and consumption reduction.

The literature indicates that many studies have reported waste-to-energy technology. It should be noted that the method to enhance CCHP systems with infectious waste incinerators did not appear in recent literature. This novel CCHP system represents an interesting approach to infectious waste management that should be analyzed in terms of energy, economics, and environment, corresponding to the following aims of this study:

- To perform model simulations for systematic optimization purposes.
- To analyze the CCHP thermal performance based on energy, economics, and environment.

2. System description

The concept of the designed CCHP system designed in this study is illustrated in Fig. 1. The system consists of three subsystems: the first system is an incinerator involving an organic Rankine cycle (ORC). The second system is an absorption system for combined cooling. The third system is a centralized drying room for combined heating.

The required heat energy of the system is supplied by a heat source comprising the combustion process of infectious waste in the form of refuse-derived fuel type 3 (RDF-3). The output of the incinerator consists of exhaust gas, ash, and combustion heat. Exhaust gas is sent to the treatment loop via a hot air blower and double absorber to eliminate small particulates, after which moist gas is reheated and evaporated before reducing the dry gas temperature with a cooling set and vacuum filter in the final treatment step (points 1e–6e). Ash is a byproduct of the combustion process and is ejected below the combustion chamber. The final output, i.e., combustion heat, is sent to the ORC system via the hot fluid loop (points 1h–5h). Then, combustion heat is transferred through the ORC loop (points 1–5). A dry refrigerant type constitutes the working fluid in the isentropic process of the refrigerant loop (points 1–4). The liquid-phase refrigerant is boiled in the boiler to generate superheated vapor, which flows into the expander to drive a generator. A lubricant oil loop is used to reduce the friction loss in the expander (points 1O–2O). Then, the vapor-phase refrigerant is condensed to produce subcooled liquid.

The absorption system is used to produce cooled water as the ORC working fluid instead of the ORC condenser and to generate working fluid instead of the evaporator and absorption condenser. Hot water originating from the ORC system (point 6h) is sent to the absorption system of the generator unit, which contains a working pair of solutions. Subsequently, absorbate (water) is extracted from the dilute solutions and heated in the form of superheated vapor, and the solution is concentrated enough to function as a strong solution (points 5a–10a). Heat is extracted from vapor in the condenser to yield the liquid phase (point 1a). Liquid refrigerant is throttled through the thermostatic expansion valve (TXV) and evaporator to produce cooled water (points 2a–3a). Liquid-phase water is converted into the vapor phase under negative-pressure conditions at the cooling process (point 4a). Then, the obtained vapor is absorbed by a concentrated solution to form a dilute solution in the absorber.

The centralization drying room is used to extract moisture from RDF-3 after the steam sterilization process. Hot water originating from the absorption system (point 7h) is sent to the drying coil to transfer heat into moist air. Thereafter, hot water passes through the hot fluid tank (point 8h) to again obtain heat energy from the combustion process.

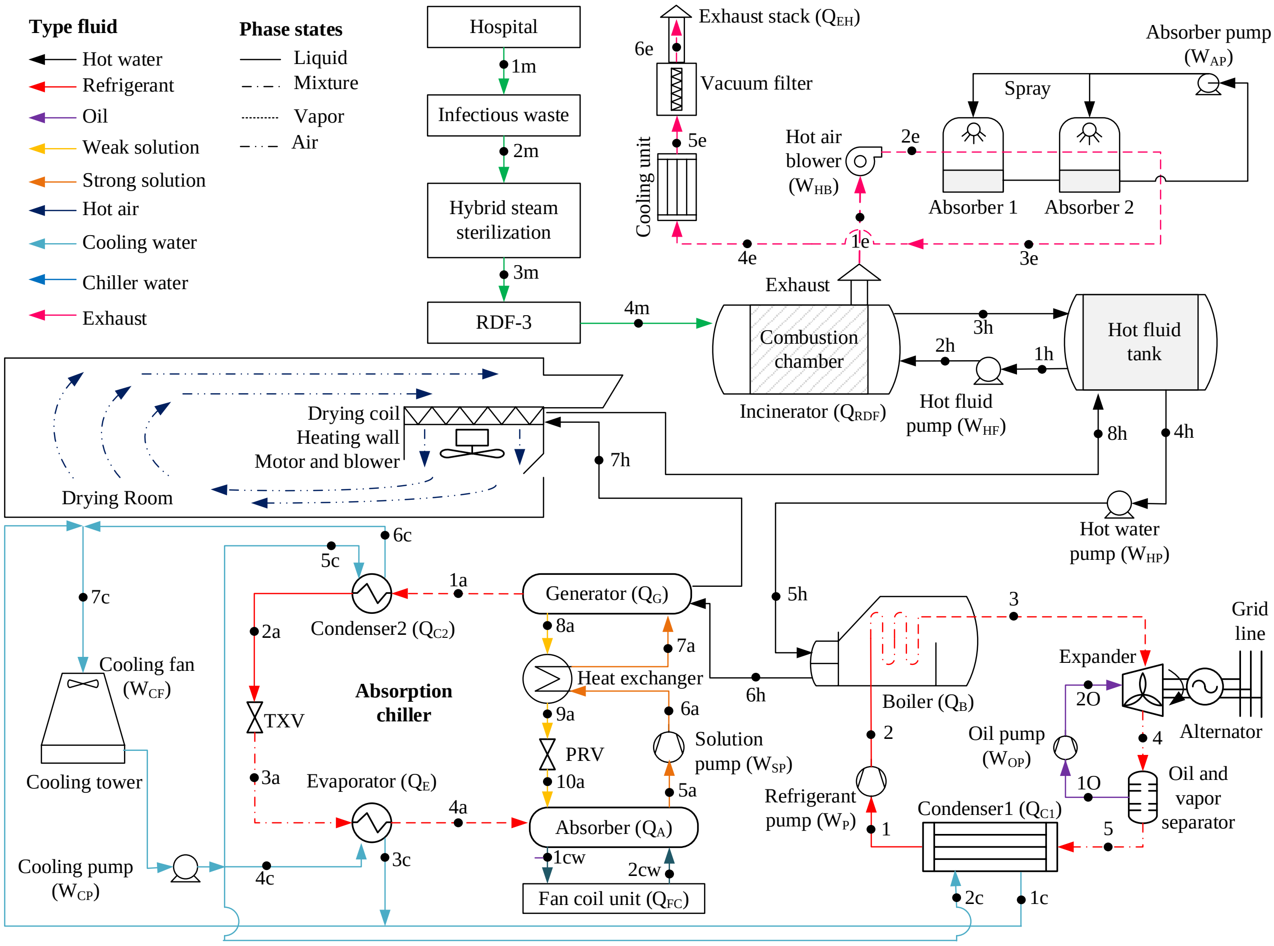

Fig. 1 A schematic diagram of the CCHP system

3. Methodology
The steps to determine the suitable CCHP system for this study are as follows:

Thermal performance of the CCHP system
The CCHP system is analyzed by using the REFPROP program (NIST, 2018) for retrieval of the working fluid properties. The thermal performance simulation steps are shown in Fig.2

The operating conditions of the incinerator unit
- The lower heating value of RDF-3 (LHV_{RDF-3}) is 26.92 MJ/kg (Yatsuntea and Chaiyat, 2020),
- The efficiency of the incinerator (η_{IC}) is 31.66% (Yatsuntea and Chaiyat, 2020),
- The effectiveness of the incinerator (ε_{IC}) is 80% (Sengnavong et al., 2018).

The operating conditions of the ORC unit
- The working fluid of the ORC system is R-245fa,
- The temperature of the hot water inlet boiler (T_{5h}) is 105 °C (Sengnavong et al., 2018)
- The difference in temperature between the hot water inlet and outlet boiler (ΔT_{HW-B}) is 15 °C (Chaiyat and Kiatsiriroat, 2015),
- The difference in temperature between the cooling water inlet and outlet condenser (ΔT_{CW}) is 5 °C (Chaiyat and Kiatsiriroat, 2015),

- The difference in temperature between the hot water inlet and refrigerant of boiler (ΔT_{HW-ref}) is 3 °C (Yatsunthea et al., 2019),
- The difference in temperature between cooling water inlet and refrigerant of condenser (ΔT_{CW-ref}) is 2 °C (Yatsunthea et al., 2019),
- The superheating (SH) is 10 °C, and the subcooling (SC) is 5 °C (Yatsunthea et al., 2019),
- The efficiency of generator (η_G) is 80% (Yatsunthea et al., 2019),
- The isentropic efficiency of pump ($\eta_{S,P}$) is 80% (Sengnavong et al., 2018),
- The isentropic efficiency of expander ($\eta_{S,Exp}$) is 80% (Sengnavong et al., 2018),
- The effectiveness of boiler (ε_B) is 80% (Sengnavong et al., 2018).

The operating conditions of the absorption unit

- The working fluid is a water-lithium bromide solution (H_2O-LiBr) as referred to the ASHRAE (ASHRAE, 2009),
- The difference in temperature between hot water inlet and outlet of generator (ΔT_{HW-G}) is 5 °C (Inthavideth and Chaiyat, 2016),
- The difference temperature in the working flow of the generator, condenser, evaporator, and absorber (ΔT_{Sol}) is 3 °C (Inthavideth and Chaiyat, 2016),
- The isentropic efficiency of solution pump (η_{SP}) is 85% (Inthavideth, 2017),
- The effectiveness of heat exchanger (ε_{HX}) is 85% (Inthavideth, 2017),
- The maximum solution concentration (X_{max}) is 60%LiBr (Inthavideth, 2017),
- The minimum solution concentration (X_{min}) is 55%LiBr (Inthavideth, 2017).

The operating conditions of the drying room unit

- The dimensions of the centralized drying room are 3.6 m (width) x 6.0 m (length) x 3.0 m (height) (Chaiyat et al., 2020),
- The difference in temperature between the hot water inlet and outlet heat exchanger (ΔT_{HW-HX}) is 9 °C (Chao ngew, 2019),
- The efficiency of the heat exchanger (η_{HX}) is 85% (Chao ngew, 2019).

3.1 The economics assessment

This study is analyzed by using the levelized energy costing (LEnC) for normalizing the output in terms of power, cooling, and heating of the CCHP system. The function parameters consist of investment cost (Inv), operating and maintenance costs (OM), discount rate (r), operating time (t_{OT}), real interest rate (i_{Real}), and inflation rate ($i_{Inflation}$). The LEnC value can be estimated by:

$$LEnC_{CCHP} = \frac{Inv + \sum_{t=1}^{n} \frac{OM}{(1+r)^t}}{\sum_{t=1}^{n} \frac{(W_{CCHP,net} + Q_E + Q_{DR})t_{OT}}{(1+r)^t}} \tag{1}$$

$$r = \left(\frac{1+i_{Real}}{1+i_{Inflation}}\right) - 1 \tag{2}$$

3.2 The environmental assessment

This study evaluated environmental impacts of the operation phases of the CCHP system with a life span of 20 years and a functional unit of 1 kWh are considered for gate-to-gate boundary condition. In accordance with ISO standard series 14040 (principles and framework). The life cycle assessment (LCA) framework of the CCHP unit is depicted in Fig. 3.

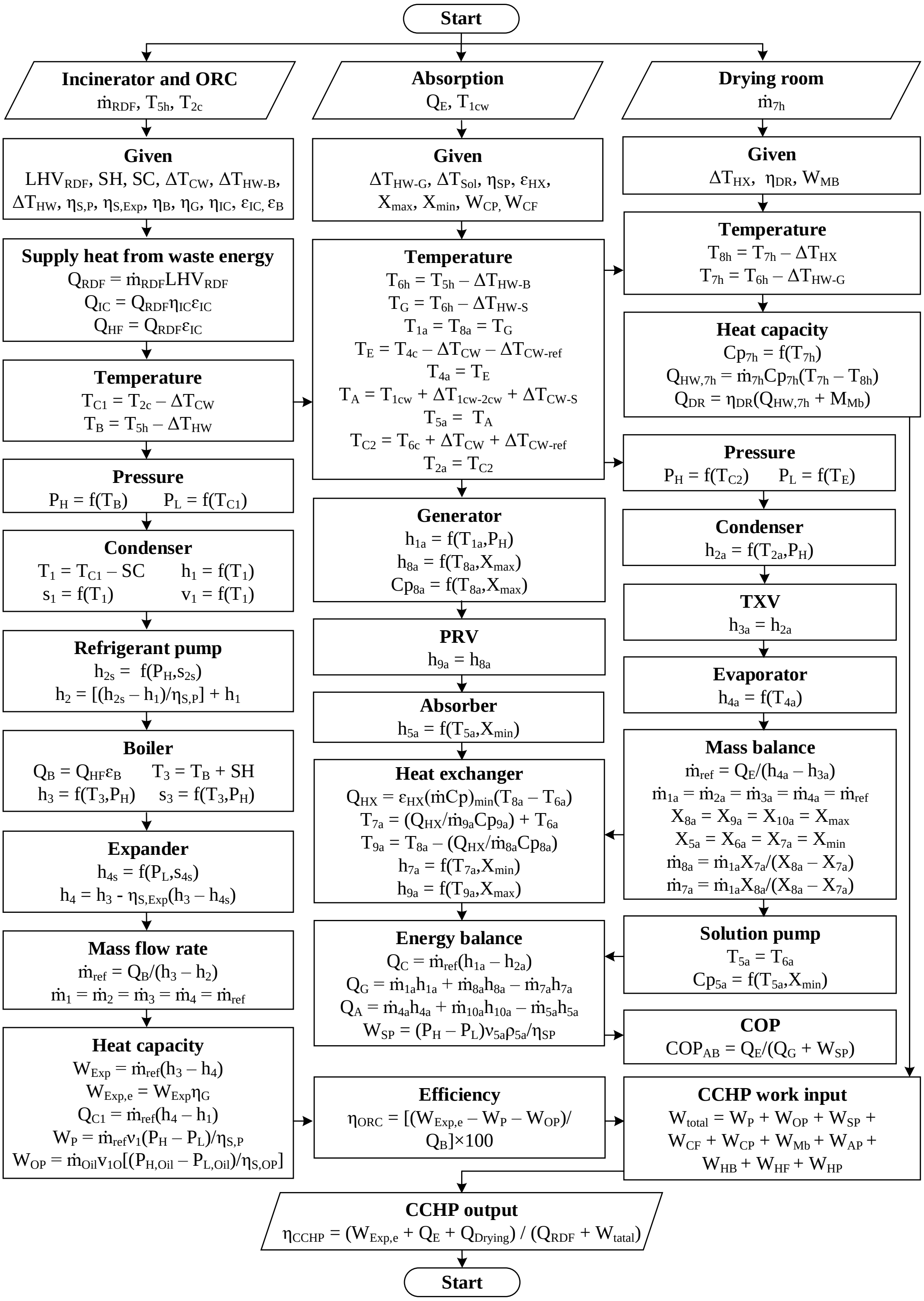

Fig. 2 Flow chart for the simulation of energy of the CCHP system

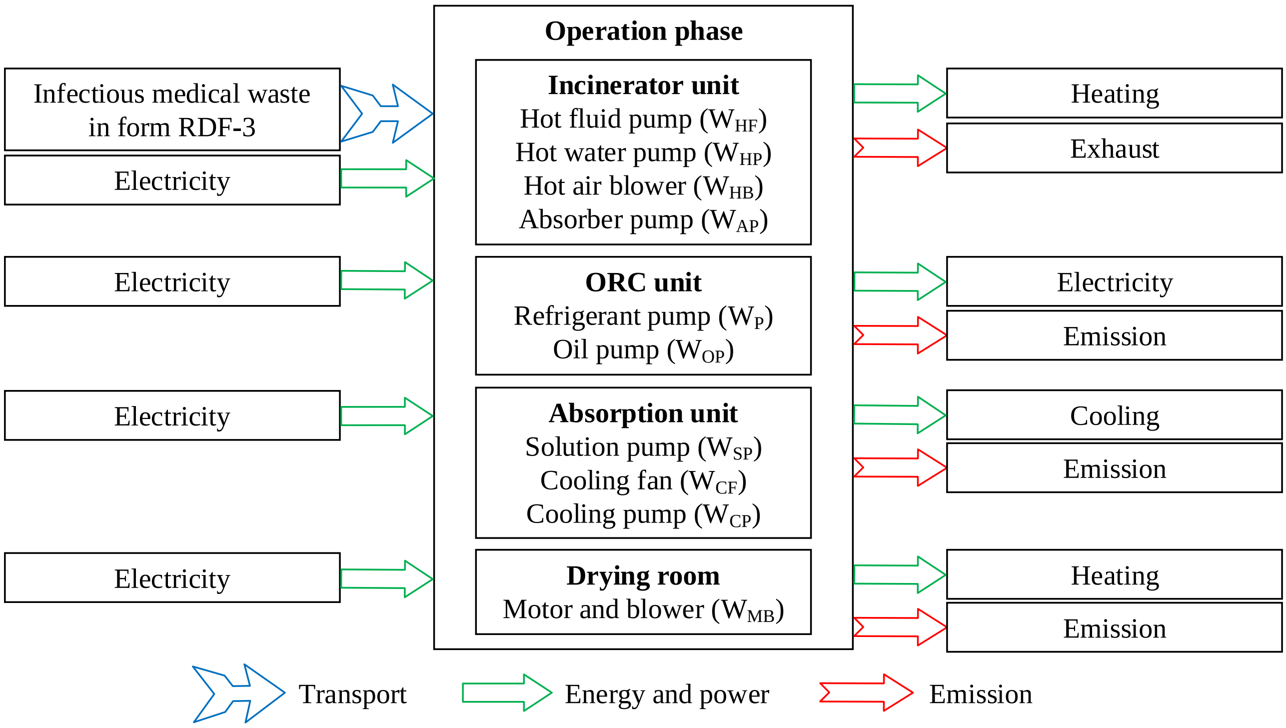

Fig. 3 System boundary diagram for the environment assessment

4. Results and discussion

4.1. The thermal performance results

From the mathematical simulation can be present the results are as follow:

Incinerator

The average values of infectious medical waste on 1-4 December 2021 at Nakornping hospital is 430 kg/day, as shown in Fig. 4. In the incinerator, the WtE is used RDF-3 from Nakornping hospital for combustion at an operating time of 8 h/day. The RDF-3 at a mass flow rate ($\dot{m}_{RDF}$) of 53.69 kg/h generates a combustion heating capacity (Q_{RDF}) of 401.91 kW and the hot fluid with heating capacity (Q_{HF}) of 148.22 kW. Power consumption from absorber pump (W_{AB}) of 0.25 kWe, hot air blower (W_{HB}) of 1.5 kWe, and hot fluid pump (W_{HF}) of 2.2 kW_e are supplied to drive the incinerator system.

Fig. 5, presents the energy efficiency of the incinerator and heat capacity based on the temperature profile. According to the simulated results, it can be observed that the energy efficiency and heat capacity of hot fluid have curves that reveal the same trend when the increase in temperature difference.

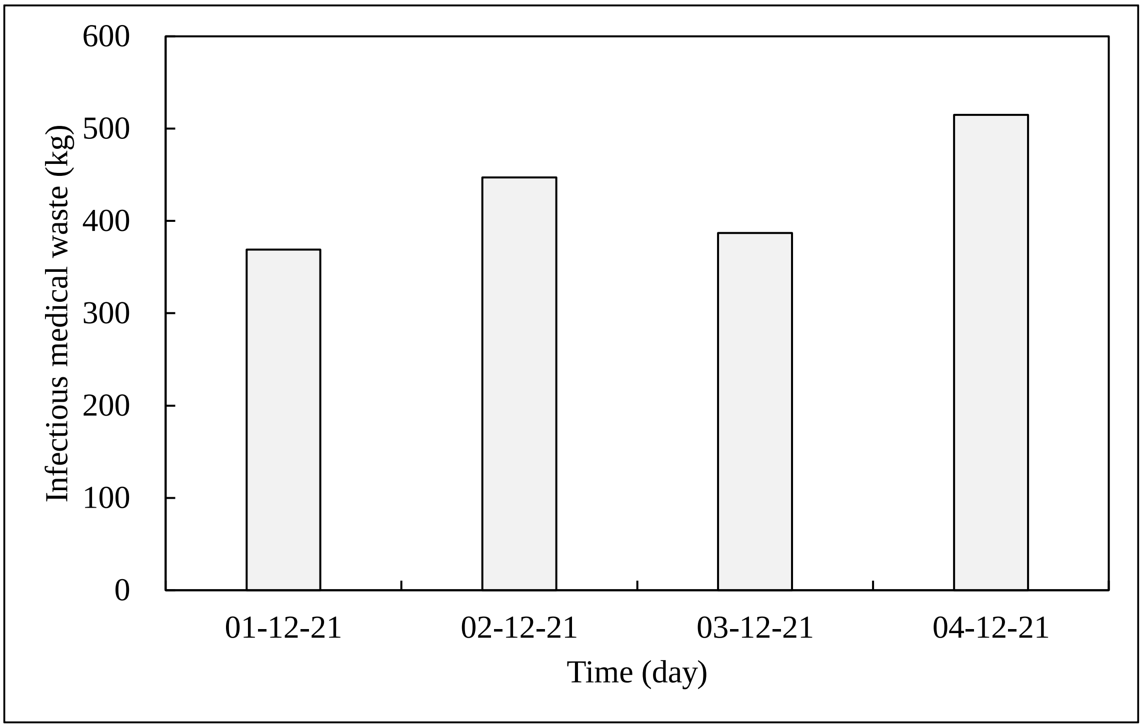

Fig. 4 Infectious medical waste at Nakornping hospital

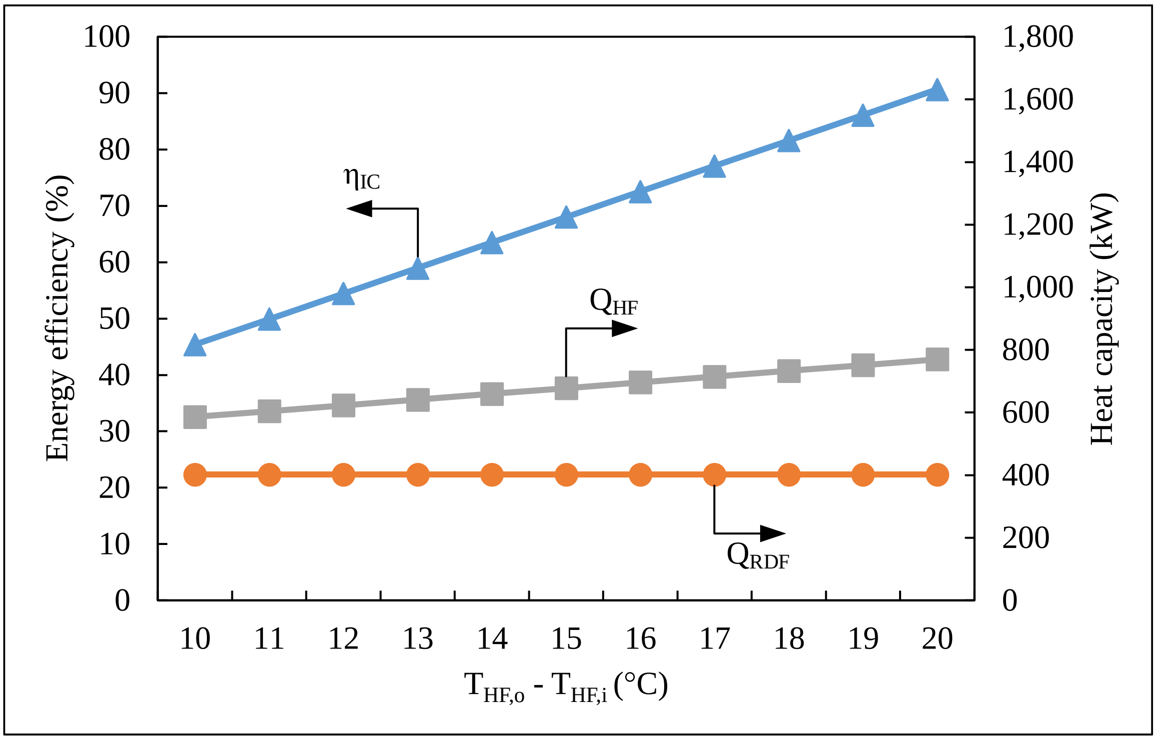

Fig. 5 Energy efficiency and heat capacity of the incinerator

ORC

The hot water entering the boiler (T_{5h}) of 105 °C is used to boil working fluid at the superheated vapor temperature (T_3) of 96.20 °C, high pressure (P_H) of 936.89 kPa, and transfer heat into the boiler at heat capacity (Q_B) of 147.38 kW. Which can produce electric power from the expander ($W_{Exp,e}$) of 13.57 kWe. Then, the superheated vapor temperature at low-side pressure (P_L) of 137.75 kPa and temperature (T_5) of 51.32 °C is sent into the condenser. Power consumption from refrigerant pump (W_P) of 0.42 kW and oil pump (W_{OP}) of 0.23 kW. A net electric power ($W_{ORC,net}$) of 12.93 kWe. The energy efficiency (η_{ORC}) of 8.77%

Fig. 6, presents the energy power output and heat capacity of the ORC system based on the temperature profile. It can be observed that the energy power and heat capacity have curves that reveal the same trend when the increase in temperature difference.

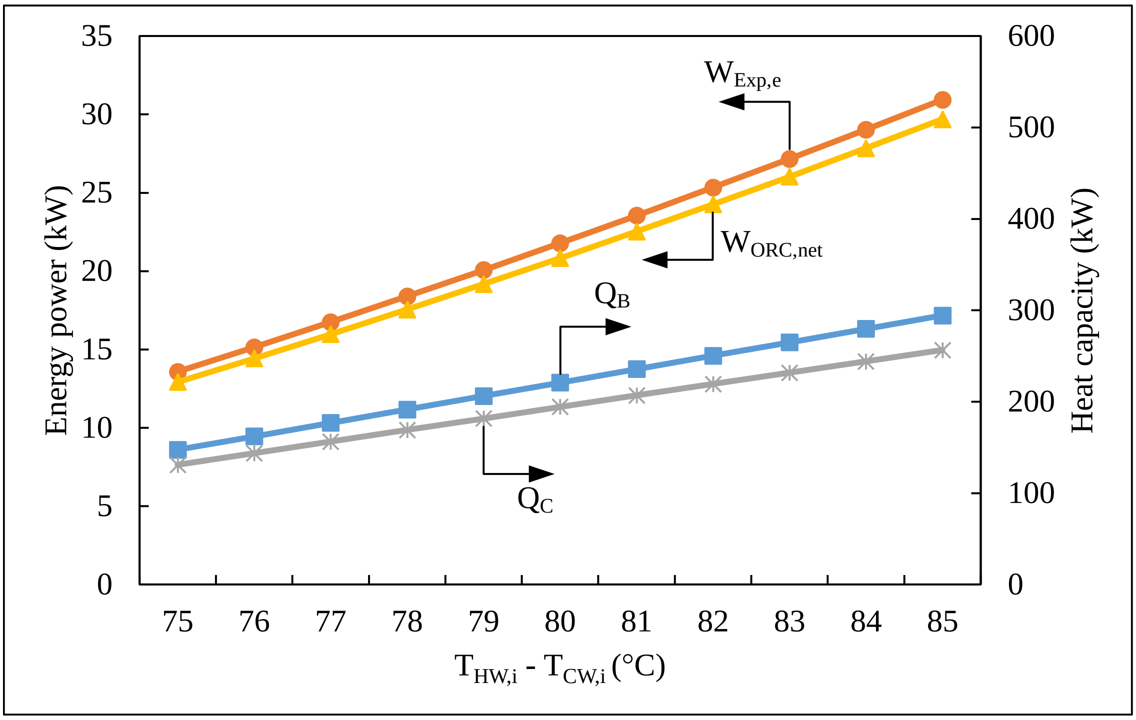

Fig. 6 Energy power and heat capacity of the ORC

Absorption chiller

The hot water entering the generator (T_{6h}) of 90 °C. the temperature of absorber (T_A), condenser2 (T_{C2}), evaporator (T_E), and generator (T_G) are 39.7 °C, 38 °C, 27 °C and 87 °C, respectively. The heat capacity of heat exchanger (Q_{HX}), condenser2 (Q_{C2}), generator (Q_G), and absorber (Q_A) are 5.38 kW, 15.71 kW, 17.55 kW, and 17.88 kW, respectively. The COP_{AB} of 0.85 under the operating condition of the cooling capacity of the evaporator (Q_E) 10 kW. The calculation as shown in Fig. 7.

Centralized drying room

The operating condition of the centralized drying room based on a sizing room at 3.6 m × 6.0 m × 3.0 m. which energy efficiency (η_{DR}) of 56.16%, the effectiveness of heat exchanger (ε_{HX}) 85%, different temperature hot water at heat exchanger (ΔT_{HX}) of 9 °C, and power consumption from motor and blower (W_{MB}) of 0.84 kW. The heat capacity of centralized drying room (Q_{DR}) of 22.14 kW.

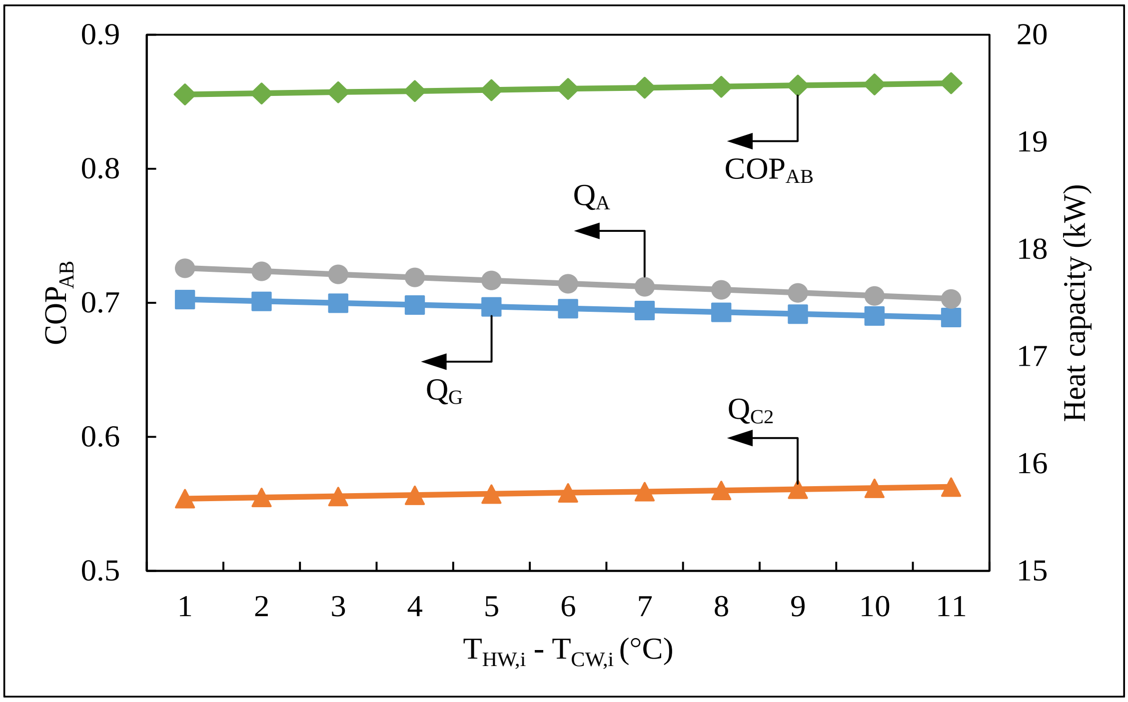

Fig. 7 Heat capacity of the absorption system

The CCHP system

The CCHP system is produced electricity power, cooling, and heating production. A total energy output ($W_{CCHP,net}$) of 45.06 kW and total energy input ($W_{Power,i}$) of 9.54 kW with energy efficiency (η_{CCHP}) of 10.95%. The energy efficiency from this study is nearly the CCHP hot spring system at 11.6% (Chaiyat et al., 2020), and the CCHP evacuated tube solar collectors at 10.06% (Karim et al., 2021). But a comparison of hot water entering system found in this study uses low-temperature heat of 105 °C. While The CCHP by hot spring uses temperature of 113 °C, and the CCHP by solar energy uses temperature of 125 °C, as shown in Fig.8.

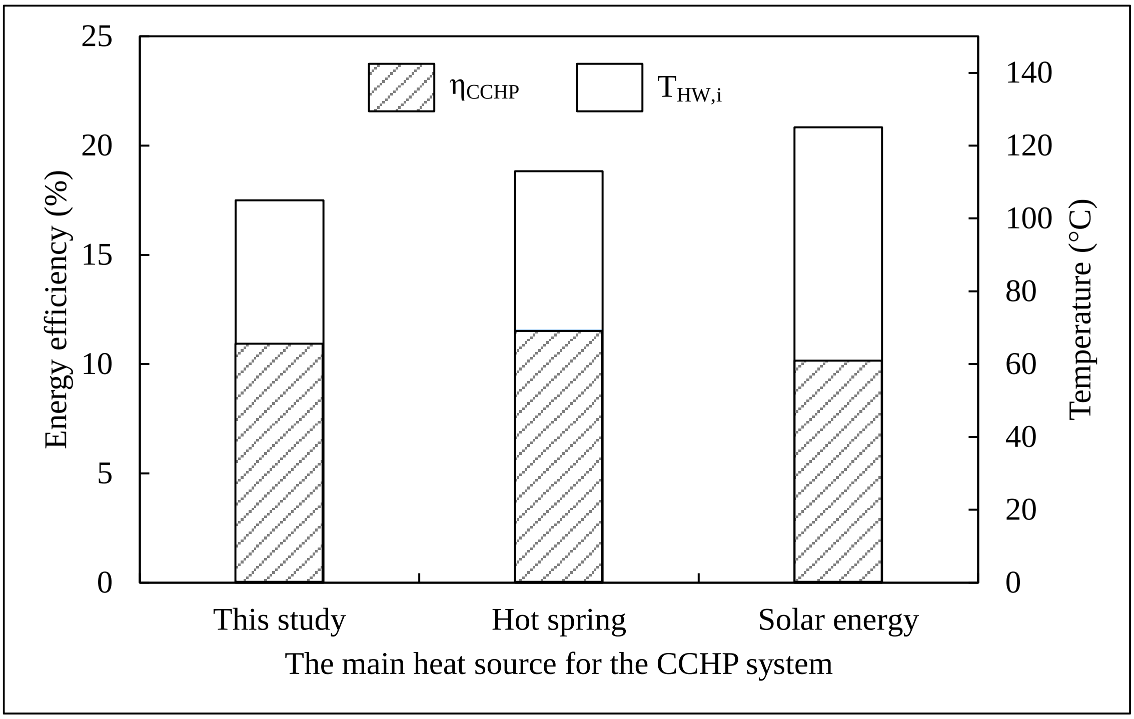

Fig. 8 The comparison with other study

Fig. 9, presents the energy efficiency and energy power of the CCHP system based on the temperature profile. It can be observed that the energy efficiency and energy power have curves that reveal the same trend when the increase in temperature difference.

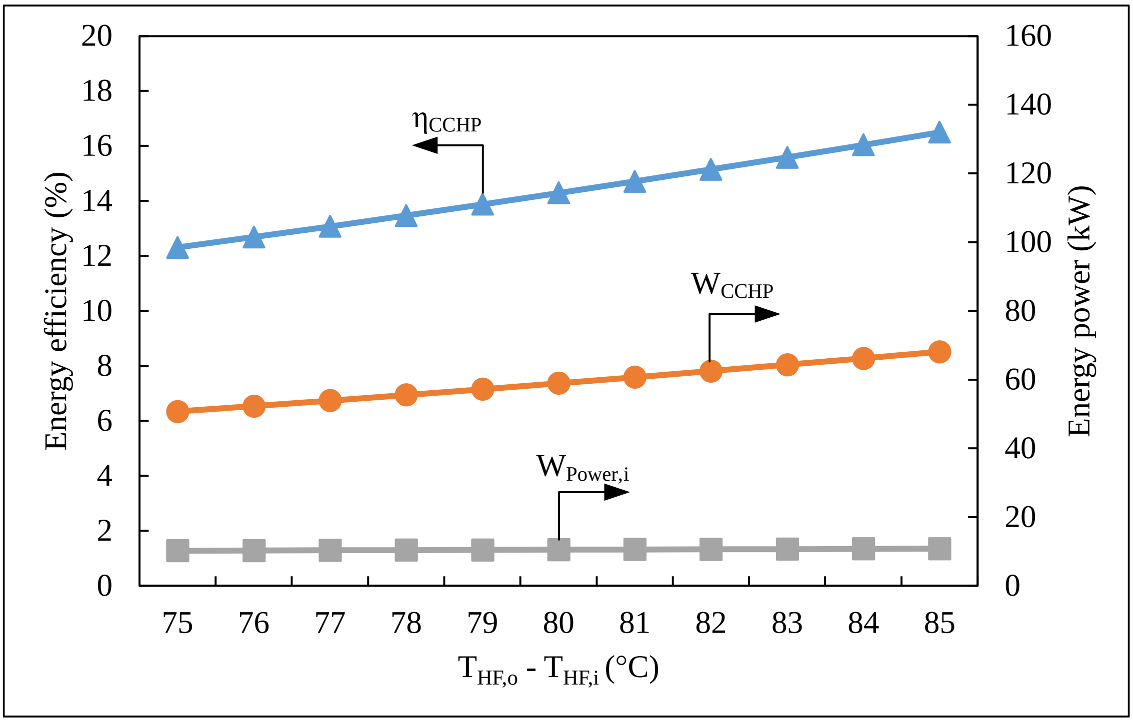

Fig. 9 Energy efficiency and energy power of the CCHP system

4.2. The economic results

The economic result focuses on the LEnC for normalizing the output in terms of power, cooling and heating of the CCHP system. A lifespan (n) of 20 y and operating time of 8 h/d and 350 d/y. In the results the LEnC is 0.158 USD/kWh, as specified in Table 1.

Table 1 The economic results.

Properties	**Value**	**References**
Capital cost of incinerator (Z_{IC}, USD)	14,787	Pokson and Chaiyat, (2022)
Capital cost of the hot fluid tank (Z_{Tank}, USD)	14,787	Pokson and Chaiyat, (2022)
Capital cost of the ORC (Z_{ORC}, USD)	73,934	Pokson and Chaiyat, (2022)
Capital cost of absorption (Z_{AB}, USD)	7,393	Pokson and Chaiyat, (2022)
Capital cost of drying room (Z_{DR}, USD)	5,915	Pokson and Chaiyat, (2022)
Capital cost of piping and insulation (Z_{PI}, USD)	5,915	Pokson and Chaiyat, (2022)
Total investment cost (Inv, USD)	122,731	Pokson and Chaiyat, (2022)
Maintenance cost (OM_{OP}, USD/y)[1]	6,553	Calculation
Operating and maintenance costs (OM, USD/y)[2]	9,553	Calculation
Real interest rate (i_{Real}, %)	4.70	CEIC, (2022)
Inflation rate ($i_{Inflation}$, %)	-0.85	Word data, (2022)
Discount rate (r, %)	5.6%	Calculation
Energy potential ($W_{CCHP}t_{OT}$)	126,179	Calculation
Levelized energy costing (LEnC, USD/kWh)	0.158	Calculation

Note: [1]The minimum labor cost in Thailand (OM_{Man}) 9.76 USD/person·day
[2]Maintenance cost at 5% of investment cost

4.3. The environmental result

The environmental result focuses on the carbon dioxide emissions from operation phase with lifespan of 20 y and functional unit (FU) of 1 kWh. In the results, the carbon dioxide emission is 0.2567 kg CO_2-eq/kWh, as specified in Table 2.

Table 2 The environmental result

Properties	Value	References
Total infectious medical waste (M_{RDF}, kg)	3,006,500	Calculation
Net power output (W_{CCHP}, kWh)	2,523,589	Calculation
Net power input ($W_{Power,i}$, kWh)	596,624	Calculation
Emission factor of exhaust gas from electricity generation by medical waste (EF_{RDF}, kg CO_2-eq/kg$_{RDF}$)	0.0967	Sonesack, (2018)
Emission factor for electricity consumption ($EF_{Electricity.}$, kg CO_2-eq/kWh)	0.5986	TGO, (2022)
Total CO_2-eq from CCHP ($Total_{CO2\text{-}eq}$, kg CO_2-eq)	647,868	Calculation
The CO_2-eq per functional unit ($CFP_{CCHP,}$ kg CO_2-eq/kWh)	0.2567	Calculation

5. Conclusion

From the study results, it can be concluded as follow:

- The energy efficiency of the CCHP system was strongly influenced by the process of the temperature profile.
- The infectious medical waste of 53.69 kg/h used to be the heat source in combustion process for the incinerator of 430 kg/day.
- Net electric power from the ORC system of 12.93 kW_e with ORC efficiency of 8.77%
- The cooling capacity of the evaporator is 10 kW with the COP_{AB} from absorption system of 0.85.
- The heating capacity of centralized drying room of 22.14 kW with energy efficiency of 56.16%
- The CCHP system can produce electrical power, cooling, and heating production in terms of energy at 45.06 kW with energy efficiency of 10.95%.
- Total investment cost of 122,731 USD and operating and maintenance costs of 9,553 USD/y directly effects to the levelized energy cost of 0.158 USD/kWh.
- The carbon dioxide emissions of 0.2567 kg CO_2-eq/kWh.

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7. Abbreviations and symbols

Nomenclature

COP	coefficient of performance, (-)
CFP	carbon footprint emissions (kg CO_2-eq)
EF	greenhouse gas emissions factor, (kg CO_2-eq / unit)
i	interest rate, (%)
Inv	investment cost, (USD)
LEnC	levelized energy cost, (USD/kWh)

n	life span, (y)
OM	operating and maintenance costs, (USD/y)
Q	heat transfer rate, (kW)
r	discount rate, (%)
t	time, (h)
T	temperature, (∘C)
Z	capital cost, (USD)

Abbreviation

AB	absorption system
AD	adsorption system
CCHP	combined cooling, heating, and power
DR	drying room
HF	hot fluid
IC	incinerator
LiBr	lithium bromide
ORC	organic Rankine cycle
PRV	pressure reducing valve
RDF	refuse derived fuel
TXV	thermostatic expansion valve

Subscript

A	absorber
AP	absorber pump
B	boiler
BW	blower
C	condenser
CW	cooling water
e	electricity
E	evaporator
EH	exhaust gas
Exp	expander
FC	fan coil
G	generator
H	high
HB	hot air blower
HF	hot fluid
HW	hot water
I	isentropic
L	low
OP	oil pump
OT	operating time
P	refrigerant pump
PI	piping and insulation
SP	solution pump

8. References

Ai, T., Chen, H., Jia, J., Song, Y., Zhong, F., Yang, S. and Xue G. 2022. Thermodynamic analysis of a CCHP system integrated with a regenerative organic flash cycle. Applied Thermal Engineering, 202, 117833.

America society of heating, Refrigerating and air-conditioning engineering, Inc. (ASHRAE), 2009. Refrigerants, Atlanta, American.

Anvari, S., Mahian, O., Taghavifar, H. and Wongwises, S. 2020. 4E analysis of a modified multigeneration system designed for power, heating/cooling, and water desalination. Applied Energy, 270, 115107.

CEIC. 2022. Thailand long term interest rate [Online]. Available at: https://www.ceicdata.com/en/indicator/thailand/long-term-interest-rate [Accessed on 20 October 2021].

Chaiyat, N. 2021. Energy, exergy, economic, and environmental analysis of an organic Rankine cycle integrating with infectious medical waste incinerator. Thermal Science and Engineering Progress, 22, 100810.

Chaiyay, N., Chaongew, S., Ondokmai, P. and Makarkard, P. 2020. Levelized energy and exergy costings per life cycle assessment of a combined cooling, heating, power and torism system of the San Kamphaeng hot spring, Thailand. Renewable Energy, 146, 828-842.

Chaiyat, N. and Kiatsiriroat, T. 2015. Analysis of combined cooling heating and power generation from organic Rankine cycle and absorption system. Energy, 91, 363-370.

Chiang Mai Provincial Office. 2022. General information of Chiang Mai Province [Online]. Available at: https://www.chiangmai.go.th/managing/public/D8/8D01Feb2017150134.pdf [Accessed on 13 February 2022].

Chao ngew, S. 2019. Combined cooling heating and power from cascade geothermal energy technology of San Kamphaeng hot spring. M.Eng. dissertation, Maejo University.

EPPO (Energy Policy and Planning Office). 2018. Alternative Energy Development Plan 2018-2037 [Online]. Available at: https://www.dede.go.th/download/Plan_62/20201021_TIEB_AEDP2018.pdf [Accessed on 3 December 2021].

Inthavideth, X. and Chaiyat, N. 2016. Performance analysis of an Organic Rankine cycle combine with an absorption chiller. Conference session presentation at the meeting of 15th The heat transfer and mass transfer and processes, Surat Thani, 30-31 March 2016.

Inthavideth, X. 2017. Performance Analysis of an Organic Rankine Cycle Combined with an Absorption Chiller. M.Eng. dissertation, Maejo University.

Jia, J., Chen, H., Liu, H., Ai, T. and Li, H. 2021. Thermodynamic performance analyses for CCHP system coupled with organic Rankine cycle and solar thermal utilization under a novel operation strategy. Energy Conversion and Management, 239, 114212.

Karim, S., Tofiq, T., Sharati, M., Rad, H. and Ghasemi, A. 2021. 4E analyses and multi-objective optimization of a solar-based combined cooling, heating, and power system for residential applications. Energy Report, 7, 1780-1797.

Ma, W., Fan, J., Fang, S., Hassan, N., Zhang, Y., Wu, X., Li, Y., Hu, R. and Liu, G. 2021. Energy efficiency indicators for combined cooling, heating and power systems. Conversion and Management, 239, 112187.

Mehregan, M., Abbasi, M., Khalilan, P., Hashemian, S. and Madadi, A. 2022. Energy, economic, environmental investigations and optimization of a combined cooling, heating and power system with hybrid prime mover of gas engine and flat plate solar collector, Energy Conversion and Management, 251, 115018.

Nami, H. and Moghaddam, A. 2020. Small-scale CCHP systems for waste heat recovery from cement plants: Thermodynamic, sustainability and economic implications. Energy, 192, 116634.

NIST (National institute of standards and technology), Inc. (Refprop version 10: Customer number 40754). Thermodynamic properties of refrigerants and refrigerant mixtures software, America. 2018.

Pokson, C. and Chaiyat, N. 2022. Thermal performance of a combined cooling, heating, and power (CCHP) generation system from infectious medical waste. Case studies in chemical and environmental engineering, 6, 100221.

Sengnavong, S., Chaiyat, N., Jaisin, C. and Thawonngamyigsakul, C. 2018. Energy costing of Organic Rankine cycle using medical waste from mathematical model a case study: Lampang hospital. Conference session presentation at the meeting of the 3rd national conference on informatics, agriculture, management, business administration, engineering, science and technology, Chumphon, 24-25 May 2018.

TGO (Thailand greenhouse gas management organization). 2022. Emission factor [Online]. Available at: http://thaicarbonlabel.tgo.or.th/admin/uploadfiles/emission/ts_af09c20f4.pdf [Accessed on 20 October 2021].

World data. 2022. Inflation rates in Thailand [Online]. Available at: https://www.worlddata.info /asia/thailand/inflation-rates.php [Accessed on 20 October 2021].

Xu, J., Lua, E. and Hochgreb, S. 2021. A thermoacoustic combined cooling, heating, and power (CCHP) system for waste heat and LNG cold energy recovery. Energy, 227, 120341.

Yatsuntea, T. and Chaiyat, N. 2020. A very small power plant – Municipal waste of the organic Rankine cycle and incinerator from medical and municipal waste. Thermal Science and Engineering Progress, 18, 100555.

Yatsuntea, T., Munsin, R. and Chaiyot, N. 2019. Selection working fluid of an Organic Rankine cycle for low-temperature heat source. Conference session presentation at the meeting of 7th Asian academic society international conference, Songkhla, 12-14 November 2019.