Sustainability of Alternative Energy for Organic Rankine Cycle Power Plant in Thailand

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Abstract

This paper studies the possibility of power generation by using alternative energy in Thailand, which are geothermal energy, solar energy and waste energy based on the energy, economic and environment indicators. An Organic Rankine Cycle (ORC) is used to generate electricity from heat sources of hot springs, solar water heating system and RDF-5, respectively. In this study, a 20 kW_e ORC system with using R-245fa as working fluid was tested and evaluated the system efficiency. From the testing results, it could be found that the efficiency of ORC system was around 8%, when hot water temperature was higher than 100 °C. From simulation results, the values of electricity costs (EC) of geothermal energy, solar energy and waste energy are 0.166, 0.747 and 1.037 USD/kWh, respectively. For environmental impact, the carbon dioxide intensity per net electricity output of geothermal, solar and waste power plants are 0.186, 0.537 and 2.380 kg CO_2/kWh, respectively. The suitable alternative energy for generating electricity is geothermal energy, which is beneficial than the solar and waste energy power plants based on the energy, environment and economic results. Free operating cost is the main factor, which supports that the geothermal power plant is the suitable technique.

Keywords: Organic Rankine Cycle, Geothermal Energy, Solar Energy, Waste Energy, Electricity Costs

Introduction

Thailand relies on imported energy, of which the volume has grown continuously. In 2011, the energy imports increased 30.2% compared in 2010 (Energy Policy and Planning Office, 2010). The government has set a framework and direction of the country's energy policy which focuses on energy security to ensure national energy independence and stability by encouraging energy development, and development of renewable and alternative energy to be 25% of the total power of the country in 2021. Therefore, for supporting the strategic of Ministry of Energy to produce electricity from alternative energy, and then 3 types of alternative energy of geothermal, solar and waste have been considered for generating electricity in this study.

The technique to generate electricity from hot spring, the several method are presented such as Chaiyat, & Chaichana, 2009. reported the technology to generate electricity of binary system and thermoelectric module. Combs, Garg, & Pritchett, 1997, pp. 389-402. studied the small geothermal power plant in America and Japan at capacity around 100-1,000 kW_e. The technologies of the slim hole and binary-cycle technology were selected to use for the off-grid area. It could be found that the environmental impact from the geothermal power plant was lower than the fossil power plant, this result was similarly Brophy, 2005, pp. 67-79. which presented the effects of CO_2, NO_x and SO_2 of the electric power 1 kW_e from the alternative energy. For the simulation studies, the selection of suitable working fluids for the ORC system was the hot issue, which had many reports to study this topic such as Hettiarachchi, Golubovica, Worek, & Ikegamib, 2007, pp. 1698-1706. studied the optimum design criteria for an Organic

Rankine Cycle using low-temperature geothermal heat sources. Schuster, Karellas, & Karl, 2005 simulated an innovative stand-alone solar desalination system with an Organic Rankine Cycle. Guo, Wang, & Zhang, 2011, pp. 2639-2649. evaluated the parameters optimization for a novel cogeneration system driven by low-temperature geothermal sources. Sauret, & Rowlands, 2011, pp. 4460-4467. represented candidate radial-inflow turbines and high-density working fluids for geothermal power systems. Liu, Riviore, Coquelet, Gicquel, & David, 2012, pp. 285-294. investigated a two stage Rankine cycle for electric power plants. Edrisi, & Michaelides, 2013, pp. 389-394. presented the effect of the working fluid on the optimum work of binary-flashing geothermal power plants. Li, Zhu, & Zhang, 2013, pp. 1132-1141. analyzed the series and parallel geothermal systems combined power, heat and oil recovery in oilfield. Rodriguez, et al., 2009. presented exergetic and economic comparison of ORC and Kalina cycle for low temperature heat. From the above studies, it was found that the suitable working fluid of those results were different because the system conditions of each study were different. But the most suitable working fluid of those studies introduced R-134a and R-245fa.

In addition, the ORC system was integrated with a solar water heating system. Thawonngamyingsakul, & Kiatsiriroat, 2012. studied the performance and analyzed a solar water heating system of flat-plate and evacuated-tube solar collector types to generate and supply heat to ORC in the northern part of Thailand. It was found that the values of levelized electricity costs (LEC) from flat-plate and evacuated-tube solar collectors were 0.939 and 0.747 USD/kWh, respectively. Ketjoy, & Rakwichian, 2006. reported the cost of energy at 0.781 USD/kWh of solar parabolic technology and biomass hybrid for power generation by using the ORC technique in Thailand. There were some reports on the ORC with different heat source such as waste heat (Hung, 2001, pp. 539-553), solar thermal (Jing, Gang, & Jie, 2010, pp. 3355-3365), biomass (Drescher, & Bruggemann, 2007, pp. 223-228) and etc.

The main objective of this research is to study the possibility of power generation by using alternative energies in Thailand, which are geothermal energy, solar energy and waste energy based on the energy, environment and economic indicators.

It could be noted that based on the abovementioned literature review, there was no sufficient knowledge for this topics in the recent literatures.

System Descriptions, Materials and Methods

Organic Rankine Cycle System

Figure 1 shows a schematic diagram of the ORC cycle. The main components of the ORC system are boiler, turbine, generator, condenser and pump. In the conventional ORC, high temperature heat is absorbed at the boiler at temperature around 80-120 °C. After that the working fluid at the high pressure and temperature enters to the turbine for producing the electricity at the generator. Next, the working fluid at the low pressure is condensed at the condenser at temperature of cooling fluid around 25-35 °C. The working fluid in liquid phase is pumped to the boiler and the new cycle is started again.

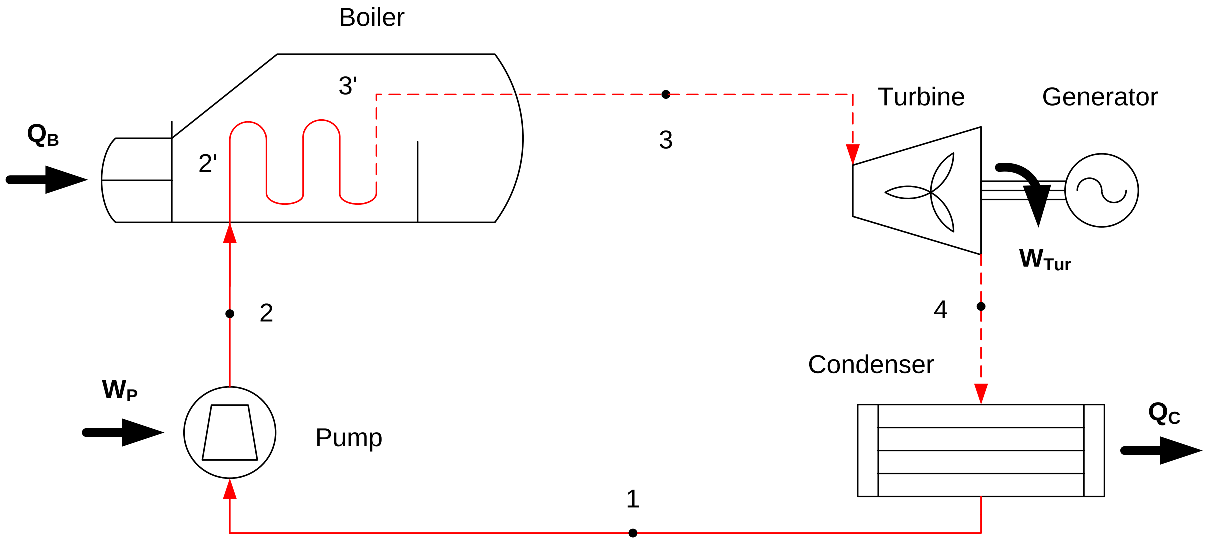

Figure 1 Schematic of Organic Rankine Cycle (Chaiyat, 2013, p. 344).

In this study, a 20 kW ORC system as shown in Figure 2 will be tested and carried out the thermal performance. Working fluid of the ORC system is R-245fa. Table 1 shows the descriptions of the ORC components and the experimental implement. In the experimental process, diesel and liquefied petroleum gas (LPG) burners will be used to heat hot water at temperature between 80-120 °C. The testing result of the ORC system will be used to consider the potential of each alternative energy.

Figure 2 The ORC Prototype with using R-245fa as working fluid

Table 1 The description of elements operating with the ORC system

Components	Data
20 kW_e ORC	• Hanbell model: RC2-300 • Gross power: 20 kW_e, Net power: 16 kW_e, 3 Phase, 380 V, 50 Hz • Refrigerant: R245fa • Expander: semi-hermetic twin screw type expander, displacement volume 3,000 rpm • Evaporator: SUS 316 plate type heat exchanger • Condenser: shell and tube heat exchanger, shell: carbon steel 12 in x 3 m, tube: 3/4 in copper tube • Oil separator: vertical type oil separator with oil tank 18 in diameter 0.7 m • Oil pump: Viking heavy duty oil pump GG4195, motor: 3 hp, 3 phase, 380 V, 50Hz • Liquid pump: Vertical multi-stage centrifugal pump VFD drive, model: BN3-17, motor: 2 hp, 3 phase, 380 V, 50 Hz
Hot water pump/ Cooling pump	• Ebora model CMB/E 3 T • Electrical consumption 2.2 kW_e • Flow rate 100-280 L/m
Cooling tower	• Model BKC 80 RT • Electrical consumption of fan motor 1.12 kW_e (1.5 hp)

Geothermal Resources

In 2012, Department of Mineral Resources ("Geothermal", Department of Mineral Resources) reported 112 hot springs in Thailand, which almost of them are found in the northern area of the country. The potential of hot springs in Thailand are classified them into three groups as high (higher than 80 °C), moderate (between 60-80 °C) and low (lower than 60 °C) potentials (Chiang Mai University, 2008).

In this study, high potential hot springs will be chosen to analyze the geothermal reservoir potential. Moreover, the reservoir potential of hot spring will be evaluated by the geochemistry. Thus 6 geothermal resources as shown in Table 2 are investigated the reservoir geothermal potential by the drilling technique.

Figure 3 shows a schematic diagram of geothermal energy from the drilling hole combined with the ORC system. Hot spring from the drilling hole (point 1HP) enters to glasgate type of plate heat exchanger by the natural force for transferring heat to clean water (point 3g). After that hot spring is sent to other processes (point 2HP) such as drying room, absorption system and etc. Clean water is upgraded to high temperature level (point 1g) at higher than 100 °C and sent to the ORC system (point 2g) by hot water pump.

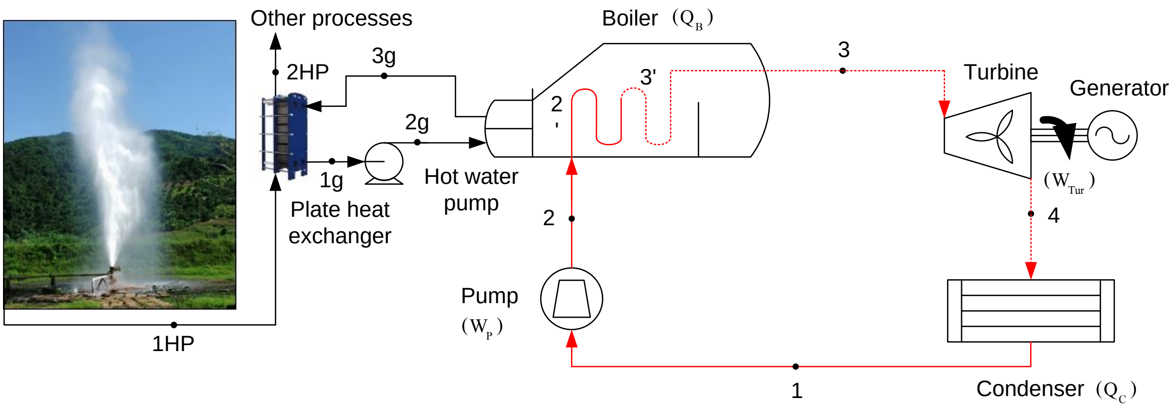

Figure 3 Schematic diagram of the geothermal-ORC system

Table 2 The geochemistry properties of hot spring resources

Hot Springs	Temperature[1] (°C)	Flow rate[2] (L/s)	SiO_2 (ppm)	Na (ppm)	K (ppm)	Ca (ppm)
Mae Chan	93.0	5.56[3]	149.0	121.2	7.2	1.3
San Kamphaeng	88.5	5.56[3]	120.0	80.9	7.9	2.4
Fang	98.1	1.56	110.0	81.7	4.4	1.7
Pong Duet	95.0	5.56[3]	110.0	164.1	18.8	20.3
Tep Phra Nom	98.9	1.65	108.3	134.9	24.7	42.1
Mueang Paeng	96.0	5.56[3]	80.5	70.4	2.8	8.7

Remarks: [1] Surface hot spring temperature [2] Surface hot spring flow rate

[3] Hot spring flow cannot measure, thus, assumed at around 20 m^3/h

Solar Water Heating System

Figure 4 shows a schematic sketch of solar-Organic Rankine Cycle, which is a solar water heating system combined with the ORC system. Solar heat is absorbed by solar collector and transfers heat to water (points 1s-2s). After that hot water is pumped to hot water tank (point 3s) and accumulate heat until water temperature in tank higher than a useful temperature. The useful water (point 4s) is supplied to the ORC system (around 80-120 °C) through hot water pump (point 5s). Hot water is dropped down temperature and sent back to hot water tank (point 6s).

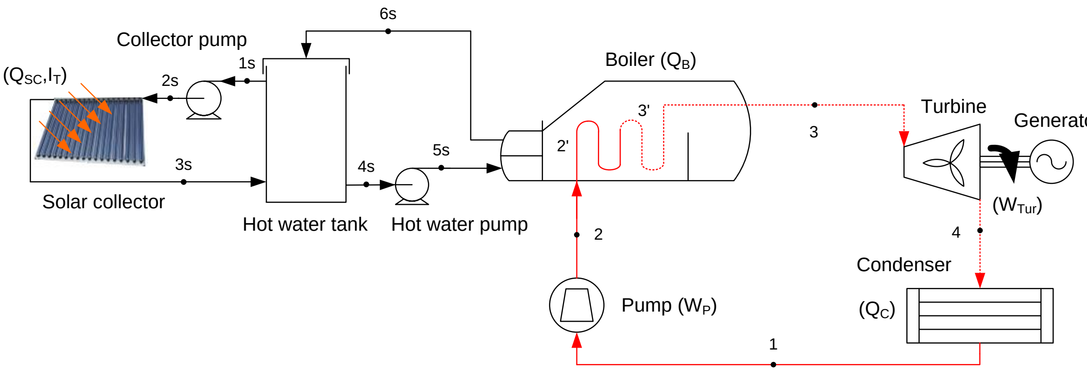

Figure 4 Schematic diagram of the solar-ORC system

Compound parabolic solar collector (CPC) is one type of solar collector, which is selected in this study for generating high temperature heat at around 90-120 °C. The CPC-solar water heating system will be used to evaluate the optimum conditions combining with the 20 kW_e ORC system. The working conditions for the evaluation are as follows:

1. The solar radiations (I_T) and the weather data of Chiang Mai, Thailand ("RETScreen", n.d.; "The ambient", n.d.) are taken as the input information, which is shown in Table 3.

2. Supplied water flow rate ($\dot{m}_{SC}$) to solar collector refers from the testing data of 20 kW_e ORC system.

3. Water temperature difference between inlet and outlet of the ORC system refers from the testing data of 20 kW_e ORC system.

4. $F_R(\tau\alpha)$ and F_RU_L of the compound parabolic solar collector are constants at 0.642 and 0.885 $W/m^2{\cdot}K$, respectively, at 2.41 m^2/unit ("CPC", n.d.), respectively.

5. The set point temperature for using water in hot water tank is 100 °C.

6. Water storage tank is 15,000 liter.

7. Water as working fluid of solar water heating system is assumed to be saturated liquid.

8. Thermodynamic properties of water are based upon REFPROP (National Institute of Standards and Technology, Inc., 2013).

9. Steps for calculating hot water temperature of solar water heating system (Chaiyat, & Kiatsiriroat, 2014, pp. 166-174) are stated in Figure 5.

10. Solar collector each unit is the parallel connection.

Table 3 The average solar radiation of Chiang Mai, Thailand ("RETScreen", n.d.; "The ambient", n.d.)

Month	Jan	Feb	Mar	Apr	May	Jun
I_T ($MJ/m^2{\cdot}d$)	17.82	20.34	21.71	22.36	19.69	16.88
Month	Jul	Aug	Sep	Oct	Nov	Dec
I_T ($MJ/m^2{\cdot}d$)	15.66	15.23	15.77	15.73	15.84	16.45

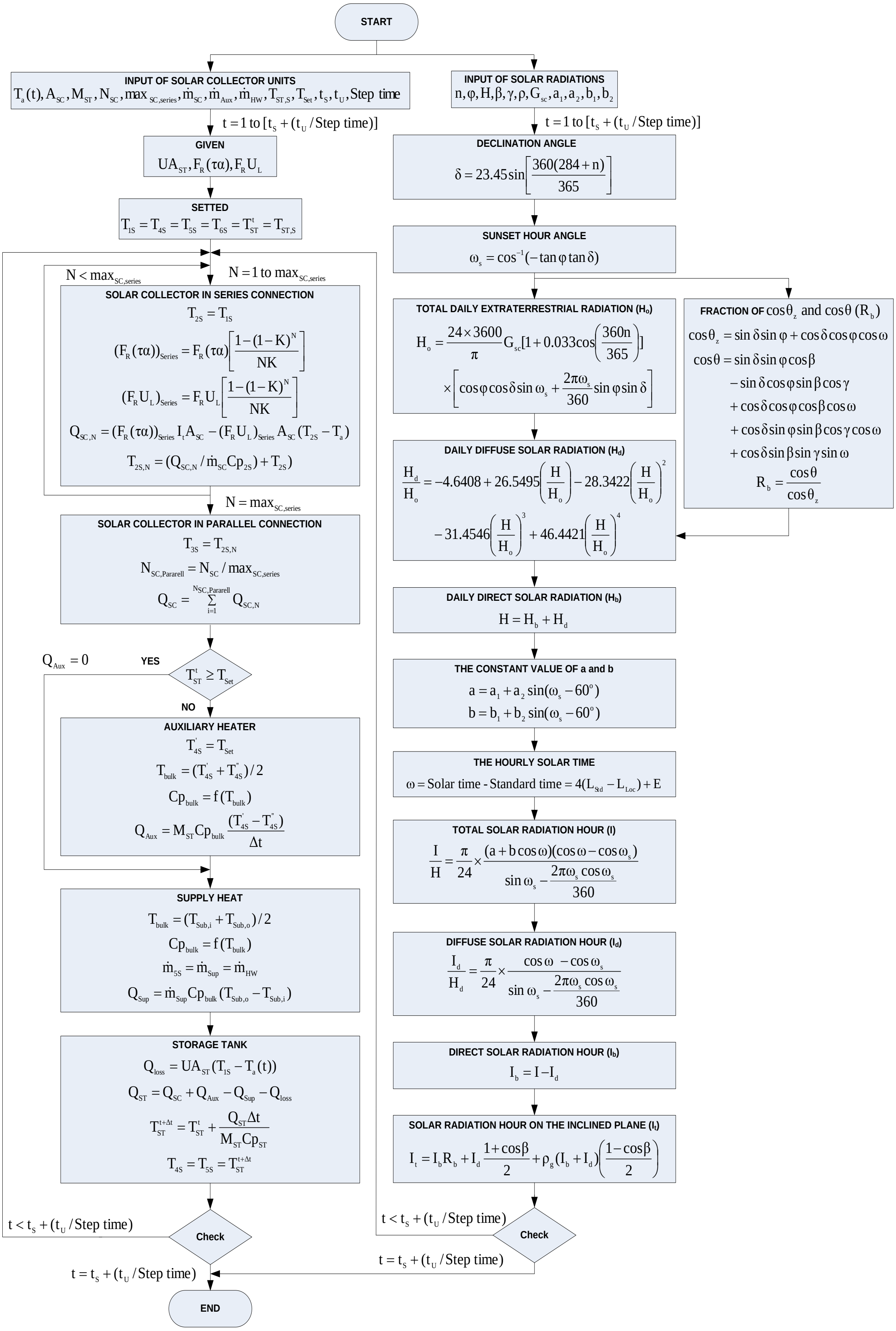

Figure 5 Calculation steps for evaluating performance of the solar water heating system (Chaiyat, & Kiatsiriroat, 2014, pp. 166-174)

Waste Energy

Waste management is hot issue in Thailand. Waste energy is a new solution to reduce the waste pollution in the society. The majority of waste consists of household waste, agriculture waste, industrial waste, bio medical waste and etc. One of the best solution for waste management is converting to Refuse Derived Fuel (RDF). The waste fuel is used in heating process as shown a schematic diagram in Figure 6. RDF is obtained to furnace for burning the waste fuel. After that hot gas flows to heat exchanger area, which clean water (point 3g) is pumped to receive heat and sent to the ORC system (points 1g-2g).

In this study, the fuel data of RDF-5 is based on the study result of Chiang Mai University (Chiang Mai University, 2014) as shown in Table 4. The possibility to generate electricity from using RDF-5 with the 20 kW_e ORC system will be analyzed.

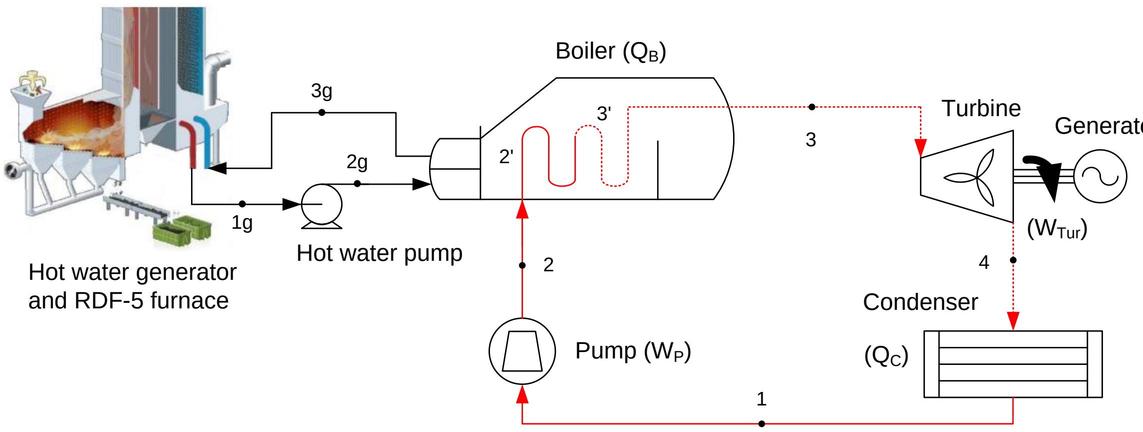

Figure 6 Schematic diagram of the RDF-5 ORC system

Table 4 The RDF-5 properties (Chiang Mai University, 2014)

Properties	Data
Heating Value (MJ/kg)	27.57
Composition	Leaf : Paper : Plastic (1:1:1)
Combiner (% by mass of RDF)	Lime 20% by mass
Electrical power consumption (kWh/kg)	0.39
Operating cost (USD/kg of RDF)	0.168

Results and Discussion

Efficiency of R-145fa ORC Technology

From the testing results, the 20 kW_e ORC system with using R-245fa as working fluid was tested and measured in laboratory. Hot water temperature varying 85-120 °C was supplied to the ORC system at the boiler. While, cool water temperature around 28-32 °C was pumped to the condenser. The thermal performance of ORC was evaluated by 5 conditions of heat source temperature as shown in Table 5. It could be found that the system efficiency of R-245fa ORC system was lower than 5%, when hot water temperature was lower than 90 °C. While, efficiency could be increased to be around 8%, when hot water temperature was higher than 100 °C. This testing results corresponded with the above literature reviews, which the almost ORC efficiency was around 8-12%. Moreover, it could be noted that when hot water temperature entering the boiler increased, the ORC efficiency increased linearly too, which followed the Carnot efficiency concept.

Figure 7 also shows the volume of R-245fa entering turbine. It could be seen that if the amount of volume was high, the ORC efficiency was low. From the testing results, it could be observed that the volume of R-245fa was nearly constants, when the high temperature heat source (higher than 100 °C) was supplied. Thus, the suitable heat source temperature for supplying the R-245fa ORC system was around 100 °C at the ORC efficiency around 8%, and these thermal performance was used to evaluate the alternative energy potential for generating electricity in Thailand in the next part.

Table 5 The average testing data of 20 kW_e ORC system with using R-245fa as refrigerant

Descriptions	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Unit
Boiler						
Hot water inlet	116	107.8	97	88.9	87.8	°C
Heat source capacity	243.2	248.2	203.4	188.3	208.9	kW
Condenser						
Cool water inlet	28	28	28	30.1	31.2	°C
Heat sink capacity	219.0	215.6	210.9	211.0	211.0	kW
Turbine						
Turbine inlet pressure	1,097.1	1,120.0	1,074.0	811.3	836.3	kPa-Abs
Turbine outlet pressure	227.4	227.4	227.0	239.3	256.3	kPa-Abs
Turbine inlet temperature	93.7	94.6	92.8	85.7	79.7	°C
Working Fluid Pump						
Pumping power	1.78	1.90	1.19	1.24	1.26	kW_e
Mass flow rate of refrigerant	0.938	1.008	1.016	0.752	0.863	kg/s
Efficiency						
Gross power	21.50	21.36	16.70	9.00	9.10	kW_e
System efficiency	8.73	8.49	8.11	4.71	4.30	%

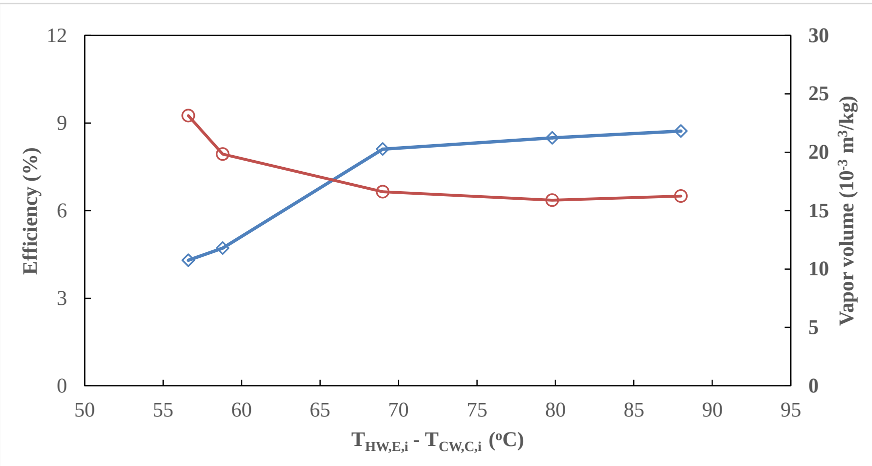

Figure 7 Thermal performance of the ORC system

Energy Potential of Geothermal Energy

From Table 2, the geochemistry of 6 hot springs is used to find out the reservoir temperature of each geothermal resource. Equation of quartz maximum steam loss is selected, because of the precision to predict the geothermal reservoir temperature under the geochemistry of Thailand (Chiang Mai University, 2008). From simulation results, it could be found that the reservoir temperature of those hot springs are higher than the surface hot spring around 30 °C as shown in Table 6. Thus it could be concluded that the geothermal power plant by using the R-245fa ORC technique could operate under the geochemistry of Thailand.

Table 6 also shows the rate of electricity from the reservoir potential. It could found that if 6 geothermal resources are developed to generate electricity, the aim of the ministry of energy, Thailand as producing electricity from geothermal energy at 1 MW in 2021 is possible (Energy Policy and Planning Office, 2010).

Table 6 Geothermal resources with electricity generating potential from the reservoir data

Hot Springs	Temperature[1] (°C)	Flow rate[2] (L/s)	Potential[3] (kW_e)	Potential[4] (MWh/y)
Mae Chan	152.37	41.67	348	2,926
San Kamphaeng	141.47	41.67	348	2,926
Fang	137.25	11.70	98	822
Pong Duet	137.25	41.67	348	2,926
Tep Phra Nom	136.50	12.38	103	869
Mueang Paeng	122.77	41.67	348	2,926

Remarks: [1] Reservoir temperature of Quartz (Maximum steam loss) from equation $T_{GS} = (1{,}522/[5.75-\log(SiO_2)])-273.15$

[2] Flow rate from proposed well, based on 10 times of natural flow, and 75% of the maximum rate (Electricity Generating Authority of Thailand, 1988)

[3] Potential calculated from $W_e = \eta_{ORC}\dot{m}_{HS}Cp_{bulk,HS}\Delta T_{HS}$, η_{ORC} was the efficiency of ORC system around 8%, $Cp_{bulk,HS}$ was specific heat capacity which equal to 4.18 kJ/kg·K, ΔT_{HS} was temperature difference of hot water in and out of the ORC system which approximately equal to 25 °C (ΔT_{HS}, from testing data of the ORC) and density of hot spring assumed 1,000 kg/m^3

[4] Based on operation time of 24 h/d and 350 d/y (Electricity Generating Authority of Thailand, 1988)

In the comparative of electricity price of each alternative energy, the same size of ORC system at 20 kW_e is used as the reference parameter. Economic evaluation is conducted to find out electricity price from alternative energy and the value of electricity costs (EC) is selected to present in this study. The electricity price of renewable power in Thailand is calculated by using payback period at 10 y (Tongsopit, & Greacen, 2012). Thus, the values of each alternative EC are determined at payback period 10 y. The initial conditions of economic evaluation are as follows:

1. The capacity of ORC system is 20 kW_e.
2. Payback period of renewable project is 10 y.
3. Costs of well-drilling (1 km depth) is around 46,000 USD per power plant (Pers. comm, Ormat Technologies, Inc., 2013).
4. Capital cost of ORC system is 4,000 USD/kW_e based on system world price (Industrial Technology Research Institute, 2012).

5. Land of power plant is 6,400 m^2.

6. Land price is 9.57 USD/m^2 based on land price of Chiang Mai province, Thailand (Department of Lands, 2015).

Table 7 shows the EC of geothermal power plant by calculating at payback period 10 y. It could be seen that the suitable EC of geothermal power plant is 0.166 USD/kWh. This result is nearly electricity cost of Indonesia, which is Feed-in-Tariff (FiT) at around 0.1-0.17 USD/kWh (Indonesia raises geothermal feed-in-tariff, n.d.).

Table 7 Economic analysis of the geothermal-ORC system

Properties	Data
ORC pricing (USD)	80,000
Cost of well-drilling at 1 km (USD)	45,916
Land price (USD)	61,222
Cost of building and piping system (USD)	61,222
Project investment[1] (USD)	248,360
The electrical power of hot water pump (kWh/y)	18,480
ORC net electrical power[2] (kWh/y)	168,000
Station net electrical power (kWh/y)	149,520
EC of geothermal energy (USD/kWh)	0.166

Remark: [1] Project investment = cost of ORC system + cost of well-drilling + land price + plant building and piping system
[2] Based on operation time of 24 h/d and 350 d/y (Electricity Generating Authority of Thailand, 1988)

Energy Potential of Solar Energy

The solar radiation (I_T) and the ambient temperature (T_{amb}) of Chiang Mai in August, the lowest month as shown in Table 3, are selected for the calculation. From simulation results, it could be noted that when the solar radiation is higher than 500 W/m^2 at after 9 a.m. of the second day, hot water temperature (T_{HW}) from the solar water heating system is higher than 100 ^oC. The minimum number of solar collectors for supplying heat to the ORC is found to be 143 units. The system could be operated continuously about 8 h/d as shown in Fig. 7. The solar heater supplies heat about 200 kW at the boiler of ORC.

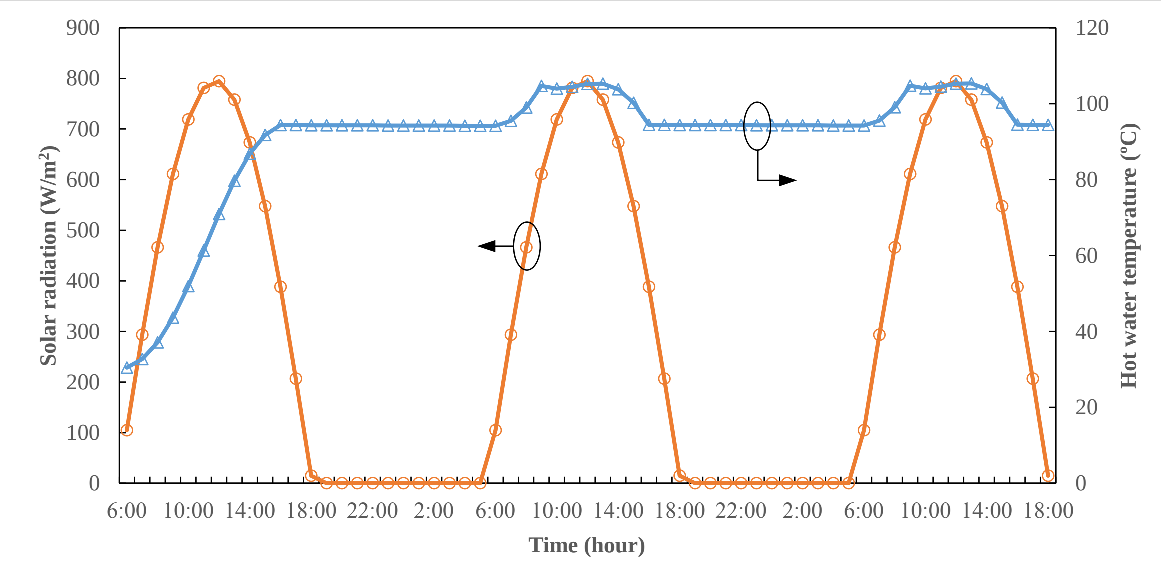

Figure 8 Hot water temperatures at 143 units of compound parabolic solar collectors during time of the average day of August

In economic results, the solar-ORC performance is performed with payback period at 10 y. Table 8 shows the cost descriptions of solar power plant. It could be found that the EC of the solar-ORC system is higher than the geothermal-ORC system, which is 0.747 USD/kWh. This result is nearly with Thawonngamyingsakul, & Kiatsiriroat, 2012. at around 0.7 USD/kWh for using evacuated-tube solar collector combined with the ORC system.

Table 8 Economic analysis of the solar-ORC system

Properties	Data
Type of solar collectors	Compound parabolic collector
ORC pricing (USD)	80,000
Land price (USD)	61,222
Cost of solar collector (950 USD/unit) (“CPC”, n.d.) (USD)	135,850
Cost of building, storage tank and piping system (25% of solar collector cost) (USD)	33,963
Project investment[1] (USD)	292,377
Number of collector pump[2] (unit)	3
The electrical power of collector pump (kWh/y)	19,272
Net ORC electrical power[3] (kWh/y)	58,000
Station net electrical power (kWh/y)	39,128
EC of solar energy (USD/kWh)	0.747

Remark: [1] Project investment = cost of ORC system + cost of solar collector + land price + plant building, storage tank and piping system

[2] Water mass flow rate at 0.02 kg/s for collector area 1 m^2 (Chaiyat, & Kiatsiriroat, 2014, pp. 166-174)

[3] Based on operation time of 8 h/d and 365 d/y

Energy Potential of Waste Energy

From the study result of Chiang Mai University (Chiang Mai University, 2014), the RDF-5 property is used to carry out the EC of waste energy. From simulation results, it could be found that the ORC system required heat from burning process of RDF-5 is around 32.64 kg/h. The EC of the RDF-5 ORC system is higher than geothermal energy and lower than solar energy, which is 1.037 USD/kWh as shown in Table 9. In additional, the electrical power consumption of RDF-5 production process is the disadvantageous point of this technique.

Table 9 Economic analysis of the RDF-5 ORC system

Properties	Data
Heat source from RDF-5 (kW)	200
Hot water generator efficiency	80%
Heating value of RDF-5 (MJ/kg) (Chiang Mai University, 2014)	27.57
Time for burning of RDF-5 (h/kg)	1
The among of RDF-5 (kg/h)	32.64
Cost of RDF-5 (USD/y)	39,975
ORC pricing (USD)	80,000
Land price (USD)	61,222
Cost of building, hot water generator and piping system (USD)	30,611
Project investment[1] (USD)	242,419
The electrical power of hot water pump (kWh/y)	7,700
The electrical power production of RDF-5 (kWh/y)	46,469
ORC net electrical power[2] (kWh/y)	73,000
Station net electrical power (kWh/y)	18,831
EC of waste energy (USD/kWh)	1.037

Remark: [1] Project investment = cost of ORC system + cost of RDF-5 + land price + plant building, hot water generator and piping system

[2] Based on operation time of 10 h/d and 365 d/y

Environmental Assessment

Environmental assessment in this study presents the amount of carbon dioxide intensity from electrical power consumption of each production process. The specifications of each element including of collector pump, hot water pump, cooling pump, RDF-5 production process, cooling tower and refrigerant pump are used to evaluate the environment impact combined with a carbon dioxide intensity of electricity of Asia ("Carbon dioxide intensities of fuels and electricity for regions and countries", n.d.). It could be seen that the carbon dioxide intensity from production process of geothermal energy, solar energy and waste energy are 27,762 kg CO_2/y, 21,030 kg CO_2/y and 44,815 kg CO_2/y, respectively, as shown in Table 10.

Table 10 also shows the carbon dioxide intensity per net electricity output of each power plant. It could be found that geothermal power plant is 0.186 kg CO_2/kWh, while solar and waste power plants are 0.537 kg CO_2/kWh and 2.380 kg CO_2/kWh, respectively. Environmental impact in term of CO_2 of solar and waste power plant are 2.89 times and 12.67 times, respectively, compared with geothermal power plant based on electricity 1 kWh.

Table 10 Electrical power consumptions of each energy for the ORC power plant

Descriptions	Solar	Geothermal	RDF-5
Power of heating process	Collector pump 3 units at 2.2 kW_e/unit (Ebora model CMB/E 3 T, Flow rate 100-280 L/min)	Hot water pump at 2.2 kW_e (Ebora model CMB/E 3 T, Flow rate 100-280 L/min)	- Hot water pump at 2.2 kW_e (Ebora model CMB/E 3 T, Flow rate 100-280 L/min) - Drying and ozone systems 0.0004 kWh/kg RDF-5 - Plastic cutting process 0.14 kWh/kg RDF-5 - Paper cutting process 0.06 kWh/kg RDF-5 - Leaf cutting process 0.02 kWh/kg RDF-5 - Mixer process 0.04 kWh/kg RDF-5 - Fuel briquette process 0.14 kWh/kg RDF-5 (Chiang Mai University, 2014)
Electrical power consumption of the ORC machine	- Refrigerant pump at 1.9 kW_e (referred data in Table 5) - Hot water pump at 2.2 kW_e (referred data in Table 1) - Cooling pump at 2.2 kW_e (referred data in Table 1)		
Annual electricity power consumption (kWh/y)	34,514	45,563	73,552
Carbon dioxide intensity of electricity of Thailand (kg CO_2/kWh) ("Carbon", n.d.)		0.6093	
Carbon dioxide intensity of electricity production process (kg CO_2/y)	21,030	27,762	44,815
Carbon dioxide intensity per net electricity output (kg CO_2/kWh)	0.537	0.186	2.352

From the above results, it could be concluded that the geothermal power plant is beneficial than the solar and waste energy power plants in terms of energy, environment and economic results.

For the future study, the maximum potentials of each geothermal resource should be studied. From Table 6, it could be observed that the total capacity of 6 geothermal power plants is around 3 MW_e, which corresponds the framework of the country's energy policy to develop geothermal energy to be 1 MW_e in 2021. Moreover, Feed in Tariff (FiT) or Feed in Premium (FiP or Adder) should be focused for geothermal power plant and the new alternative energy in Thailand.

Conclusions

The 20 kW_e ORC system with using R-245fa as working fluid was tested the thermal performance for using to find out economic and environment results. From experimental results, it could be found that the ORC efficiency was around 8%, when hot water temperature was higher than 100 °C. From simulation results, the values of electricity costs (EC) of geothermal energy, solar energy and waste energy are 0.166, 0.747 and 1.037 USD/kWh, respectively. For environmental impact, the carbon dioxide intensity per net electricity output of geothermal, solar and waste power plants are 0.186, 0.537 and 2.380 kg CO_2/kWh, respectively. From the above results, it could be concluded that the suitable alternative energy for generating electricity is geothermal energy. Free operating cost is the advantage point of the geothermal energy. For the future study, the maximum potentials of each geothermal resource should be studied to support the framework of the country's energy policy at 1 MW_e in 2021. Moreover, Feed-in-Tariff (FiT) or Feed-in-Premium (FiP or Adder) should be focused for geothermal power plant in Thailand.

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Nomenclature and Symbol

Nomenclature

A	area, (m^2)
Cp	heat capacity, (kJ/kg·K)
F_R	collector heat removal factor
I_T	solar radiation, (W/m^2)
M	mass, (kg)
$\dot{m}$	mass flow rate, (kg/s)
n	number of day
N	number of solar collector, (Unit)
Q	heat rate, (kW)
SiO_2	concentrate of quartz (ppm)
t	time, (s)
T	temperature, ($^{\circ}C$)
U	overall heat transfer coefficient, ($W/m^2 \cdot K$)
U_L	collector overall heat loss coefficient, (W/m^2)
v	specific volume, (m^3/kg)
W	work, (kW_e)

Greek symbol

τ	transmission coefficient of glazing
α	absorption coefficient of plate
η	efficiency, (%)
ρ	density, (kg/m^3)

Subscript

a	ambient
Aux	auxiliary
B	boiler
bulk	bulk temperature
C	condenser
Coll	solar collector
e	Electrical power
HP	hot spring
HS	heat source
HW	hot water
i	inlet
o	outlet
P	pump
S	start
SC	solar collector
Set	setting
SP	solution pump
ST	storage tank
Sup	supply
Tur	turbine
U	using
UF	useful

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