Assessment 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 and economy 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 ORC system with using R-245fa as working fluid was tested and evaluated the system efficiency. It could be found that the efficiency of ORC system was around 8%, when hot water temperature was higher than 100 ºC. The values of levelized electricity costs (LEC) of geothermal energy, solar energy and waste energy were 0.148, 0.547 and 0.442 USD/kWh, respectively. The suitable alternative energy for generating electricity was the geothermal energy which was beneficial than the solar and waste energy power plants in terms of energy and economy results.

Keyword-Organic Rankine Cycle, Geothermal Energy, Solar Energy, Waste Energy, Levelized Electricity Cost

I. INTRODUCTION

Thailand relies on imported energy, of which the volume has grown continuously. In 2011, the energy imports increased 30.2% compared in 2010 [1]. 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 and Chaichana [2] reported the technology to generate electricity of binary system and thermoelectric module. Combs et al. [3] studied the small geothermal power plant in America and Japan at capacity around 100-1,000 kW. 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 which was similarly Brophy [4] Kose [5] and Dagdas [6]. 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 et al. [7] Schuster et al. [8] Guo [9] Sauret et al. [10] Liu et al. [11] Edrisi et al. [12] Li et al. [13] and Rodriguez et al. [14]. 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 and Kiatsiriroat [15] 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 and Rakwichian [16] 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 [17], solar thermal [18,19], biomass [20] and etc.

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

II. MATERIALS AND METHODS

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A. *Efficiency of ORC Technology*

Fig. 1 shows the main components of the ORC system which are boiler, turbine, generator, condenser and pump. In the conventional ORC, high temperature heat is absorbed at the boiler at temperature around 90-120 °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 20-35 °C. The working fluid in liquid phase is pumped to the boiler and the new cycle is started again.

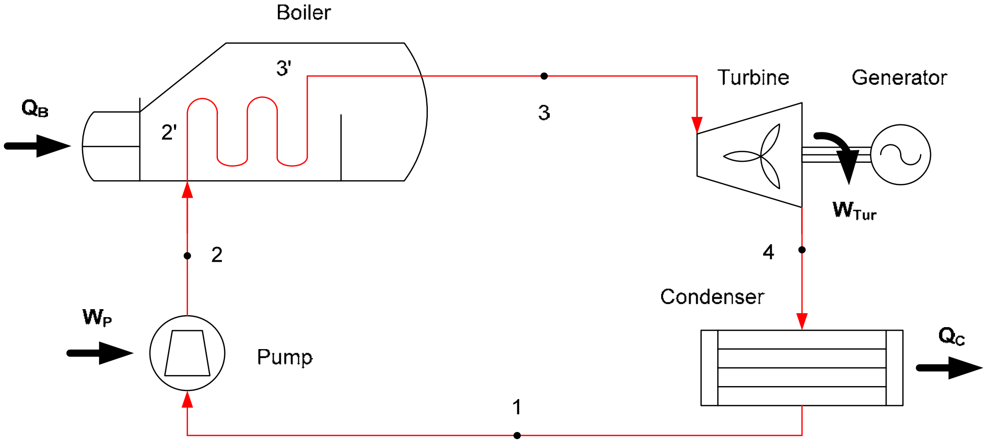

Fig. 1. Schematic of Organic Rankine Cycle.

In this study, a 20 kW Organic Rankine Cycle (ORC) system as shown in Fig. 2 was tested and carried out the thermal performance. The ORC system had R-245fa as working fluid. The testing data of the ORC system was considered with the potential of each alternative energy.

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

B. *Geothermal Resources*

In 2012, Department of Mineral Resources [21] reported 112 hot springs in Thailand which almost of them were found in the northern area of the country. The potential of hot springs in Thailand were classified them into three groups as high, moderate and low potential [22]. For high potential hot spring, the surface water temperature was higher than 80 ˚C. Moderate and low potential hot springs referred the surface water temperature between 60-80 ˚C and lower than 60 ˚C, respectively.

In this study, high potential hot springs were chosen to analyze the geothermal reservoir potential. Moreover, the reservoir potential of hot spring was evaluated by the geochemistry. The results stated that 6 geothermal resources were capable to generate the electricity as shown in Table 1.

Table 1. The geochemistry properties of hot spring resources.

Hot Springs	Temperature[1]	Flow rate[2]	SiO_2	Na	K	Ca
	(°C)	(L/s)	(ppm)	(ppm)	(ppm)	(ppm)
Mae Chan	93	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	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	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

C. Solar Water Heating System

Fig. 3 shows a schematic sketch of solar-Organic Rankine Cycle which is a solar water heating system combined with the ORC system. Solar heat is supplied to the boiler at a high temperature (around 80-120 °C) and rejected a low temperature heat (around 35-45 °C) at the condenser.

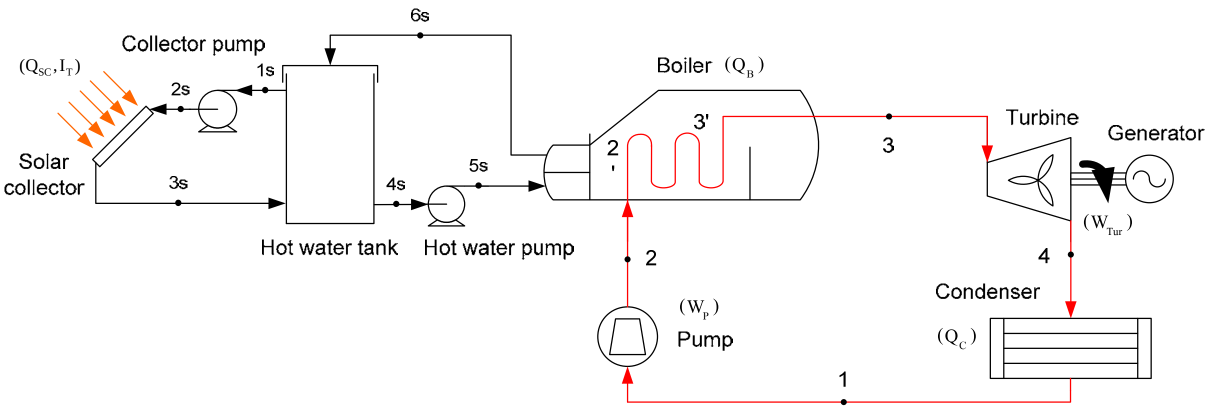

Fig. 3. Schematic diagram of the solar-ORC system.

Solar water heating system transfers solar heat to be hot water and accumulates heat in storage tank at a high temperature level. Compound parabolic solar collector (CPC) is a one type of solar collector which is used to generate a high temperature heat at higher than 90 °C. Thus in this study, the CPC type was chosen to evaluate the optimum conditions, when it was combined with the 20 kW ORC system. The working conditions for the evaluation were as follows:

1. The solar radiations (IT) and the weather data of Chiang Mai, Thailand [23,24] were taken as the input information.
2. Supplied water flow rate $(\dot{m}_{SC})$ to solar collector came from the testing data of 20 kW ORC system.
3. Temperature difference between the entering and leaving supplied hot water of the ORC system came from testing data of 20 kW ORC system.
4. $F_R(\tau\alpha)$, F_RU_L and area of the compound parabolic solar collector were constants at 0.642, 0.885 W/m^2·K and 2.41 m^2/unit [25], respectively.
5. The temperature point for using hot water was 100 °C.
6. Water storage tank was 15,000 Liter.
7. Working fluid was assumed to be saturated liquid.
8. The properties of water based upon REFPROP [26].
9. The steps for calculating hot water temperature of the solar water heating system [27,28] was stated in Fig. 4.

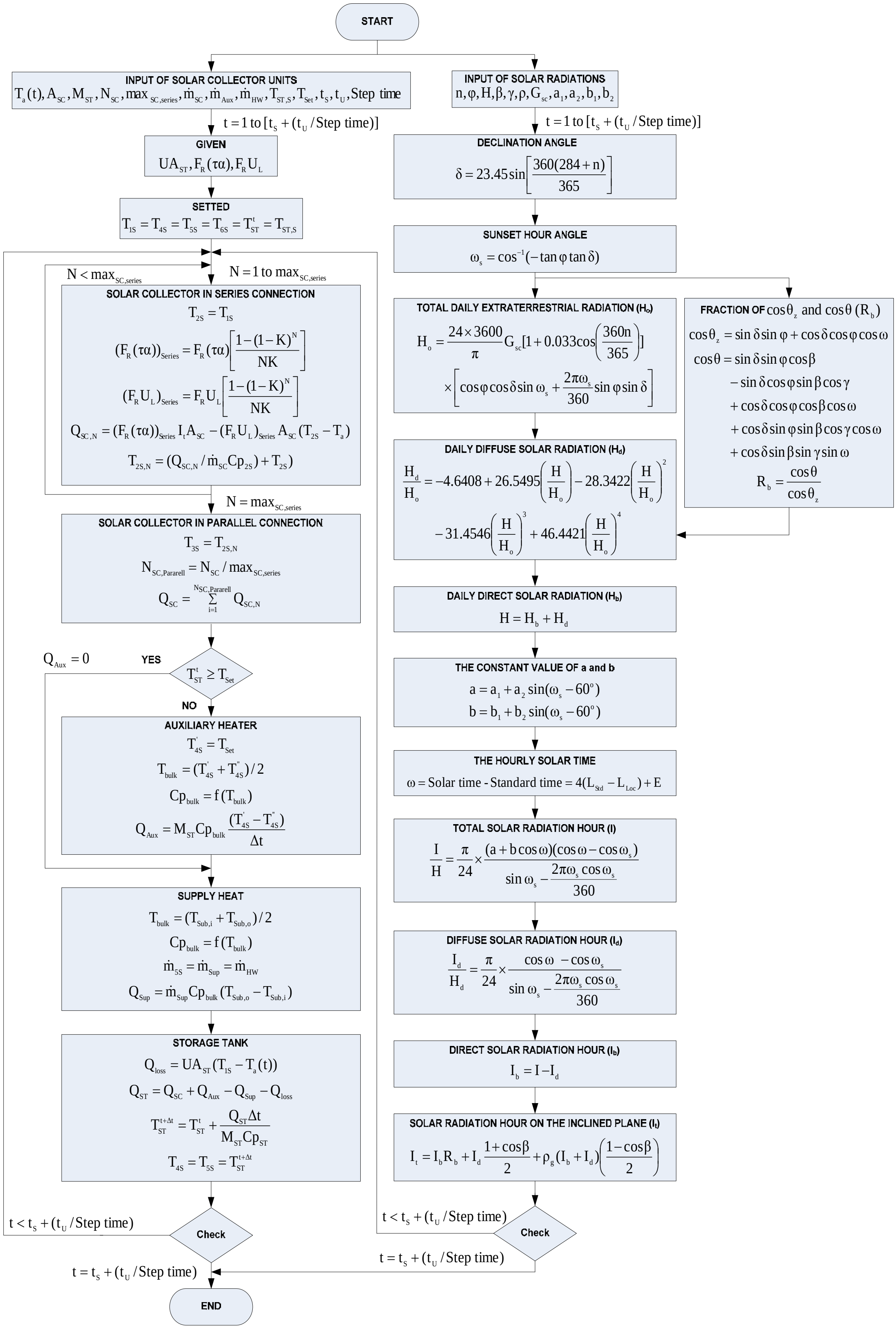

Fig. 4. Calculation steps for evaluating performance of the solar water heating system.

D. *Waste Energy*

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-5). The waste fuel is used in heating process as shown the schematic diagram in Fig. 5.

In this study, the fuel data of RDF-5 was based on the study result of Kiatsiriroat [29] as shown in Table 2. The possibility to generate electricity from using RDF-5 with the 20 kW ORC system were analyzed.

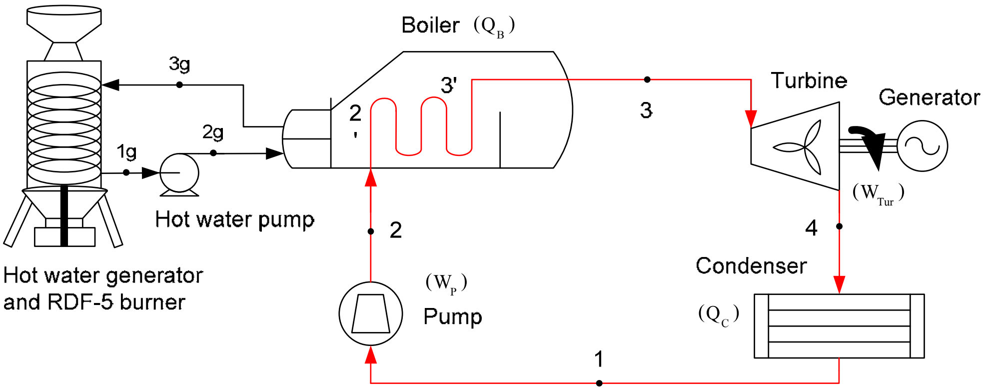

Fig. 5. Schematic diagram of the RDF-5 ORC system.

Table 2. The RDF-5 properties.

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

III. Results and Discussion

A. *Efficiency of ORC Technology*

From the testing results, the 20 kW ORC system with using R-245fa as working fluid was tested and measured in laboratory. Hot water temperature between of 90-120 °C was supplied to ORC system at the boiler. While, cool water temperature around 25-30 °C was pumped to the condenser. The thermal performance of ORC was evaluated by using 3 set point temperatures as shown in Table 3. It could be found that the system efficiency of R-245fa ORC system decreased to be around 6%, when hot water temperature was lower than 100 °C. While, efficiency could be increased to be around 8%, when hot water temperature was higher than 100 °C.

Table 3. The average testing data of 20 kW ORC system with using R-245fa as refrigerant.

Descriptions	Condition 1	Condition 2	Condition 3	Unit
Boiler				
Hot water inlet	116	107.8	97	°C
Heat source capacity	244.0	238.3	228.8	kW
Condenser				
Cool water inlet	28	28	28	°C
Heat sink capacity	219.0	215.6	210.9	kW
Turbine				
Turbine inlet pressure	1,097.1	1,120.0	1,074.0	kPa-Abs
Turbine outlet pressure	227.4	227.4	227.0	kPa-Abs
Turbine inlet temperature	93.7	94.6	92.8	
Working Fluid Pump				
Pumping power	1.78	1.90	1.19	kW_e

Descriptions	Condition 1	Condition 2	Condition 3	Unit
Mass flow rate of refrigerant	0.938	1.008	1.016	kg/s
Efficiency				
Gross power	21.50	21.36	16.70	kW_e
System efficiency	8.08	8.16	6.78	%

From the above results, it could be noted that the system efficiency of ORC system with using R-245fa as working fluid was around 8% for using hot water temperature over 100 °C. Thus, these thermal performance was used to evaluate the alternative energy potential for generating electricity in Thailand.

B. Energy Potential of Geothermal Energy

From Table 2, the geochemistry of 6 hot springs were used to find out the reservoir temperature of each geothermal resource. It could be found that the reservoir temperature of those hot springs were higher than surface hot spring around 30 °C as shown in Table 4.

Table 4 also shows the rate of electricity from the reservoir potential. It could found that if 6 geothermal resources were developed to generate electricity, the aim of the ministry of energy, Thailand as producing electricity from geothermal energy at 1 MW in 2021 was possible [1].

Table 4. Geothermal resources with electricity generating potential from the reservoir data.

Hot Springs	Temperature[1] (°C)	Flow rate[2] (L/s)	Potential[3] (kW)	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 [30]

[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 [30]

In the comparative of electricity price of each alternative energy, the same size of ORC system at 20 kW was used as the reference parameter. Economic evaluation was conducted to find out electricity price from alternative energy and the values of levelized electricity costs (LEC) was selected to present in this study. The electricity price of renewable power in Thailand was calculated by using payback period at 10 y [31]. Thus, payback period was determined in economic evaluation based on the initial conditions as follows:

1. The capacity of ORC system was 20 kW.
2. Payback period of renewable project was 10 y.
3. Costs of well-drilling (1 km depth) was around 46,000 USD per power plant [32].
4. Capital cost of ORC system was 4,000 USD/kW based on system world price [33].

Table 5 shows the LEC of geothermal power plant by calculating at payback period 10 y. It could be seen that the suitable LEC of geothermal power plant was 0.148 USD/kWh.

Table 5. Adder rate analysis of geothermal electricity using ORC system.

Properties	Data
ORC pricing (USD)	80,000
Cost of well-drilling at 1 km (USD) [32]	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 generation[2] (kWh/y)	168,000
LEC of geothermal energy (USD/kWh)	0.148

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 [30]

C. Energy Potential of Solar Energy

From the testing results of ORC system, the appropriate hot water temperature for generating electricity was around 100 °C. The solar radiation (I_T) and the ambient temperature (T_{amb}) of Chiang Mai in April, the hottest month, were selected for the calculation. It could be noted that when the solar radiation was higher than 600 W/m^2 at after 9 a.m. of the second day, hot water temperature (T_{HW}) from the solar water heating system was higher than 100 °C. The minimum number of solar collectors for supplying heat to the ORC was found to be 123 units. The system could be operated continuously about 8 h/d as shown in Fig. 6. The solar heater supplied heat about 200 kW at the boiler of ORC.

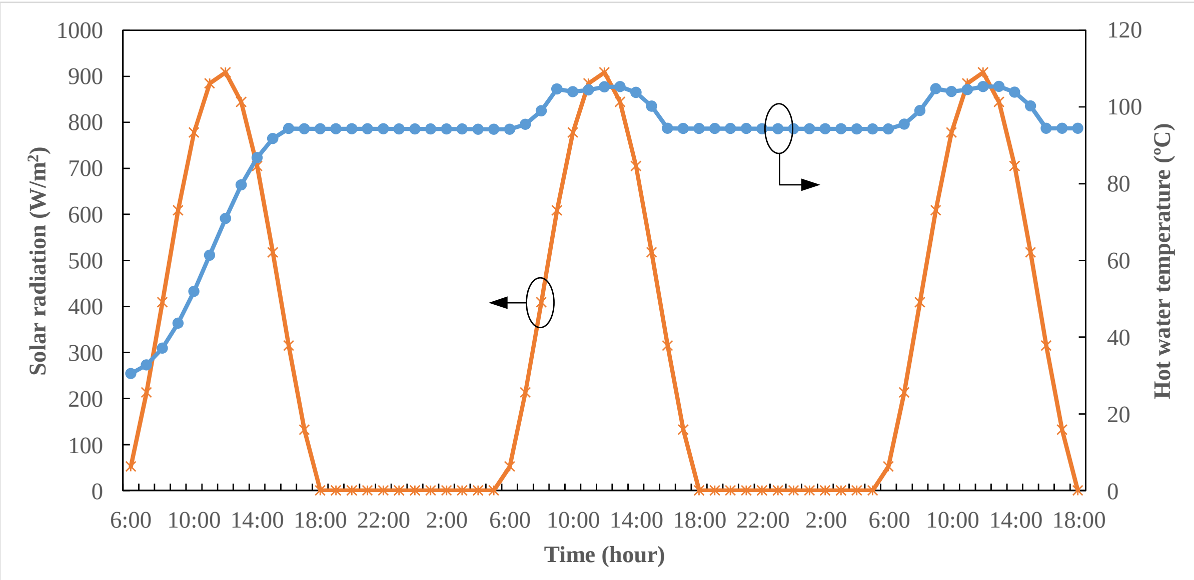

Fig. 6. Hot water temperatures at 123 units of compound parabolic solar collectors during time of the average day of April.

The solar energy analyses of the solar-ORC system was performed for economic analysis. Table 6 shows the cost descriptions of solar power plant. It could be found that the LEC of the solar-ORC system was higher than the geothermal-ORC system which was 0.547 USD/kWh.

Table 6 Descriptions of the solar-ORC system and costs.

Properties	Data
Type of solar collectors	Compound parabolic collector
ORC pricing (USD)	80,000
Land price (USD)	61,222
Cost of building, storage tank and piping system (USD)	61,222
Cost of solar collector (950 USD/unit) [25] (USD)	116,850
Project investment[1] (USD)	319,294
The electrical power generation[2] (kWh/y)	58,000
LEC of solar energy (USD/kWh)	0.547

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

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

D. Energy Potential of Waste Energy

From the study result of Kiatsiriroat [29], the RDF-5 property was used to carry out the LEC of waste energy. It could be found that the ORC system required heat from burning process of RDF-5 was around 65.29 kg/h. The LEC of the RDF-5 ORC system was higher than geothermal energy and lower than solar energy which was 0.442 USD/kWh.

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

Table 7 Descriptions of the RDF-5 ORC system and costs.

Properties	Data
Heat source from RDF-5 (kW)	200
Hot water generator efficiency	80%
Heating value of RDF-5 (MJ/kg) [29]	27.57
Time for burning of RDF-5 (h/kg)	2
The among of RDF-5 (kg/h)	65.29
Cost of RDF-5 (USD/y)	119,977
ORC pricing (USD)	80,000
Land price (USD)	61,222
Cost of building, hot water generator and piping system (USD)	61,222
Project investment1 (USD)	322,421
The electrical power generation[2] (kWh/y)	73,000
LEC of waste energy (USD/kWh)	0.442

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

IV. CONCLUSIONS

From this study, the conclusions are as follows:

1. The 20 kW ORC system with using R-245fa as working fluid had the system efficiency around 8%, when hot water temperature was higher than 100 $^{\circ}$C.
2. The values of levelized electricity costs (LEC) of geothermal energy, solar energy and waste energy were 0.148, 0.547 and 0.442 USD/kWh, respectively.
3. The suitable alternative energy for generating electricity was the geothermal energy which was beneficial than the solar and waste energy power plants in terms of energy and economy results.

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NOMENCLATURE AND SYMBOL

Nomenclature

Cp	Heat capacity, (kJ/kg·K)
$\dot{m}$	Mass flow rate, (kg/s)
SiO_2	Concentrate of quartz in surface water (ppm)
T	Temperature, ($^{\circ}$C)
W	Work, (kW)

Greek symbol

η	Efficiency, (%)

Subscript

HW	Hot water
e	Electricity

REFERENCES

[1] Energy Policy and Planning Office (EPPO), "Annual year final report", 2010.
[2] N. Chaiyat, C. Chaichana, "Drying Room from Geothermal Energy", In: Proceeding of Seminar on the 10th Conference on Energy, Heat and Mass Transfer in Thermal Equipments and Processes. Chiang Rai, Thailand; 2009.
[3] J. Combs, S. K. Garg, J. W. Pritchett, "Geothermal slim holes for small off-grid power projects, Renewable Energy", vol. 10, pp. 389-402, 1997.
[4] P. Brophy, "Environmental advantages to the utilization of geothermal energy", Renewable Energy, vol. 10, pp. 367-377, 1997.
[5] R. Kose, "Research on the generation of electricity from the geothermal resources in Simav region Turkey", Renewable Energy, vol. 30, pp. 67-79, 2005.
[6] A. Dagdas, "Heat exchanger optimization for geothermal district heating systems: A fuel saving approach", Renewable Energy, vol. 32, pp. 1020-1032, 2007.
[7] H. D. M. Hettiarachchi, M. Golubovica, W. M. Worek, Y. Ikegamib, "Optimum design criteria for an Organic Rankine Cycle using low-temperature geothermal heat sources", Energy, vol. 32, pp. 1698-1706, 2007.
[8] A. Schuster, S. Karellas, J. Karl, "Simulation of an innovative stand-alone solar desalination system with an Organic Rankine Cycle", In: the 46th Conference on Simulation and Modeling, Trondheim, Norway, October 13-14, 2005.
[9] T. Guo, H. X. Wang, S. J. Zhang, "Fluids and parameters optimization for a novel cogeneration system driven by low-temperature geothermal sources", Energy, vol. 36, pp. 2639-2649, 2011.
[10] E. Sauret, A. S. Rowlands, "Candidate radial-inflow turbines and high-density working fluids for geothermal power systems", Energy, vol. 36, pp. 4460-4467, 2011.
[11] B. Liu, P. Riviore, C. Coquelet, R. Gicquel, F. David, "Investigation of a two stage Rankine cycle for electric power plants", Applied Energy, vol. 100, pp. 285-294, 2012.
[12] B. H. Edrisi, E. E. Michaelides, "Effect of the working fluid on the optimum work of binary-flashing geothermal power plants", Energy, vol. 50, pp. 389-394, 2013.
[13] T. Li, J. Zhu, W. Zhang, "Comparative analysis of series and parallel geothermal systems combined power, heat and oil recovery in oilfield", Applied Thermal Engineering, vol. 50, pp. 1132-1141, 2013.
[14] C. E. C. Rodriguez, J. C. E Palacio, O. J. Venturini, L. E. E. Silva, V. M. D. Cobas, D. M. Santos, F. R. L. Dotto, V. Gialluca, "Exergetic and economic comparison of ORC and Kalina cycle for low temperature Antonio Yock", In: Proceeding of Seminar on Short Course on Surface Exploration for Geothermal Resources, El Salvador, October 17-30, 2009.
[15] N. Ketjoy, W. Rakwichian, "Techno-Economic Study of Solar Parabolic Trough-Biomass Hybrid Power Plant", In: the 2nd Conference on Energy Network of Thailand, Nakornrachasima, Thailand, 27-29 July, 2006.
[16] C. Thawonnagamyingsakul, T. Kiatsiriroat, "Performance and Economic Analysis of a Solar Organic Rankine Cycle with Flat-Plate and Evacuated-Tube Solar Collectors as Heat Source in the Northern Part of Thailand", In: the 1st ASEAN Plus Three Graduate Research Congress. Chiang Mai, Thailand, 2012.
[17] T. C. Hung, "Waste heat recovery of organic Rankine cycle using dry fluids", Energy Conversion and Management, vol. 42, pp. 539-553, 2001.
[18] S. K. Achary, E. Obermeier, A. Schaber, "Use of R-114 as the working fluid in a flat-plate collectors system for electric power generation", Applied Energy, vol. 13, pp. 59-68, 1983.
[19] L. Jing, P. Gang, J. Jie, "Optimization of low temperature solar thermal electric generation with Organic Rankine Cycle indifferent areas", Applied Energy, vol. 87, pp. 3355-3365, 2010.
[20] U. Drescher, D. Bruggemann, "Fluid selection for the Organic Rankine Cycle (ORC) in biomass power and heat plants", Applied Thermal Engineering, vol. 27, pp. 223-228, 2007.
[21] Department of Mineral Resources, Geothermal Energy Resources, Available from: www.dmr.go.th, 6 June 2014.
[22] Chiang Mai University (CMU), "Study for conservation and development of low potential hot springs for multipurpose usage", Final Report submitted to the Department of Alternative Energy Development and Efficiency (DEDE), 2008.
[23] RETScreen Data, Available from: http://eosweb.larc.nasa.gov/sse/RETScreen/, 5 June 2014.
[24] The ambient temperature of Chiang Mai, Available from: http://www.tmd.go.th/thailand.php, 5 June 2014.
[25] Andy Schroder, "CPC Evacuated Tube Solar Thermal Collectors", Available from: http://www.andyschroder.com/CPCEvacuatedTube/, 21 September 2014.
[26] National Institute of Standards and Technology, Inc. (NIST, REFPROP Version 9.1). "Thermodynamic Properties of Refrigerants and Refrigerant Mixtures Software", 2013.

[27] J. A. Duffie, W. A. Beckman, “Solar engineering of thermal processes”, English, 1980.
[28] N. Vorayos, N. Vorayos, T. Kiatsiriroat, “Experimental investigation of ethanol distillation system with different types of solar collectors”, In: Annual Conference of ANZSES 2003 – Destination Renewables, November 26-29, 2003.
[29] T. Kiatsiriroat, “Developing a pilot plant to produce solid fuel from waste”, 2014.
[30] Electricity Generating Authority of Thailand (EGAT), “Project of Geothermal Energy for Multipurpose”, Amphoe Fang, Chiang Mai Province, 1988.
[31] S. Tongsopit, C. Greacen, “Thailand’s Renewable Energy Policy: FiTs and Opportunities for International Support”, WRI-ADB Workshop on Feed-in Tariffs, Manila, Philippines, 2012.
[32] Pers. comm, Ormat Technologies, Inc., “Cost of Geothermal Power Plant”, 2013.
[33] Industrial Technology Research Institute, “ORC Design and Development in Taiwan”, Green Energy and Environment Research Lab Natural Resources Technology Division ORC Team, Taiwan, 2012.

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