DESIGN OPTIMIZATION AND EXPERIMENTAL DATA OF LOW ENTHALPY GEOTHERMAL POWER PLANT DESIGN BY USING ORGANIC RANKINE CYCLE

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Abstract

A lot of heat energy can be tap to produce electricity by converting the heat and enthalpy to move a steam turbine cycle, or usually known as Rankine Cycle. But steam cycle has to have a high temperature and high enthalpy, so lower temperature and lower enthalpy source such as geothermal brine water, solar thermal, and waste heat gas cannot be tap to produce electricity. These potential belongs to ORC or Organic Rankine Cycle. ORC has no need to utilized high temperature and enthalpy, it can use temperature as low as 80ºC instead of 170ºC or more. By utilizing ORC system, these sources is open to produce electricity. These days a lot of research for ORC is done either by simulation or by experiment and the source is also varied. For this case, the source is geothermal brine water. The design of ORC begins with calculating the overall ORC heat balance using Cycle Tempo. Thus the duty of preheater, evaporator, turbine, condenser, pump, and cooling tower can be obtained. Then using working fluid n-pentane, we calculate and optimized the thermal efficiency. After that, every individual equipment is designed and calculated by using HTRI. Design optimization which had been obtained then used as reference to do the experiment. Unfortunately, the data from the latest experiment showed that the temperature from the geothermal brine water has not met requirement yet. Therefore, further experiment has to be done with some improvement to the system.

Keywords*: ORC Cycle, Rankine, geothermal, refrigerant.*

INTRODUCTION

Generally, the source of energy in Indonesia is from fossil fuels such as petroleum and coal. And it's availability is limited and pose a serious threat to the environment and human life such as air pollution and global warming [1]. Reducing the air pollution and global warming which are result of burning fossil fuels, would require the role of renewable energy and utilization of waste heat energy to meet the needs and optimizing the use of fossil fuel. Renewable energy sources in Indonesia widely available such as geothermal, wind, nuclear, and solar energy.

For example in Dieng geothermal energy site, Wonosobo Central Java, they have a geothermal potential of 400 MW of electricity. But only 168 MW has been erected. Dieng geothermal has a characteristic of low steam fraction (0.6-0.7) and relatively mid temperature (320ºC). There are totally 47 wells available in Dieng geothermal energy.

Recently a lot of research and development of renewable energy sources have been done in the world including in Indonesia. For example by Denny Widhiyanuriyawan, et al. and Warjito, et al. According to the results of their study, Indonesia have a wind potential of 2 m/s to 4.16 m/s [2][3].

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Based on the data obtained from EMR, the geothermal potential energy in Indonesia is estimated at 28 112 Mwe, which is the largest in the world [4]. Indonesia's location on the equator makes solar energy potential is quite large, with eastern Indonesia has a radiation intensity of about 5.1 kWh / m² and in the western part is varying from 4.5 kWh / m² with an average 4.8 kWh / m² [5][6].

Organic Rankine Cycle is abbreviated from ORC, developed by William John Macqourn Rankine in December 1872 [7]. ORC is a Rankine cycle which using organic as a working fluid, thus it can utilize a heat from low temperature source such as industrial heat waste, exhaust air conditioning, condenser, and heat the rest of the power plant [8][9]. Generally ORC for simple system has four main components: pumps, evaporators, turbines, and condensers. ORC system is more economical and non-polluting compared to other plant systems. According to Research by EH Wang A. R245fa is most suitable for ORC because it has the lowest negative impact that is safe for the environment [10]. Research on ORC is done on three variables: the working fluid, heat source, and type of the turbine. ORC working fluid selection must be adjusted to the heat source and the working pressure. It must meet several requirements: non-toxic, nonflammable, readily available, economical, and have good thermodynamic properties.

1. THEORETICAL BASIS AND METHODS

Basically ORC uses the same principle as the ordinary steam rankine cycle. There are evaporator, pump, condenser, preheater, and turbine. Although in ORC, they use hermetic turbine to prevent fluid leakage.

The differences between steam Rankine cycle and organic Rankine cycle are not only from the working fluid and the heat source which used, but thermodynamically ORC has a different T-s curve than steam cycle. This is due to different fluid substance. ORC T-s curve has a smaller and steeper at the saturation steam area compare to ordinary steam cycle. As shown in Figure 1 that water fluid has a wet curve compare to organic fluid that has isentropic curve or dry curve.

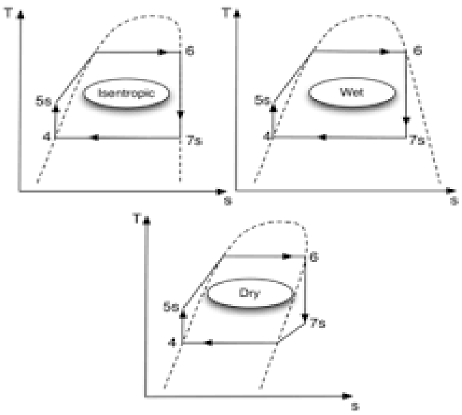

Figure 1 Water and Organic T-s Curve

The water fluid has a negative dT/ds and organic fluids have 0 or positive dT/ds. These affect the expansion process in the turbine. As the fluid expand around 70-80% from isentropic, so isentropic curve will have an advantage for being “dry” in the outlet of the turbine as opposed to “wet” state in the water curve. So, the state in the water curve has to be superheated first before entering the turbine.

The water fluid cycle also has to have a higher temperature to run the cycle. As seen in Figure 2 shows the difference between water T-s diagram of water and several organic fluid.

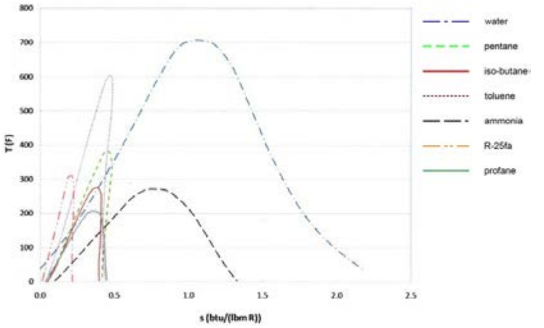

Figure 2 T-s Diagram for several kind of fluid

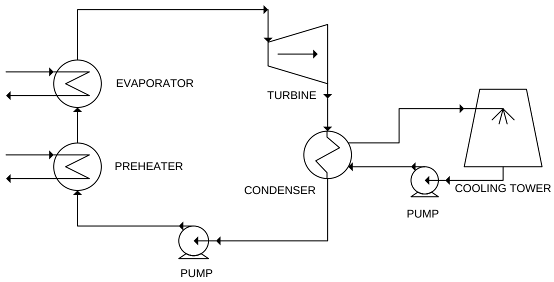

Figure 3 ORC Schematic Diagram

As shown in Figure 3 is the schematic diagram of the ORC. The entering energy is divided into preheater and evaporator, with indirect heating through water as a mediator. Turbine is using hermetically sealed, and then the rest of the equipment is the same as the ordinary steam cycle.

To calculate the isentropic efficiency, equation (1) is used.

$$\eta_{e,is} = \frac{Pe}{\dot{m}\left(h_{in} - h_{out,is}\right)} \qquad (1)$$

Where:

$\eta_{e,is}$ = isentropic efficiency
P_e = turbine power
$\dot{m}$ = fluid mass flow
h_{in} = inlet specific enthalpy
$h_{out.is}$ = outlet specific enthalpy isentropically

And to calculate ORC efficiency can be obtain with equation (2).

$$\eta_{ORC} = \frac{P_e - P_p}{\dot{m}\left(h_{vg,out} - h_{vg,in}\right)} \qquad (2)$$

Where:

η_{orc} = ORC efficiency
P_e = turbine power
P_p = pump power
$\dot{m}$ = fluid mass flow
$h_{vg,in}$ = generator inlet specific enthalpy
$h_{vg,out}$ = generator outlet specific enthalpy isentropically

After the system is calculated, each equipment duty is calculated using HTRI program. This program is automatically calculate thermal duty, but the input parameter is determined from system calculation. Basically heat exchanger use two main equation as follow:

$$Q = \dot{m}\, c_p\, \Delta T$$

Where: Q = heat duty
$\dot{m}$ = mass flow
c_p = specific heat capacity at constant pressure
ΔT = inlet-outlet temperature difference

And,

$$Q = U\, A\, \Delta T_{EMTD}$$

Where: Q = heat duty
U = overall heat transfer coefficient
A = heat transfer area
ΔT_{EMTD} = Effective Mean Temperature Difference

2. ANALISYS METHOD

There are several steps to do the analysis. First is to design the system. The optimized design is calculated by program such as Cycle Tempo and HTRI. In this step, several output parameters are determined and ready to be fabricated. Next step is fabrication. Fabrication starts with shell and tube equipment (i.e. evaporator, preheater, and condenser), and then the structure and piping. The turbine-generator, cooling tower, control system are fabricated separately. Then assembly and erection process are the next step.

At this point, experiment can be started. Experiment consists measuring the output parameter of the design. Comparing between measuring and design output is important, to prove that the design and/or the manufacturing process is right.

3. DESIGN PARAMETERS

Before any fabrication or even experiment could begin, engineering design had to be completed first. Thermal balance of the system, as shown in Attachment 1 was designed by using Cycle Tempo. The design shows several important things. First is the heat input section.

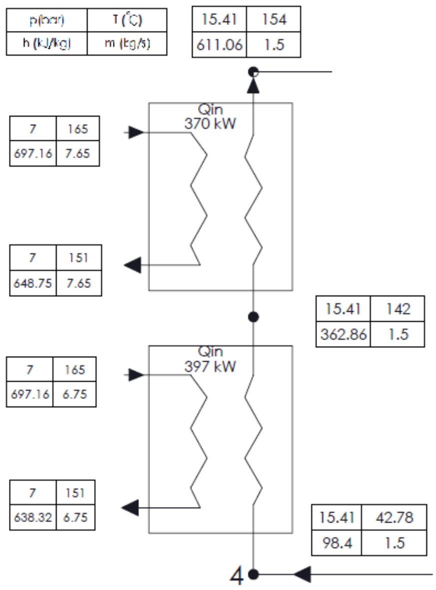

Figure 4 . Thermal balance of heat input

Heat input section contain 2 heat exchanger, preheater and evaporator. The preheater raised the temperature to the saturation liquid point, before it continued to the evaporator, which boiled the water to the saturation vapor point. As shown in Figure 4 is the parameters output for this section.

For the turbine section, the turbine generates 121.99 kW of thermal power, which would be transformed into electricity power. The pressure drop is 15.41 bars to 1.41 bar, and temperature drop is 154ºC to 95.55ºC. After the turbine section, the n-pentane condenses in the condenser. The thermal process is shown in Figure 5.

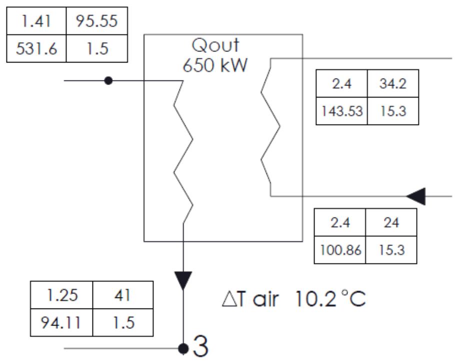

Figure 5. Thermal balance of condencer

From all of the design output parameters, thermal efficiency is obtained and the result is 9.19%. This is normal or within the range of thermal efficiency of ORC cycle. The data above then can be used as reference for the experiment.

4. EXPERIMENT RESULT & ANALYSIS

The experiment was conducted in Dieng Geothermal site on Friday, 28 November 2014. From the experiment, the data which obtained are as follow.

Geothermal brine water temperature from the separator in the Pre-Heater was obtained 103 ºC (inlet) and 98.2 ºC (outlet) while in the Evaporator was obtained 120.3 ºC (inlet) and 96.7 ºC (outlet). For refrigerant temperature in the Pre-Heater was obtained 22.1 ºC (inlet) and 105.6 ºC (outlet) while in the Evaporator was obtained 105.6 ºC (inlet) and 112 ºC (outlet). Those data showed that the temperature from the separator which entered the Pre-Heater and Evaporator was not met requirement which has to be at least 165 ºC with pressure 7 bar for the entire cycle running well and the turbine can produce the electricity as planned in the design optimization.

5. CONCLUSION

From this experiment some point are to be considered. The thermocouple in the separator showed that the outlet temperature of geothermal brine water from separator was around 165 ºC with pressure around 8 bar. But when the temperature of geothermal brine water in the inlet of Pre-Heater and Evaporator were measured, the results showed that the temperature in the Pre-Heater inlet was 103.0 ºC while temperature in the Evaporator inlet was 120.3 ºC which different from the temperature in the separator outlet. It could be concluded that there were some technical problem along the pipe which used to distribute the geothermal brine water to the system.

Then next the temperature of the refrigerant in the Pre-Heater and Evaporator also had not met the requirement yet. Both inlet showed that the temperature of refrigerant n-pentane was less than 110 ºC, mean that the refrigerant was not in the superheated condition yet. Those concluded that the entire system could not run well with that condition. Therefore, further experiment need to be conducted again with some improvement to the system especially with the connection from separator to the Pre-Heater and Evaporator so then the temperature of geothermal brine water will be as required.

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