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# UTILIZATION OF JABOI GEOTHERMAL RESOURCES BY USING BINARY CYCLE POWER PLANT

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## ABSTRACT

The conceptual model of binary cycle power plant for Jaboi geothermal field is proposed. The evaporator pressure and geothermal fluid flow rate is optimized. The geothermal fluid inlet temperature is estimated 200°C and injection temperature is calculated 80.68°C. The analysis shows to produce 3 MW net power output electricity, it is required 95 kg/s geothermal flow rate.

The evaporation pressure of secondary working fluid is optimized at 1700 kPa, which yield the maximum net power output production.

## INTRODUCTION

Jaboi geothermal prospect is situated in Suka Jaya district, city of Sabang, Weh Island. Geographically, Suka Jaya is located between 95° 12' 00" - 95° 23' 00" E and 05° 46' 00" - 05° 55' 00" N. Weh Island is one of young volcanoes within western Indonesia volcanic arc which reaches from Sumatra, Java, Bali to Nusa Tenggara.

Reconnaissance exploration of Jaboi geothermal area started in 1972 with observation of the surface manifestation and geo-electrical surveys during 1983 and 1984. More geological survey was conducted in 2000. The integrated survey data (geochemical, geomagnetic, gravity, head on resistivity and geo-electrical) was compiled during 2005–2006 (Sumintadireja et al, 2010). It is estimated Jaboi geothermal field has 11.5 MWe of the possible resources (Castlerock, 2010).

Jaboi geothermal system is classified as water dominated system which has top reservoir around 600- 800 m depth (Dwipa et al, 2006)

## ELECTRICITY NEED IN SABANG

Currently, the electricity peak load in Sabang is about 3 MW which is supplied from diesel generator power plant. The electricity consumption is estimated 18 GWh/year. However, It is estimated the electricity consumption in next 5 years can reach 30 GWh.

Considering electricity system in Sabang is isolated system, which means the electricity production is unable to be transferred to another load area, therefore for the first phase it is proposed to design Jaboi geothermal power plant with capacity 5 MW.

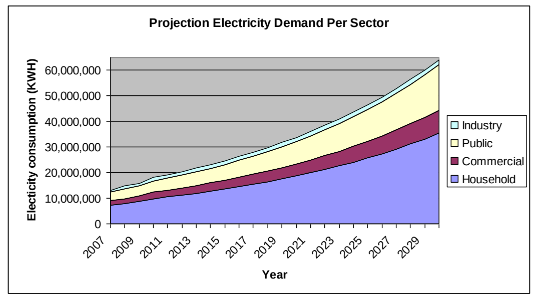


*Figure 1: Electricity demand projection in Sabang*

## UTILIZATION CONCEPT

The proposed concept is to design a typical binary cycle power plant with capacity 3 MW net power output. Since the stage of field development still in exploration phase, some required data i.e accurate brine temperature and well head pressure need to be assumed.

The model is simulated by using Engineering Equation Solver (EES) software. The simulation model is presented in Figure 2.

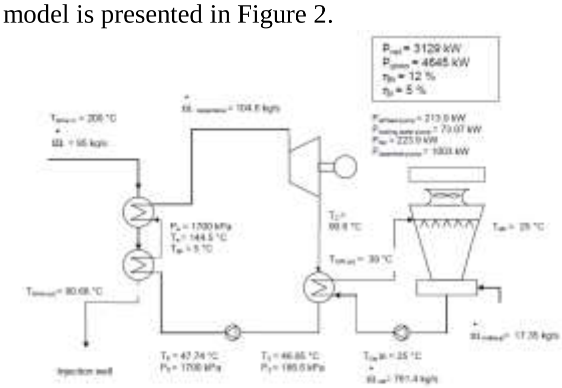

*Figure 2: Model flow diagram*

Isopentane will be used as secondary working fluid. The properties of isopentane which has boiling point at 28°C and critical temperature 187.8 °C, is considered suitable to Jaboi geothermal resources.

## Brine Temperature

The temperature of brine is estimated to be 200 °C which is obtained from around 1000 m drilling depth. The assumed temperature is estimated based on geothermal gradient profile.

$$Geothermal\,Gradient = \frac{BHT - MAST\ x\ 100}{D} \qquad [1]$$

Where BHT is bottom hole temperature which is 74.4 °C (in 250 m depth), MAST is mean annual surface temperature which is assumed 25 °C. D is respective bottom hole depth in meter**.** The gradient is expressed in degrees centigrade (°C/100 m).

Thus, the calculation shows the temperature at 1000 m depth is 200 °C.

## Well Head Pressure

The selection of well head pressure is very important in determining how much flow rate can be extracted from the well. In this simulation the well head pressure will be estimated 18 bars (or 1800 kPa) in order to avoid flashing of geothermal fluid in the surface plant equipment.

## Assumption Used

Some assumptions used for modeling are described below.

1. Efficiencies ( Saadat et al, 2010 )
   - Isentropic turbine efficiency = 0.75
   - Feed pump efficiency = 0.8
   - Downhole pump efficiency = 0.75
   - Cooling pump efficiency = 0.8
   - Generator efficiency = 0.95
   - Cooling fan efficiency = 0.8

2. Minimum heat exchanger temperature difference ($\Delta T_{pp}$) = 5 °C

3. Cooling tower
   - Raise of pressure on fan = 170 Pa (Valdimarsson, retrieved from Lukawski 2009)
   - Height of cooling tower = 1.5 m (Frick, et al, 2010)
   - Cooling water approach to wet bulb temperature 3 °C (El Wakil retrieved from Lukawski, 2009)
   - Raise of cooling water temperature in condenser = 13 °C (El Wakil retrieved from Lukawski, 2009)
   - Pressure losses = 1 bar (Frick, et al, 2010)
   - Rise of air pressure in the fan in cooling tower = 170 Pa (Lukawski, 2009)

4. Down hole pump
   - Production Index (PI) = 160 $m^3/(h.MP_a)$
   - Static fluid level ($h_{SFL}$) = 295 m
   - Dynamic Fluid Level ($h_{DFL}$) = 597 m
   - Friction loss = 10 kPa (Aksoy, 2007)
   - Diameter casing : 8.5 inch (Frick et al, 2010)

## Simulation Result

### *Evaporation Pressure*

The saturated vapor pressure of working fluid is designed at 1700 kPa. Based on the simulation of the model, at pressure 1700 kPa net power output gains maximum value. The implementation of the pressure above 1700 kPa will decrease net power output. One of the reason is because of the increases of auxiliary power demand of isopentane feed pump (see figure 3).

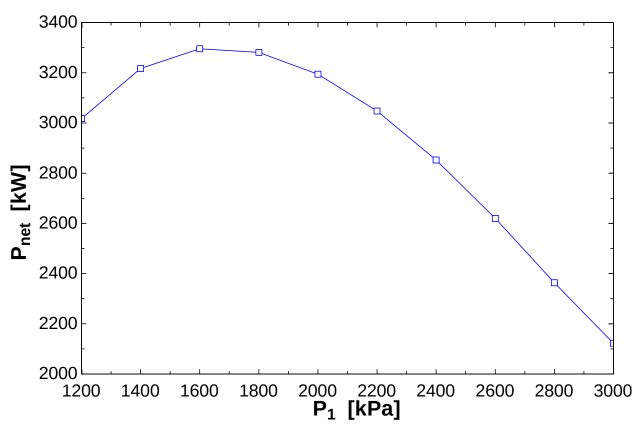


*Figure 3: Optimization of working fluid evaporation pressure*

### *Brine Mass Flow Rate*

The simulation of relationship between mass flow rate and power production is plotted in figure 4. The maximum flow rate of the well is assumed 160 kg/s and will produce around 5.5 MW of net power output. To produce 3 MW net power output (or around 4.6 MW of gross power), therefore a 95 kg/s mass flow rate of geothermal fluid should be able to be supplied from the well.

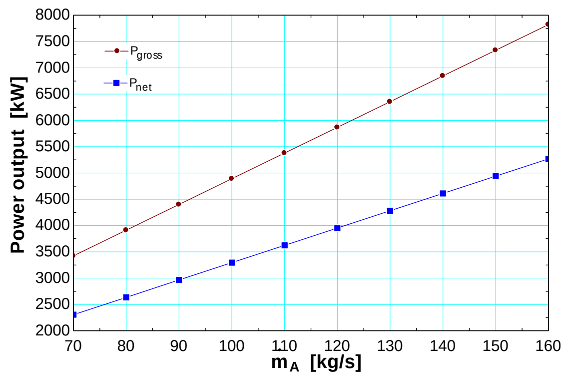


*Figure 4: Optimization of brine mass flow rate*

### *Reinjection Temperature*

The input of heat from geothermal fluid with mass flow rate 95 kg/s to raise the enthalpy of isopentane steam to 174.7 KJ/kg, preheater contributes 56 % of heat transfer to the isopentane (figure 5). The reinjection temperature is calculated 80.68 °C. Practically, the reinjection temperature is limited to the level where no scaling problem occurs in the injection pipeline. This limitation will limit the extraction of heat from geothermal fluid.

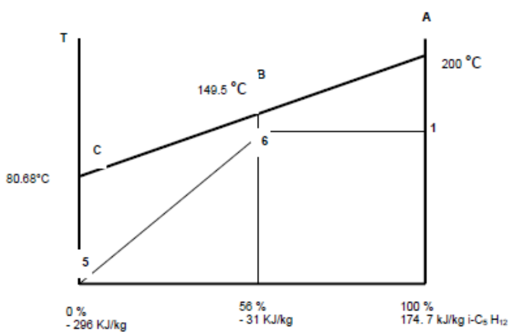


*Figure 5: Temperature – Heat Transfer diagram*

### *Condensing System*

The exhaust temperature of working fluid steam from the turbine is 90.6 °C. The steam flows through the condenser where it will be condensed by cold water with temperature 25 °C to temperature 46.85°C. After cooling down the steam, the heat rejected to cooling water is calculated 411.6 KJ/kg and the temperature of cooling water is raised to 38 °C.

### *Cooling System*

The hot water is cooled again in cooling tower. The type of cooling tower used in simulation is induced draft type air cooling tower. The mass flow rate of cooling water is calculated to be 791.4 kg/s. To circulate this water it is required pumps with capacity 73.7 kW. In Integrated Pollution Prevention and Control (IPPC) 2001 European Commission reported the range of power consumption for the cooling water pumps varies between 5 – 20 $kW_{el}$ $MW_{th}^{-1}$ (Huenges, 2010). Due to the losses of cooling water, it is necessary to calculate the make-up water. In this case, it requires 17.35 kg/s of mass flow rate of make-up water. The pump power to pump the make-up water is calculated to be 2.17 kW. According to IPPC in Huenges (2010), the make-up water is about 1 – 5 % of cooling water.

The hot water entering the cooling tower is cooled through the heat exchange with cold air. The temperature of dry air ($T_{db}$) is assumed as 30 °C which will be similar to the wet bulb temperature ($T_{wb}$) when the relative humidity of the air is approximately 100%. The cooling tower outlet temperature of air is raised to 35 °C. To induce 1533 kg/s of air, it requires 223.9 kW auxiliary power for fans. The power consumption of the fan varies between 5 – 10 $kW_{el}$ $MW_{th}^{-1}$ (Huenges, 2010).

### *Auxiliary Power Demand*

Total auxiliary power demand is calculated 1516 kW or consumes around 32 % of gross power output. Net power output of power plant is calculated 3129 kW.

*Table 1: Auxiliary power demand.*

| **Auxiliary power demand** | **Capacity (kW)** |
|---|---|
| Downhole pump | 1003 |
| Working fluid feed pump | 213.9 |
| Cooling water pump | 73.7 |
| Make up water pump | 2.17 |
| Cooling tower fans | 223.9 |
| **Total** | **1516** |
| **Gross power** | **4645** |

### *Power Plant Performance*

The calculations show the designed plant has 12 % of thermal efficiency and 5 % of utilization efficiency. A typical geothermal binary power plant has thermal efficiency 10 – 13 %. It can be seen that the utilization efficiency is very low even lower than thermal efficiency. This is because of the pinch point located at the bubble point and so much heat required to pre-heat the working fluid, so that the irreversibility in the preheater are very large due to very large temperature difference (Di Pippo, 2008).

This issue might be solved by lowering the boiler pressure, the evaporating line 6 - 1 (see figure 5) will drop and point 6 will move down and to the left, creating more balance heat load between evaporator and preheater. This also will lower brine outlet temperature and result in lower brine flow rate. Thus the brine exergy rate will be less for the same net power output and the utilization efficiency will increases.

## CONCLUSION

This paper is to propose new approach in developing geothermal resources in Indonesia as alternative to flash system which is already exist. Binary cycle power plant commonly is used to utilize low and medium enthalpy geothermal resources. Jaboi geothermal field is expected to supply brine with temperature 200 °C which is obtained from 1000 m drilling depth.

The design approach is based on net power output instead of gross power output since the auxiliary power demand has major influence in determining the power plant efficiency. In this case, the auxiliary power demand consumes 32% of total power production. The auxiliary power demand varies according to specific site i.e downhole pump power demand will depend on its dynamic and static fluid level.

To produce 3 MW of net power output, it is required 95 kg/s brine flow rate which is highly possible to obtain from one production well. However, it hugely depends on specific characteristics of the geothermal site.

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