OPPORTUNITIES FOR ELECTRICITY GENERATION WITH BINARY CYCLE POWER PLANTS IN LUMUT BALAI GEOTHERMAL AREA

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ABSTRACT

Lumut Balai Geothermal Field is a working area managed by Pertamina Geothermal Energy (PGE) in South Sumatra Province, Indonesia. This field has generated 55 MWe of electricity to the grid on the Sumatra Island after Lumut Balai Geothermal Power Plant (GPP) Unit-1 achieve the commercial operation date in the first quarter of 2020. Lumut Balai GPP Unit-2 EPCC project will follow with 55 MWe capacity in the future. The two GPP units are turbine condensing power plants.

Lumut Balai Geothermal Field is a two phase field with water predominance (dryness of around 20%) where this two phase fluid flow into the separator to separate dry steam and hot brine. Dry steam is used to turn turbines and generators to produce electricity and hot brine is injected into the reservoir through a reinjection well. The injected hot brine still has high heat potential and can be used to generate electricity using a binary cycle power plant.

This paper tries to find out how much electricity is generated from the binary cycle power plant by utilizing hot brine, which may be a binary cycle that can be used as a way to increase the generation capacity in Lumut Balai Field in the future.

1. INTRODUCTION

Lumut Balai Geothermal Field is located on Bukit Barisan mountain, about 292 km southwest of Palembang in South Sumatera- Indonesia. This field is part of the PT Pertamina Geothermal Energy working area. Lumut Balai field is water dominated geothermal type with dryness approximately 20%. In this area, PT Pertamina Geothermal Energy has carried out total project, that develop from steam field, steam gathering system, and reinjection system (upstream), and geothermal power plant (downstream). Electricity from power plant will be sell to national electric company (PT. PLN), based on electricity energy sales contract.

Now a day, Lumut Balai Geothermal Field already produce 55 MW electricity from one Geothermal Power Plant (Lumut Balai Unit-1). And the next project on the future is develop another GPP as same as Unit-1.

The Author try to find out how much electric power would be generated from hot brine by binary cycle power plant based on Binary Cycle Thermal Efficiency as initial prediction before a more in-depth and comprehensive study is carried out later.

2. LUMUT BALAI GEOTHERMAL STEAM FIELD AND POWER PLANT

Steam for LMB GPP Unit-1 are supplied from 3 well pads, with each well pad having one Steam Separator to separate dry steam and hot brine. Dry steam from each separator is sent to the power plant, where it is fed into steam turbine generator systems (direct steam expansion). Hot brine from each separator is then collected in one brine header and re-injected back into the geothermal field area through re-injection wells.

LMB GPP Unit-1 is a Single Flash and Condensing Turbine type (basic heat and mass see Figure 1). From Basic Design of Lumut Balai Power Plant (Sulistyardi, 2015), operation conditions are:

- Separation pressure: 7 bara
- Separation temperature: 164.9°C
- Total geothermal fluid mass flow rate: 733 kg/s
- Steam + NCG mass flow: 120.9 kg/s
- Inlet Turbine Pressure: 5 bara
- Inlet Turbine Temperature: 151.8ºC
- Net Output Power: 55 MW
- Brine mass flow rate: 612.4 kg/s
- Condenser pressure: 0.1 bara

The steam turbine and generator were manufactured by Toshiba – Japan. The electric power is sent to South Sumatera Region Grid of PLN.

3. BRINE BINARY CYCLE POWER PLANT

Binary cycle power plant would be installed in the middle of hot brine pipe line before reinjection well. (See Figure 2)

The hot brine from separator is fed into the vaporizer (evaporator & pre-heater) of the binary cycle system to vaporize the binary cycle working fluid and generate electricity. The used brine is delivered to reinjection wells.

Binary cycle systems have a closed cycle. After driving the turbine, working fluid flows to air fan cooler to decrease temperature and to condense the fluid before being sent back to vaporizer.

4. ELECTRIC POWER CALCULATION BASED ON BINARY CYCLE THERMAL EFFICIENCY.

The Author try to calculate how much electric power would be generated from binary cycle power plant based on Binary Cycle Thermal Efficiency with variable of two parameters:

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Brine Flow Rate and Brine Temperature Outlet from Evaporator-Preheater.

4.1 Basic Parameter and Condition

Basic parameters and conditions for the calculation of the electricity which is generated from binary cycle power plant are as follows:

- Brine Flow Rate ($\dot{M}_b$) are:
  - 612.4 kg/s (100% flow rate)
  - 551.16 kg/s (90% flow rate)
  - 459.3 kg/s (75% flow rate)
  - 306.2 kg/s (50% flow rate)
- Brine Temperature ($T_{b\text{-}in}$) = 164.9 ^{O}C (438.05 K)
- Brine Pressure (P_b) = 20 bara

  It is different from Heat & Mass Balance Diagram because in reality, there is a level gap between production cluster location and brine header location.
- Binary Cycle Thermal Efficiency.

  The Thermal Efficiency (η_{th}) of a Binary Cycle Power Plant is the ratio of the gross power generated by the turbine-generator (W_{tg}) to the heat that enters the Evaporator and Pre-Heater ($Q_{PH/E}$):

  $$\eta_{th} = \frac{W_{tg}}{Q_{PH/E}} \qquad \text{(eq. 01)}$$

  If thermal efficiency can be assumed based on the design data, and $Q_{PH/E}$ can be calculated from the hot brine property, then we can calculate the value of W_{tg} as an initial prediction.

  $$W_{tg} = \eta_{th} \times Q_{PH/E} \qquad \text{(eq. 02)}$$

  For calculations here the author uses a thermal efficiency of 14%, based on data from the thermal efficiency of the OEC Brine unit in the Sarulla Geothermal Field (Saptadji, 2018).
- Option of Brine Temperature BPP Outlet ($T_{b\text{-}out}$):

  We know that the scaling potential of silica has always been an obstacle in the utilization of geothermal fluids for the Binary Cycle Power Plant. The potential for scaling of silica is greater as the temperature of the geothermal fluid decreases. For calculations, the authors chose 5 variations of the brine temperature:
  - 130^{O}C (Monroy Parada, 2013).
  - 120^{O}C (Binary Cycle OEC Brine Sarulla)
  - 110^{O}C (reinjection temperature on Los Azufres, Mexico) (Grassiani, 2000).
  - 100^{O}C. (The rule of thumb brine reinjection temperature to prevent scaling) (Thorhallsson, 2012).
  - 90^{O}C. (Hinde and Mulazzani, 2016).

4.2 Calculation

4.2.1 Heat entering Pre-Heater & Evaporator

Heat entering Pre-Heater & Evaporator Rate ($Q_{PH/E}$) is the same as Heat from Hot Brine (Q_b), and can be calculated from equation:

$Q_{PH/E} = Q_b$

$Q_{PH/E} = \dot{m}_b.(h_{b\text{-}in} - h_{b\text{-}out})$

Because Heat Rate occur in Isobaric process:

$Q_{PH/E} = \dot{M}_b.Cp_b.(T_{b\text{-}in} - T_{b\text{-}out})$

Isobaric Heat Capacity of Brine (Cp_b) = 4.353 kJ/(kg.K)

So, for 100% flow rate and Tb-out = 130ºC (403.15 K), we get :

$Q_{PH/E}$ = 612.4 x 4.353 x (438.05 – 403.15) kW

$Q_{PH/E}$ = 93,035.62 kW or 93.04 MW

Based on Brine Flow Rate and Brine Temperature Outlet, we could make the range of heat from hot brine (see Table 1).

Flow Rate (%)	$T_{b\text{-}out}$ (ºC)				
	130	120	110	100	90
50%	46.52	59.85	73.18	86.50	99.83
75%	69.78	89.77	109.76	129.76	149.75
90%	83.73	107.72	131.72	155.71	179.70
100%	93.04	119.69	146.35	173.01	199.67

Table 1: Heat from Brine in MW for Brine Temperature Outlet vs Brine Flow Rate

Heat from Hot Brine from Lumut Balai Steam Field have the range from 46.52 MW until 199.67 MW.

4.2.2 Electric Power

Prediction of gross Electric Power from Binary Cycle Power Plant can be calculated by eq. 02. For 100% flow rate and $T_{b\text{-}out}$ = 130^{O}C, and thermal efficiency (η_{th}) 14%:

$W_{tg} = \eta_{th} \times Q_{PH/E}$

W_{tg} = 0.14 x 93,035.62 kW

W_{tg} = 13,024.98 kW or 13.025 MW

4.2.3 Gross Electric Power Range

Based on Brine Flow Rate and Brine Temperature Outlet, we could make the range of Gross Electric Power that could be generated by Binary Cycle Power Plant which is Hot Brine as Hot Fluid for vaporize working fluid.

Flow Rate (%)	$T_{b\text{-}out}$ (°C)				
	130	**120**	**110**	**100**	**90**
50%	6.51	8.38	10.24	12.11	13.98
75%	9.77	12.57	15.37	18.17	20.97
90%	11.72	15.08	18.44	21.80	25.16
100%	13.02	16.76	20.49	24.22	27.95

Table 2: Gross Power in MW for Brine Temperature Outlet vs Brine Flow Rate

Gross electric power which is generated from Binary Cycle Power Plant have the range from 6.51 MWe until 27.95 MW.

If the next geothermal power plant (LMB Unit-2) has a same design operation with the existing, and has the same hot brine flowrate, the total electric generation in Lumut Balai Field from binary cycle power plant could be two times from result at Table 2.

5. CONCLUSION

Heat rate of Hot Brine from LMB Steam Field are 46.52 to 199.67 MW. That heat could be used to generate electric power by Binary Cycle Power Plant and Electric Power (gross) which is generated from The Binary Cycle Power Plant are 6.51 to 27.95 MWe gross.

The results of these calculations are still a first estimate to convert the potential for brine heat into electricity. There are still many aspects that must be considered in planning a binary cycle power plant, such as the effect of lowering the reinjection temperature on the reservoir and the production of steam to the existing power plant, the design of the binary power plant, the economics of the project, and others. These matters must be studied more deeply and comprehensively to get mature results to help decision-making whether this power plant is needed.

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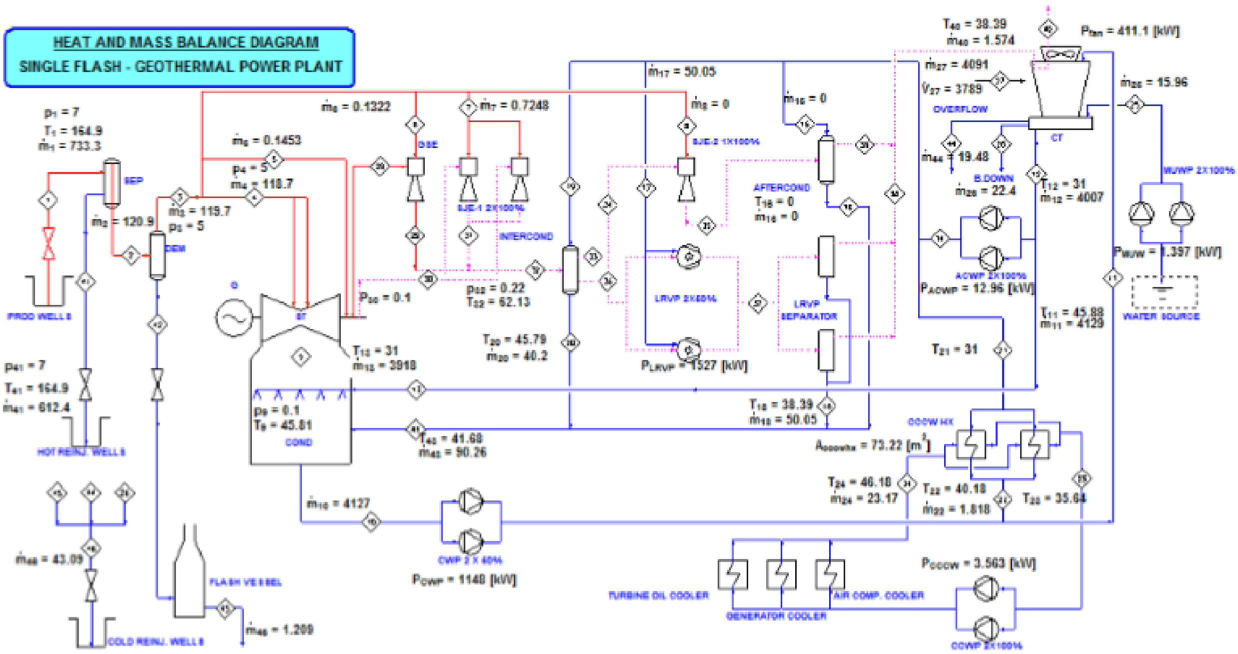

STREAM ID		1	2	3	4	5	6	7	8	9	10	11	12	13	15	16	17
FLUID		STEAM	STEAM	STEAM	STEAM	STEAM	STEAM	STEAM	STEAM	STEAM	WATER	WATER	WATER	WATER	WATER	WATER	WATER
PRESSURE	bar a	7		5	5	1.3	5	5	5	0.1						0	
TEMP.	°C	164.9		151.8	151.8		151.8	151.8	151.8	45.81	46.81	45.88	31	31	31	0	31
FLOW	kg/s	733.3	120.9	119.7	118.7	0.1453	0.1322	0.7248	0	118.7	4127	4129	4007	3918	0	0	50.05

STREAM ID		18	19	20	22	23	24	25	26	27	30	40	41	43	44	45	46
FLUID		WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	AIR	NCG	NCG	WATER	WATER	WATER	WATER	WATER
PRESSURE	bar a	0.06775									0.1		7				
TEMP.	°C	38.39	31	45.79	40.18	35.64	46.18	25	31	30.57	34	38.39	164.9	41.68	31		31
FLOW	kg/s	50.05	39.2	40.2	1.818	1.818	23.17	15.96	22.4	4091	1.572	1.574	612.4	90.26	19.48	1.209	43.09

Figure 1: Heat and Mass Balance Diagram for 1 x 55 MW Lumut Balai Geothermal Power Plant (Sulistyardi, 2015)

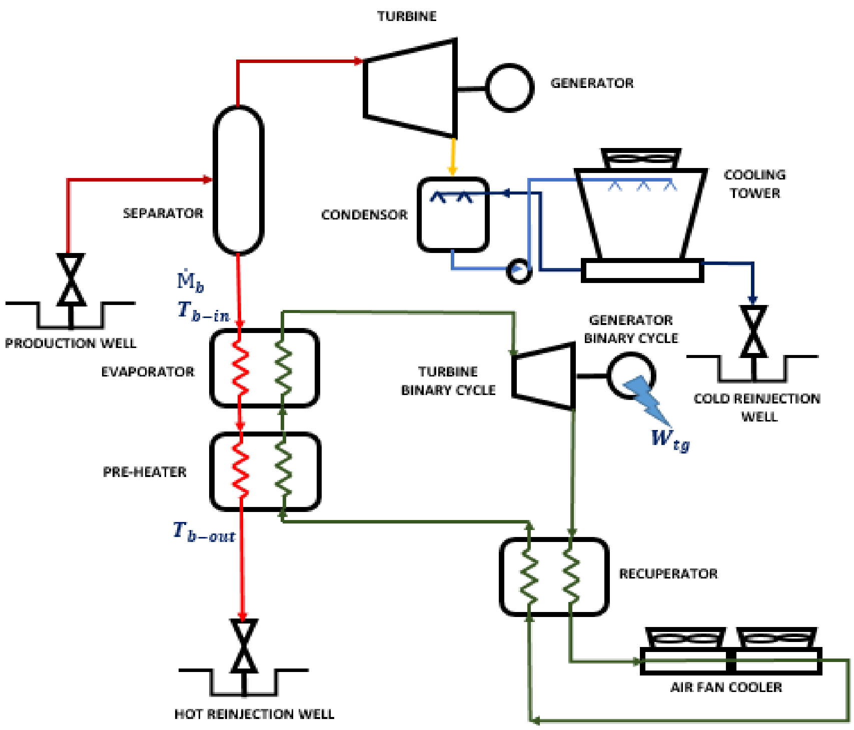

Figure 2: Diagram Combine Cycle Geothermal Power Plant