

## **An Update on the Basic Design of Lumut Balai Geothermal Power Plant, Indonesia**

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### **ABSTRACT**

Lumut Balai Geothermal Power Plant Project is a part of Power Plant Accelerated Development using Renewable Energy permitted by the Ministry of Energy and Mineral Resources (MEMR) Regulation No. 01 of 2012. This policy was taken by Government of Indonesia to increase the energy utilization based on new and renewable energy. Due to the increase in electricity demand, Lumut Balai Geothermal Power Plant is expected to strengthen energy supply in Sumatra Island electricity grid system.

This technical paper will update the basic design of the geothermal power plant according to previous research published under United Nations University Geothermal Training Programme (UNU GTP) in 2010. The update is indispensable since the project has been progressing. The update is including re-calculation on the heat and mass balance and determination of the main equipments technical specification. The UNFCCC Clean Development Mechanism Project Design Document is also taken into consideration during engineering design phase especially for the monitoring and the equipment installation aspect.

### **1. INTRODUCTION**

Lumut Balai geothermal field is located on the island of Sumatera in Indonesia, which is part of the PT Geothermal Energy working area. The project scope is categorized as total project covering the development of upstream (steam field, steam gathering and reinjection system) and downstream facility construction (geothermal power plant). PT Pertamina Geothermal Energy will sell generated electricity to the national network grid company through energy sales contract.

Basic design for Lumut Balai geothermal power plant was selected as a research topic taken by the author during 6 months training programme and the result was published under United Nations University Geothermal Training Programme (UNU GTP) in 2010. Since then the project has been progressing, an update on the basic design is becoming inevitably important to carry out. The updated design will be used as one of guideline during detailed engineering and plant construction at the later project phase.

### **2. LUMUT BALAI GEOTHERMAL POWER PLANT PROJECT**

The Lumut Balai geothermal project is located on Sumatera Island, South Sumatra Province, Penindaian village, sub-district of Semende Darat Laut, Muara Enim regency, about 292 km southwest of Palembang. The project area can be reached by four-wheel drive vehicles via the asphalted road from Palembang to Simpang Meo and onwards to the project site in Penindaian village, approximately 32 km on gravel and some paved roads. The geothermal prospect is sited around Mt. Balai, Mt. Lumut and Mt. Pagut. The average altitude of the geothermal field location is around 1000 m above sea level (m a.s.l.).

Bukit Lumut and Bukit Balai are eroded twin volcanoes exhibiting two eruption centres on Lumut (summit elevation at ~2055 m) and a third on Balai, about 5 km to the east. Active fumarole fields occur on Lumut volcano; the fields are surrounded by steaming ground with acid surface alteration (Penindayan field). Another group of manifestations occurs within the NE foothills of Balai volcano where boiling springs (Ogan Kanan group) discharge near neutral-pH sodium chloride water (estimated mass flow rate of about 300 kg/s) and deposit sinter. Cation geothermometers point to equilibrium temperature higher than 240 °C (Hochstein and Sudarman, 2008).

The Lumut Balai geothermal power plant project occupies an area which is planned for geothermal power plant units 1 & 2 and also for units 3 & 4, which will be developed in the next phase. The production wells are distributed on four wellpads. Reinjection wells are located at two different wellpads.

The bidding process for the first unit of 55 MW was commenced in end of 2013 and the expected commercial operation is planned in 2016.

### **3. GEOTHERMAL POWER PLANT BASIC DESIGN UPDATE**

#### **3.1 Design parameters and conditions**

Design parameters and conditions for the basic design of the geothermal power plant are as follows:

- The thermal steam cycle is a single-flash condensing cycle.
- The reservoir is water-dominated and the temperature is 270°C.
- Non-condensable gases (NCGs) are dominated by CO<sub>2</sub>.
- NCG content is 1.325% at design conditions for rated full load.
- Wet bulb temperature is 25°C at design conditions for rated full load.
- Relative humidity is 85%.
- The altitude of the geothermal power plant site is 1100 m a.s.l.

- Net output power is 55 MW of electricity for each unit of the geothermal power plant. Total net output power is 110 MWe.
- A separator is installed in each wellpad. The steam will be supplied to the power plant site as single-phase saturated steam while the brine will be delivered through a hot reinjection line and reinjected into hot reinjection wells. Condensate produced within the geothermal power plant will be delivered through a cold reinjection line and reinjected into cold reinjection wells.
- Condenser pressure is 0.1 bara.

### 3.2 Geothermal Power Plant Process Outline

Lumut Balai project, especially for Unit 1&2, is categorized as green field project whose resource risk is still high. The resource information such as under-exploitation reservoir and fluid characteristic data are still limited or even unknown. Thus, conservative development approach is selected to minimize those resource risk. The single flash technology is just to mention of how conservative development approach is implemented in the project development phase.

The single flash steam cycle with condensing turbine is recommended for the project so that the brine in the reinjection system will be kept at high pressure and high temperature. The single flash steam cycle is suitable for water-dominated resources of relatively low NCG content as is presented in Lumut Balai geothermal field. The single flash steam cycle is able to deliver large capacity of output power. It has the advantage over the double flash steam cycle in preventing silica scale formation in reinjection line.

The single-flash steam plant is maturely-developed, well-proven technology and is the mainstay of the geothermal power industry. It is often the first power plant installed at a newly-developed liquid-dominated geothermal field. As of July 2004, there were 135 units of this kind in operation in 18 countries around the world. Single-flash geothermal power plants account for about 29% of all geothermal plants. They constitute nearly 40% of the total installed geothermal power capacity in the world (DiPippo, 2005). By 2010, the single-flash geothermal power plants population is about 41% of all geothermal plants (Bertani, 2012).

Within the geothermal power plant system the steam flows to a steam turbine through mist eliminator, strainer, main stop valves, and control valves. Exhaust steam from turbine flows into direct contact type main condenser through exhaust duct. Expansion joint is installed between turbine and condenser to accommodate erection allowance and thermal expansion. In condenser, exhaust steam is condensed by direct contact with cold water from cooling tower basin, and mixture of cold water and condensate is sent to cooling tower top by circulating water pumps. In cooling tower, the mixture is cooled down and send back to the condenser by gravity and condenser vacuum. NCG is cooled down in main condenser to reduce accompanied steam and extracted by gas removal system and send to cooling tower fan stacks for dispersion into the atmosphere. The gas removal system consists of 1<sup>st</sup> stage steam jet ejector, inter-condenser, 2<sup>nd</sup> stage LRVP and LRVP separator. The backup for LRVP system as 2<sup>nd</sup> stage ejector is steam jet ejector and after-condenser. After first stage compression, inter-condenser is installed to condense motive steam. The separator will be installed after liquid ring vacuum pump to separate NCG and from LRVP working fluid. For the case of second stage compression using a steam jet ejector, the after-condenser will be used to condense motive steam from the NCG stream. The motive steam for the ejectors is drawn from the main steam line. Drain of inter-condenser, LRVP separator and after-condenser are led into the main condenser. Cold water from cooling tower basin is used not only for condenser cooling but also for turbine oil cooler, generator air cooler, air compressor cooler, inter-condenser, LRVP separator and after-condenser. Cooling tower is of multi cell mechanical induced draft wet type, counter flow type. Cooling tower is equipped with maintenance stair and lifting facilities. At the outlet of cooling tower basin, mesh screen is installed to eliminate foreign particles entering into the system. Excess water from the cooling tower is sent to settling basin, and sent to cold reinjection wells.

### 3.3 Heat dan mass balance calculation

The screenshot of thermal cycle model of the geothermal power plant developed for the project is shown in Figure 1. Graphical user interface modelling-approach is used to have better visual understanding of the overall system and it will speed up the engineering work on basic design phase to construct heat and mass balance diagram during the simulation.

### 3.4 Technical specification for main equipments and systems

Generally the equipments of the geothermal power plant shall be designed to bear operational condition in rated full load. Reasonable margin adjustment while sizing the equipments is indispensable since the geothermal power plant operational characteristic as base load power generation unit is dictated by the network grid requirement while on the other hand the performance of the geothermal power plant highly depends on climatic parameters such as wet bulb temperature and condition of steam supply like the NCG content.

#### 3.4.1 Steam turbine

Steam turbine will be a single or double flow, horizontal shaft, condensing unit. For geothermal power plant, it is essential to apply the protection for erosion/corrosion so it is considered that the rotor shall have erosion/corrosion protection overlay in the gland seal areas and nozzle stationary blade labyrinth seal areas.

The pressure at steam turbine inlet is 5 bar. The condition of steam at steam turbine inlet is saturated steam. Steam supply for guaranteed rated full load at 25°C, NCG content 1.325% and hybrid gas removal system is 118.7 kg/s.

#### 3.4.2 Condenser

The condenser is of a direct contact, spray type connected to turbine exhaust with an expansion compensator. It is designed to condense all the steam from the turbine for each of the load conditions. It is divided into two zones; condensation and gas cooling. The non-condensable gas from the condenser, after being cooled down to a temperature about 3 degrees higher than the cold water from the cooling tower, is extracted by the gas extraction system and discharged by piping through a stack to atmosphere in the cooling tower. Under guaranteed rated full load condition, the circulating water flow is 4,127 kg/s.

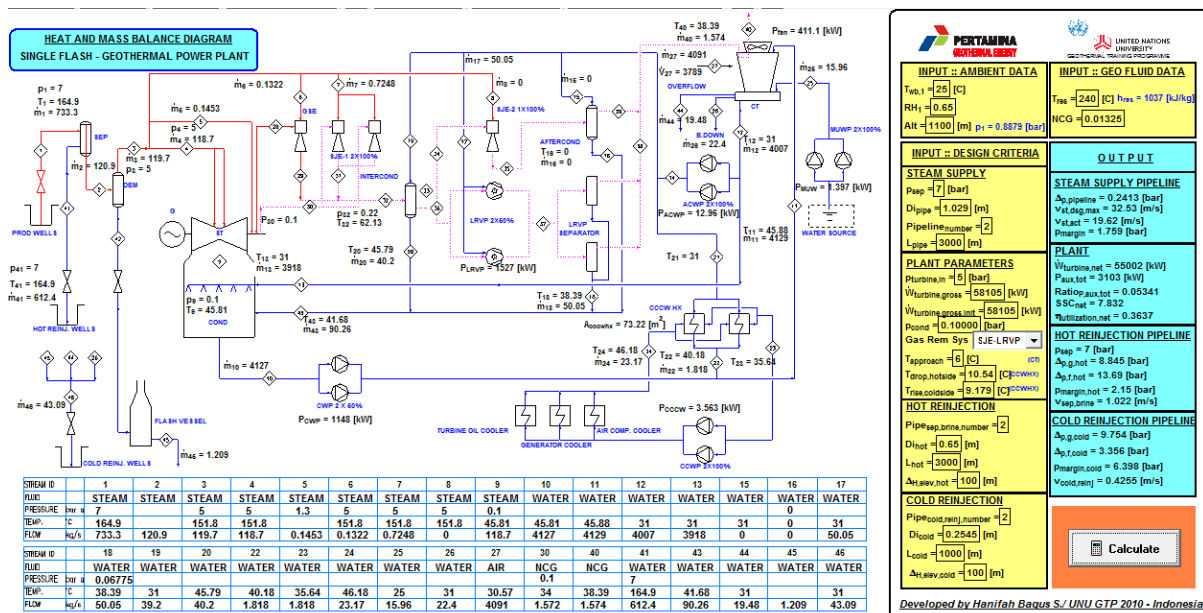


Figure 1: Heat and Mass Balance for 1 x 55 MW Lumut Balai Geothermal Power Plant

### 3.4.3 Circulating water system

Circulating water pump type is canned-type, vertical, wet suction, mixed flow. The circulating water mass flow for each pump is 2,477 kg/s with total developed head of 20 m. The configuration is 2 x 50% capacity. The power required for each motor is 689 kW.

The cooling tower is a multi cell mechanical induced draft wet, counter flow type and comprises of five cells. The total power drawn by cooling power fans is 411 kW, which is divided into five cooling tower fans, therefore the cooling tower fan motor power becomes 82.2 kW. Liquid-to-gas ratio of the cooling tower is 1.202. At design condition (wet bulb temperature 25°C, NCG 1.325%, hybrid gas removal system), approach temperature of the cooling tower is 8°C and cooling range is 13°C. Liquid-to-gas ratio will be maintained constant at any conditions while approach temperature and cooling range may vary.

### 3.4.4 Gas removal system

Two types of gas removal system will be installed. Hybrid system will be used during normal operation. Hybrid system comprises 1st stage compression using steam jet ejector. Then for 2nd stage compression the liquid ring vacuum pump employed.

The capacity of 1st stage steam ejector shall be able to handle NCG content within supplied steam ranging from 0.65% to 2% by weight. The steam supply for 1st stage ejector for rated full load is 0.725 kg/s. The configuration of 1st stage ejector is 2 x 100% while for 2nd stage ejector is 1 x 100%. The steam consumption for 2nd stage ejector, operating under dual steam jet ejector mode, is 3.23 kg/s.

The motor power for each LRVP is 763.5 kW. The LRVP configuration is 2 x 50%.

### 3.4.5 Steam gathering and reinjection system

#### 1) Wellpad separator stations

Topographical situation of the project area is hilly and the downhill slope is irregular so the option for satellite separator station or centralized separator station, in which the two-phase fluid transported through long pipeline, is not considered. Therefore, the wellpad separator option is selected as a design basis for the fluid separation and steam gathering system.

Separator stations are constructed near production well pads. After separation process, steam will be transported to the power plant through steam pipe lines, while hot brine will be collected and transported to the reinjection well pads through brine pipe lines. Hot brine reinjection of the separated liquid directly from the separators has advantages in avoiding contact with atmospheric air, therefore maintaining the pH and impeding scaling formation in the reinjection system.

The separator pressure in each wellpad is set to be 7 bar. The enthalpy of two-phase geothermal fluid flow is 1,037 kJ/kg with the steam quality of 16.46%.

There are four production wellpads that are served by one unit separator station for each wellpad. The mentioned separator station will be constructed in each production wellpad.

The requirement of total two-phase flow rate at design condition to supply 1 x 55 MW geothermal power plant is 733.3 kg/s. Then the requirement of two-phase flow for supplying 2 x 55 MW geothermal power plant at rated full load operation becomes 2 x 733.3 kg/s or 1466.6 kg/s. Added with margin then the total capacity of two phase flow for 2 x 55 MW geothermal power plant becomes 1613.4 kg/s.

If the production wellpads are assumed scattered in four locations and each wellpad is supplied with the same quantity of two-phase flow fluid then there are four separator stations that shall be fed with the capacity of 403.35 kg/s each.

## 2) Steam supply pipelines

Steam supply for one unit 55MW geothermal power plant will be served by two pipelines. According to available commercial pipe in the market (Nayyar, 2000), the selected nominal diameter of the pipe is 1,000 mm schedule 40 (Nayyar, 2000). The length of pipeline between separator station outlet header line to power plant is assumed around 3,000 m. The pressure drop along the pipeline at maximum capacity is 0.24 bar with the actual steam velocity is 19.64 m/s while the maximum steam velocity is 32.53 m/s. The pressure drop between the well head and the inlet of the power plant is around 3.43 % so the figure of pressure drop is still within an acceptable range and able to fulfill the steam turbine inlet pressure requirement which is 5 bar.

The permissible pressure drop between the assumed economic well head pressure and the designed inlet pressure to the power plant must not be exceeded. Where a wellpad separator is installed, it would be wise to allow a pressure drop of about 10% of the absolute wellhead pressure to be absorbed in the separator and its associated pipework (Armstead, 1983).

## 3) Hot reinjection system

The two-phase geothermal fluid will be separated into steam and brine streams after undergoing a flashing process in the separator. The steam will be transported to the power plant site through steam transmission pipeline while the brine will be reinjected to subsurface formation via hot reinjection wells. The brine will be transported from separator to reinjection wells through hot reinjection pipeline by means of gravitational flow.

Total brine flow rate from four production wellpads is 1,347.8 kg/s.

The insulation is required to keep the skin temperature at the surface of pipeline at an acceptable level to comply with the safety requirement and to maintain brine temperature high so the silica scaling along the hot reinjection pipeline can be minimized or even avoided.

## 4) Cold reinjection system

It is important to maintain a mass balance within geothermal power plant boundaries especially for condensate coming from overflow and blow-down in the cooling tower system. This situation is a result of direct contact condensing system that utilizes some portion of condensed steam to be re-circulated to condenser as circulating water after undergoing a cooling process in the cooling tower. However, due to a limitation of suspended solid concentration in the cooling fluid it is required to dispose this mentioned circulating water. The condensate will be disposed and reinjected to the cold reinjection wells.

### **3.5 Plant design consideration for the compliance to The UNFCCC Clean Development Mechanism Project Design Document**

According to The UNFCCC Clean Development Mechanism Project Design Document (UNFCC CDM – Executive Board, 2012), the following plant parameter monitoring shall be taken into consideration during EPC (engineering-procurement-construction) phase:

#### 1) Electricity main metering

Electricity produced will be measured by a watthour meter (connected to a digital control system and recorded continuously), which can measure both power delivered to the grid and received from the grid. Net electricity generation will be calculated from an electricity exported to the grid (electricity supplied by Lumut Balai I to the Sumatera grid) subtracting electricity imported from the grid. The measurement of electricity exported and imported will be conducted on a continuous basis and will be summarized and recorded transparently in monthly production reports. In the case of main revenue meter failure, a cross-check meter will be used as a back-up meter to measure both power delivered to the grid and received from the grid.

#### 2) Steam flow metering

The steam quantity discharged from the geothermal wells should be measured with a venturi flow meter (or other equipment with at least the same accuracy). Pressure and temperature upstream of the venturi meter is measured using the same venturi flow meter to define the steam properties. The measurement of steam quantities will be conducted on a continuous basis, where daily total flow measurement will be available. The measurement results will be summarized transparently in regular production reports.

#### 3) Geothermal well and power plant steam sampling

Non-condensable gases sampling should be carried out every three months in production wells and at the steam field-power plant interface using ASTM Standard Practice E1675 for Sampling 2-Phase Geothermal Fluid for Purposes of Chemical Analysis (as applicable to sampling single phase steam only).

#### 4) Diesel fuel flow metering

Fuel consumption will be recorded monthly, specifically for each fuel (currently only diesel consumption is expected). Measurement will be made in liters and converted to tons using a constant for fuel specific density or scientifically proven fuel densities.

## **4. CONCLUSION**

Lumut Balai project, especially for Unit 1&2, is categorized as green field project whose resource risk is still high. Thus, conservative development approach is selected to minimize the risk.

Topographical situation of the project area is hilly and the downhill slope is irregular so the wellpad separator design is selected. The steam phase fluid will be transported through cross-country pipe line instead of transporting two phase geothermal fluid from production wellpads to the power plants.

The single flash steam cycle and hot brine reinjection system are selected to keep the separated fluid pressure and temperature high so the tendency of scaling formation along reinjection pipe line can be hindered. This reinjection of hot brine directly from the separator is also beneficial to avoid contact between separated brine and atmospheric air so the fluid pH can be maintained.

Technical specification for the main equipment of the geothermal power plant is fixed based on the heat and mass balance diagram and ready as one of the input data for the next detailed engineering design phase.

Since the Lumut Balai project is listed as UNFCCC Clean Development Mechanism Project, therefore, the engineering design shall consider technical aspects, such as plant parameter monitoring, as stated in The UNFCCC Clean Development Mechanism Project Design Document.

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