

Geothermal Energy Utilization and Environment Impact Prevention on Single Flash Steam Cycle System Case Study: PLTP Ulubelu - Lampung

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Abstract: The study of geothermal energy utilization and the problem of toxic elements such as mercury, boron, arsenic, and antimony in steam is discussed to prevent the environment risk already conducted by literature tracing. The impurities gases such as methane, CO₂, SiO₂, hydrogen sulfide and ammonia also exist in low concentration in steam which can cause corrosion to engines and metal equipments and contribute to environmental impact specifically in global warming and acid rain. The main concern in harnessing the geothermal energy is minimizing the environmental risks and public healths impacts. Separators of varying working principles are the most important apparatus to eliminate the unwanted gases and elements from the steam. The prevention of silica deposition has already studied. The silica analyzing deposition methods such as Fournier, Di Pippo and SSI are also discussed. Silica deposition in pipes will increase the pipe friction coefficient and disturb the turbine working operations. Separator working with cyclone base system eliminates the heavy metallic toxic elements and gases from the superheat steam before entering the turbine on the principles of centrifugal force. The condensed fluid at the bottom of the separator body where the toxic and the impurities elements dissolved are reinjected to the earth.

Keywords: Geothermal energy, toxic elements, impurities gases, environment, separators

1. Introduction

Geothermal energy is heat energy generated and stored in the earth. The geothermal energy of the earth's crust originates from the original formation of the planet and from radioactive decay of materials in the past. The geothermal gradient, which is the difference in temperature between the core of the earth planet and its surface, drives a continuous conduction thermal energy in the form of heat from the earth core to the surface.[12]

Geothermal power is considered to be renewable because the projected heat extraction is small compared to the earth's heat content. The earth has an internal heat content of 10³¹ joules (3·10¹⁵ TW·hr), approximately 100 billion times current worldwide annual energy consumption. About 20% of this energy is residual heat from planetary accretion, and the remainder is attributed to radioactive energy decay that occurred in the past.[13]. Fluids drawn from the deep earth carry a mixture of gases, notably carbon dioxide (CO₂), hydrogen sulfide (H₂S), methane (CH₄) and ammonia (NH₃). These pollutants contribute to global warming, acid rain, and noxious smells if released to atmosphere. Existing geothermal electric plants emit an average of 122 kilograms (269 lb) of CO₂ per megawatt-hour (MW·h) of electricity, a negligible fraction of the emission intensity of conventional fossil fuel plants. [13]

In addition to dissolved gases, hot water from geothermal sources may hold in solution trace amounts of toxic elements such as mercury, arsenic, boron, and antimony. These chemicals precipitate as the water cools, and can cause environmental damage if released. The other impurities such as hydrogen sulfide, CO₂, NaCl, SiO₂ and ammonia also dissolved in low concentration in solution and due to cause corrosion to turbine blades and any other

metals equipments and contribute to global warming and smells when released. Plants that experience high levels of acids and volatile chemicals are usually equipped with emission-control systems to reduce the exhaust of toxic and smells gases to atmosphere.[14] The modern practice of injecting cooled geothermal fluids back into the earth has the side benefit of minimizing the environmental risk.

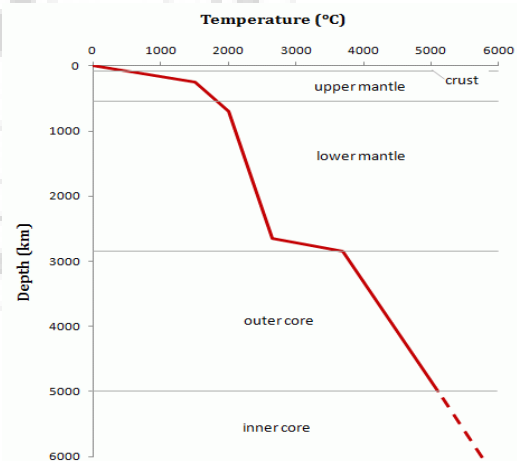


Figure 1: Geothermal gradient. Temperature inside the earth gradually increases with depth due to the interior heat flux. The average gradient in the earth crust is approximately 25°C per km.[15]

2. Indonesia Geothermal Energy Reserves

Studies indicating that the temperature of the earth core about 5400 °C to 6000 °C. Hydrothermal energy exist in many sites below the earth surface mainly at the locations near the volcanic activities. This magmatic activities make the upper layers of the earth warmed. When these layers in

touch with fluids, it produces vapour with high temperature and high pressure, which then called geothermal energy. The sites of geothermal energy sources spread out, notably at the ring of fire countries such as Indonesia, New Zealand, Japan, United States of America, Philippine, Mexico and Iceland. Geothermal energy utilization is attract much attention as one of futuristic energy source in coming decades. The superiority of geothermal energy is clean, renewable, sustainable and environmentally friendly. The operation cost is much cheaper, because no fuel required to run, but the high cost at the beginning installation, including the feasibility study, the earth exploration and the hydrothermal drilling. [16]

The geothermal energy is one of huge energy potentials in Indonesia. It is projected about 40% of the world geothermal energy potentials are deposited in Indonesia.

Geothermal electric energy contributes to Indonesian national domestic electric consumption of about 1.5% or about 435 MW from the total 10 geothermal electric generations (PLTP). Indonesia has 256 geothermal sites that is presumably feasible to developed to be the following geothermal power plant, spread in Sumatra 84 sites, Jawa 76 sites, Sulawesi 51 sites, Nusa Tenggara 21 sites, Maluku 15 sites and Kalimantan 5 sites.[17]

Regarding The Indonesian Energy Resources Ministry assessed the overall Indonesia geothermal energy capacity is about 28.994 Mwe or equivalent to 200 milliard oil barrel in 2013. It is about 4% of the total available hydrothermal energy is harnessed in Indonesia. The geothermal energy is also used as non-electric energy utility such as room heating, water heater, greenhouse heating, wood products drying, agriculture products drying etc. [1].

Indonesia energy affair ministry in the “Road Map Pengelolaan Energi Nasional” has already planned to gradually ascend the national electric consumption from geothermal energy from 1438 MW in year 2015 to 4000 MW in year 2020. (Kementerian Energi dan Sumber Daya Mineral, 2014). The ascending of national geothermal energy consumption challenge the scientist and technicians to ensure the safe and the environmental friendly operations of power plants. [2][3]

3. Ulubelu Geothermal Energy Plant

The Ulubelu Geothermal Energy Plant in Lampong, has the capacity of 220 MW or equivalent to 9,570 oil barrel per day and fulfill 25% of Lampung area electric demand. PLTP Ulubelu is located in Muara Dua village, Ulubelu subdistrict, Tanggamus Regency, Lampung Province. PLTP Ulubelu qantitatively produce 2 X 55 MW energy and constructed on area of 12.9367 hectares. [19]



Figure 2: Ulubelu power plant site

The prime problems of geothermal power plant utilization is, preventing the inpurities and toxic compound from contaminating the atmosphere and silica scaling formation in pipe. This paper will discuss about the separators working principles to purify the wet steam from the earth and what have already done in Ulubelu Lampong to prevent the unwanted chemical matters from environment pollution..

3.1 Ulubelu Separated Steam Cycle

The cyclonic or centrifugal type separator uses a series of fins to generate high-speed cyclonic flow. The velocity of the steam causes it to swirl around the body of the separator, throwing the heavier, suspended water to the wall, where it drains down to a steam trap installed under the unit and reinjected to the earth.

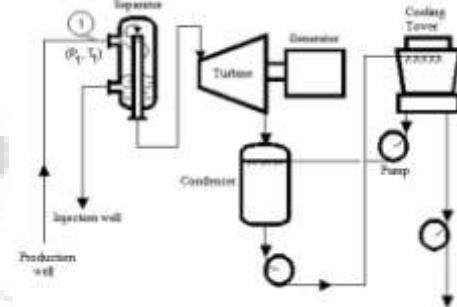


Figure 3: Separated Steam Cycle System [4]

The steam from the well enters the separator after passed through the *Steam Receiving Header*. The cyclone type separator will work on the base of centrifugal force to eliminate the impurities and toxic matters such as sodium, potassium, calcium, silica, boron, ammonia, flouride out of the steam and expanded in the turbine. These impurities and toxic elements are then reinjected to the earth through the high pressure pump due to prevent the environmental unwanted impact. [5]

3.1.1. Separators Working Principles

Separators became the most important part of the Geothermal Power Plant regarding the environment pollution prevention. In this case, some kind of separators already created.

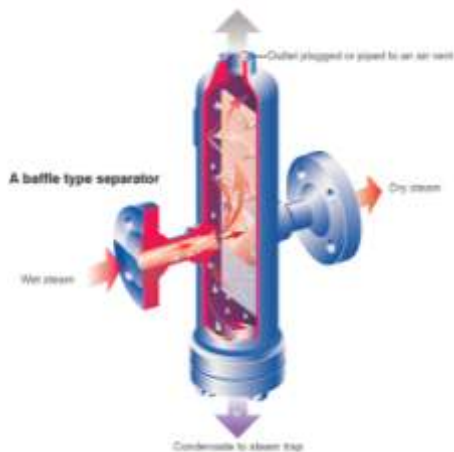


Figure 4: Baffle Type Separator

A baffle or vane type separator consists of a number of baffle plates, which cause the flow to change direction a number of times as it passes through the separator tube. The suspended water droplets have a greater mass and a greater inertia than the steam; thus, when there is a change in flow direction, the dry steam flows around the baffles and the droplets collect on the baffles. Furthermore, as the separator has a large cross-sectional area, there is a resulting reduction in the speed of the fluid. This reduces the kinetic energy of the water droplets, and most of them will fall out of suspension at the bottom of separator tube. The condensate collects in the bottom of the separator, where it is drained away through a steam trap. [20]

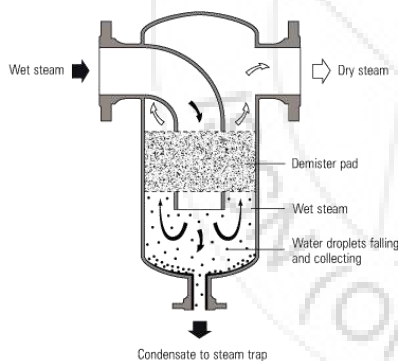


Figure 5: Coalescence Type Separator

Coalescence type separators provide an obstruction in the steam path. The obstruction is typically a wire mesh pad or sometimes referred to as a demister pad, upon which water molecules become entrapped. These water molecules tend to coalesce, producing droplets that are too large to be carried further by the gas system. As the size of the droplets increases, they become too heavy and ultimately fall into the bottom of the separator. In some cases, it is common to find separators, which combine both cyclonic type and coalescence type in operations. By combining the two methods, the overall efficiency of the separator is mostly improved. Separator efficiency is a measure of the weight of the water separated out in proportion to the total weight of the water carried in by the well steam. It is difficult to establish the exact efficiency of a separator, because it depends on the inlet dryness fraction, the fluid velocity and the flow pattern of steam.[20]



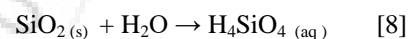
Figure 6: Cyclone type separator

The cyclonic or centrifugal type separator uses a series of fins to generate high-speed cyclonic flow. The velocity of the steam causes it to swirl around the body of the separator, throwing the heavier, suspended water to the wall, where it drains down to a steam trap installed under the unit. [9]

The Ulubelu geothermal plant uses the cyclone type separator on the basis of high efficiency consideration. [20]

3.2 Silica Scaling Prevention.

Most of minerals are dissolve in hydrothermal fluids or brine at high temperature. The solubility of minerals will decrease when the temperature drop down. Thus, to avoid amorphous silica scaling, it is common to inject geothermal water back to the well at a temperature above amorphous silica saturation. However, this method results in a relatively inefficient use of the heat energy brought to the surface.(10) The dissolution of silica in water to form monosilicic acid (monomeric silica) occurs according to the following chemical reaction.



Temperature, Enthalpy (Keenan et.al,1969) and Silica Solubilities (Fournier & Potter,1982) in liquid and gaseous water (steam) at the vapor pressure of the solution [9]

No.	T °C	H J/g	SiO ₂ mg/kg	No.	T °C	H J/g	SiO ₂ mg/kg
1.	20	84.0	6.1	18.	190	807.6	230.1
2.	30	125.8	8.1	19.	200	852.5	263.0
3.	40	167.6	10.7	20.	210	897.8	298.5
4.	50	209.3	14.0	21.	220	943.6	336.4
5.	60	251.1	18.2	22.	230	990.1	376.4
6.	70	293.0	23.5	23.	240	1037.3	418.3
7.	80	334.9	30.0	24.	250	1085.4	461.8
8.	90	376.9	37.9	25.	260	1134.4	506.2
9.	100	419.0	47.4	26.	270	1184.5	551.0
10.	110	461.3	58.6	27.	280	1236.0	595.3
11.	120	503.7	71.8	28.	290	1289.1	638.2
12.	130	546.3	87.1	29.	300	1344.0	678.4
13.	140	589.1	104.7	30.	310	1404.3	714.2
14.	150	632.2	124.6	31.	320	1461.5	743.6
15.	160	675.6	147.1	32.	330	1525.3	763.6
16.	170	719.2	172.1	33.	340	1594.2	770.1
17.	180	763.2	199.8	34.	350	1670.6	756.2

The minerals that are not soluble in brine will leave and make deposits on surfaces. The prime problem faced by geothermal power plant is silica deposition (SiO₂). The formation of quartz silica on the inner pipe surface will decrease the pipe cross section area and enlarge the

coefficient of friction of fluids even shut off the fluid flow in operation well. To prevent the scale formation, there are three theoretical approximations.

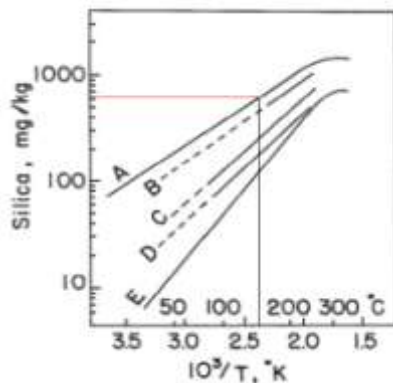
Chemical compositions of brine of Ulubelu Geothermal Power Plant.[11]

Komposisi	Nilai	Satuan
Clorida	1228	Ppm
Iron	0,86	Ppm
Silica	599	Ppm
Boron	33,3	Ppm
TDS	2620	Ppm
PH	6,35 TO	8.46

From the table it is found that the pH of brine is varied from 6 - 8. The amorphous silica content before separator is about 599 ppm. The following silica scaling analysis is plotted on the base of silica content in fresh brine from the well, where the maximum content of chemicals existed. [11]

3.2.1 Fournier Method

The content of silica in brine before separator is 599 ppm. If the data plotted on Fournier Diagram, we found the recrystallization temperature or minimum temperature required to prevent the scaling i.e, about 150 °C. The real temperature in separator is 170°C which is above the amorphous silica solubility in brine. This indicates no silica scaling deposition is possible.



Gambar 7: Silica content and saturation teperature [9]

3.2.2 Di Pippo Method

Di Pippo method the same with Fournier method, where the silica content data plotted on DiPippo diagram, and we found the saturation temperature. For the content of 599 ppm we found the silica saturation temperature of about 148°C. The real temperature of brine comes out of well is 170 °C. Indicating no silica scaling is possible. [6]

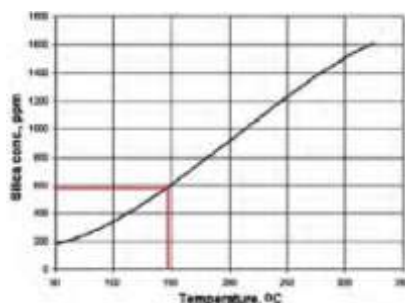


Figure 8: Silica content and saturation temperature.

3.2.3 SSI method

Silica saturation index or SSI is the ratio of silica content in brine and the solubility of silica in fluids at related temperature.

- When SSI > 1, the fluids is in supersaturated condition, where the silica formation is possible.
- When SSI = 1, the fluids is in saturated condition.
- When SSI < 1, the fluids is in undersaturated condition, where the silica formation is impossible. [10]

The solubility of silica in brine at 175⁰C is:

$$\begin{aligned} \text{Log } s &= -6,116 + 0,01625T - 1,758 \times 10^{-5}T^2 + 5,257 \times 10^{-9}T^3 = \\ &= -6,116 + 0,01625(448) - 1,758 \times 10^{-5}(448) + 10^{-9}(448)^3 \\ s &= 10^{-1,94588} \times 58400 \\ s &= 661,5028 \end{aligned}$$

Hence, the silica scaling index is:

$$\begin{aligned} \text{SSI} &= \frac{s_1}{s} \\ &= \frac{599}{661,502} \\ &= 0,845 \end{aligned}$$

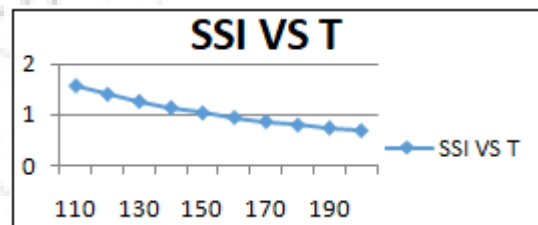


Figure 9: SSI vs Brine temperature

Hence no possibility of silica scaling formation in Ulubelu Geothermal Power Plant Lampong, regarding theoretical point of view. [11]

4. Results and Discussion

From the above explanation and calculation, it is right for the Ulubelu Power Plant Lampong to apply the cyclonic separator in order to separate the impurities and toxic matters from the wet steam comes out from the prime wells. The elements of toxic materials such as mercury, boron, arsenic, and antimony. The impurities gases such as methane, CO₂, SiO₂, hydrogen sulfide and ammonia sodium, potassium, calcium, silica, boron, ammonia and flourides separated by centrifugal power out of the steam and drop them down the separator base. These impurities matters and toxic elements are then reinjected to the earth through the high pressure pump in order to prevent the environmental unwanted impact. Moreover, to prevent the Silica Scaling formation, it is important to set the Silica Scaling Index less than one, which means the fluid is undersaturated condition, where the silica formation is impossible. Fournier method and Di Pippo method can also used as analysis tool whenever the silica content at related temperature is known.

5. Conclusion

- Cyclone type separator used in Ulubelu Power Plant Lampong is an effective apparatus in order to separate the impurities compound and toxic materials such as sodium,

potassium, calcium, silica, boron, ammonia and fluorides from the wet steam .

- The analysis of silica scaling prevention can be calculated on the base of silica content in steam at related temperature, i.e. by Fournier, Di Pippo or Silica Scaling Index method.

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