Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Successful Exploration Campaign and to be Developed in Hululais Geothermal Field, Bengkulu Indonesia

Kamah M. Y. , Palmelay A.C, , Rahardjo I.B., Thamrin M.H., Hartanto D.B, Silaban M.S., Sasradipoera S.D.

Pertamina Geothermal Energy and Upstream Thechnology Center Pertamina (Persero)

Skyline Building 15th flr, MH. Thamrin Street no. 9 Jakarta 10340 Indonesia.

yustinkamah@pertamina.com

Keywords: hululais geothermal field, exploraiton campaign, ready to develop

ABSTRACT

The Hululais geothermal field is situated about 80 km north of Bengkulu City Sumatra and has a geothermal area of 120 km^2. On August 2012, the main access road was constructed in this area to four drilling pads. Three exploratory wells have been already drilled directionally. Pertamina Geothermal Energy has conducted well production test of HLS –C1 and the well succesfully discharged geothermal fluid. It was reported that the discharged first geothermal fluid was composed of a lot of steam and brine with netral acidity. Estimated potential of the first exploratory well is aroud 10-20 MW, which is agood evidence and indicates that Hululais geothermal field is ready to develop.

1. INTRODUCTION

The Hululais geothermal field is situated about 80 km north of Bengkulu City Sumatra within 120 km^2 covered geothermal area (Figure 1). Bengkulu Province has been behind the development sectors compared with the other provinces in Indonesia. This is mainly due to the poorness of mineral and petroleum resources and the geographic characteristic of remoteness from large cities. The poor population ratio over the total population in Bengkulu Province exceeds 14.15% of the Indonesia average (18.59% as of March 2009). This is the reason why it is necessary to develop the geothermal energy as a starting point in this region to move foreward similarly with other provences in Indonesia (The Ministry of ETI, all.,2011).

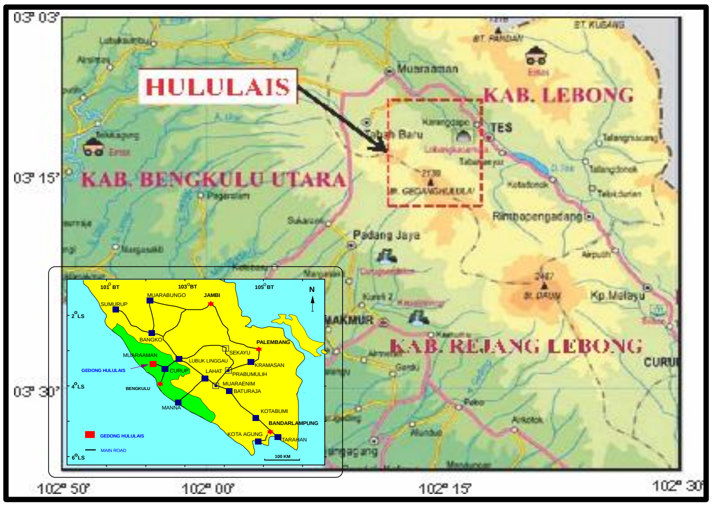


Figure 1: Location of the Hululais Geothermal Area, Bengkulu Province.

Our exploration campaign area is located in Hululais Geothermal Area Bengkulu province-Indonesia. This area is one of many geothermal features at Sumatra of the hinterland of fault system Bukit Barisan while at the southern Sumatra build active volcano of Krakatau at Sunda Strait. There are a lot of geothermal manifestations such as fumarole, mudpool, hot springs, steam heated groud and wide spread alterations. Conclusively GGG surveys (geological, geochemical and geophisical surveys) had already done by Pertamina Own through Pertamina Geothermal Energy (a subsidiary Company of Pertamina Energy Holding).

The Hululais geothermal field, owned by P.T. Pertamina Geothermal Energy (PGE), plan to develop 110 MW for two power generation units using 12 (twelve) production wells and 3 (three) injection wells. All wells will be drilled as directional wells due to the boundary prospecting geothermal area inside the untouchable protective forest.

Since August 2012 Pertamina Geothermal Energy has already prepared access road for four well pads (Pad A, Pad B, Pad C and Pad D). Three directional wells (HLS B/1, HLS C/1 and HLS A/1) have been drilled as exploratory wells until 2014. PGE also has conducted well production test of HLS C/1 and HLS A/1 and the wells discharged geothermal fluid very succesfully. The first exploratory well discharge HLS C/1 and composed a lot of steam and brine with netral acidity of fluid fortunately. From well testing, the potential production of both wells were calculated and the results were 10-20 MW. Steam availablity now is around 40 MW and PGE plan to build 110 MW power generation in year of 2017.

2. METHODS

2.1. Review of Existing GGGR Data and Information

Methods used include the evaluation of Geology, Geochemistry, Geophysics and Reservoir (GGGR). GGGR data is focusing on the structural fault and fractures analysis are structural mapping and fault plane analysis with a focus on surface and subsurface distribution. From surface we evaluated orientation (strike and dip) of faults and joint planes as well as the slip direction and subsurface concern to result from formation Micro Imager (FMI/FMS) logging. Both methods are relevant elements to determine which is the best target for drilling focus to reach Total Loss Circulaiton (TLC).

Evaluation of geochemistry data from fluid and gasses has information about fluid flow direction coresponding fault orientations and discontinuities fractures. Appearance of thermal springs, and the hydrogeochemical composition of groundwater from wells and hot springs to the surface

Review of Magnetotelluric (MT/TDEM) data resulted from 30 stations covered aroud 35 km^2 area and three Dimesional MT inversion result indicate best responship starting from 1000 m to the deeper 3,500 m depth or + 600 masl to minus 1500 m bsl. Clay cap as a good cap rock covered area at the 600-800 m below surface (+1000 m asl) roughly.

Three exploratory wells have been drilled and two of them were successful with potential aroud 10–20 MW /well. While one well HLS B/1 reached high Temperatur 200-220^{o}C but no permeability uncountered during drilling. Hydrofracturing has been done in this well but fractures close-sealed hardest by silica deposition and this job was unsuccesfull. Additional methods need to prepare data: XRD laboratory analisis, fluid inclusion laboratiry analisis and core cutting petrography thin section.

2.2. Conceptual Geothermal Model

Eventually, modeling of hydrothermal fluid flowing mechanism for geothermal modelling concept is needed. Event data result just came from three exploratory wells fully successed. The geothermal model design was based on the GGGR data combining GGGR surface dan rocks property from subsurface drilling. Conceptual geothermal model shows heat source origin, fluid flow from up-flow zone to out-flow zone, temperature distribution, gasses component, fractures distribution, fault dipping, surface view of geothermal manifestations, well pad location, fluid recharge area and fluid sources, reservoir rocks, over burden and clay cup.

Hululais Conceptual Geothermal Model was based on many parameters supporting likes distribution of manifestation, fumarole, hot springs, mudpool, altered rocks, productive fractures in fault plan, fluid trending flow, subsurface high temperature (200-300 ℃), high permeability zone and clearly resisitivy layers. Well pad location is 500 m distance outside of borderline protective porest and the well was drilled directionally with high angle inclination. Horizontal displacement (> 1500 m long distance) is needed to reach up flow zone inside the protective area.

3. RESULTS OF GEOTHERMAL FIELD DEVELOPMENT

3.1 Geothermal Resources

Quarternary volcanic rock deposit mainly cover Geothermal Prospect Area of Hululais and surrounding. Hululais Andesite rocks and Lumut formation (pleistocene age) area common outcrops appear in the prospecting area while manifestations such as fumarole, mud pool, hot spring come to surface trough fractures in this formation. Basement rocks predicted sedimentary rocks where outcrop indentified outside boundary area. Granite and granodiorite intrusion fragmentals have light white colors spread around and could be as heat source for geothermal Hululais.

The Faults trending mainly NW-SE is relevant with great Sumatra fault along Sumatra Island and indicate good permeability as open fracture (**Figure 2**).

Geothermal manifestation such as fumarole, hot spring, altered ground, mud pool, and steaming ground were identified on the north eastern side of the ridge trending southwest to northeast from Mt Hululais downward to Subang Gregok or from up flow region to downward slope as out flow region.

Geothermal geological condition under the ground was obtained from the drilled three expolation wells; HLS A/1, HLS B/1 and HLS C/1. Sequences of formation is volcanic rocks composed andesite altered basaltic andesite, andesite breccia and tuff breccia. All formations have been altered by hydrothermal fluid influencing trough open fractures. The basement rock in this filed is Pre-Neogene Sedimentary rocks but no wells reaches to this formation. The Zonation of altered zone devided fron argillic zone at upper part, continue argillic propylitic and propilitic where propilitic is dominanted at reservoir. Loss circulation during drilling was countered at deep starting at > 2000 mMD untill Total Depth 3000 mMD. Inclination is around 40-45 degree, where horizontal drilling distance is aroud 1.5 km roughly.

Well HLS A/1 and HLS C/1 founds partial and/or Total Loss Circulation (TLC) during drilling. Partial loss circulaton (PLC) is always counter at hole trajectory for csg 13 3/8 inch, liner 10 3/4 inch and liner 7 inch. PLC is first good indicator performance well before drill untill a total Depth, **Figure 3**.

Total Depths for three wells is 2500-3000 mMD, and Horizontal displacement > 1000 m distance from cellar because cellar located outside borderline of protective forest, about 500 m away. Temperature of reservoir ranges from 220 to 280 ^{0}C and reservoir pressure is 34-35 Ksc. Higher temperatur (275-280 °C) is covered at 1000-2100 mMD in hole. Similarly subsurface temperature information from fluid inclusion homogenization around 220-320^{0}C, which means tahat subsurface temperature does not change from past until present situation. Stable temperature in reservoir is needed for forcasting resources to future.

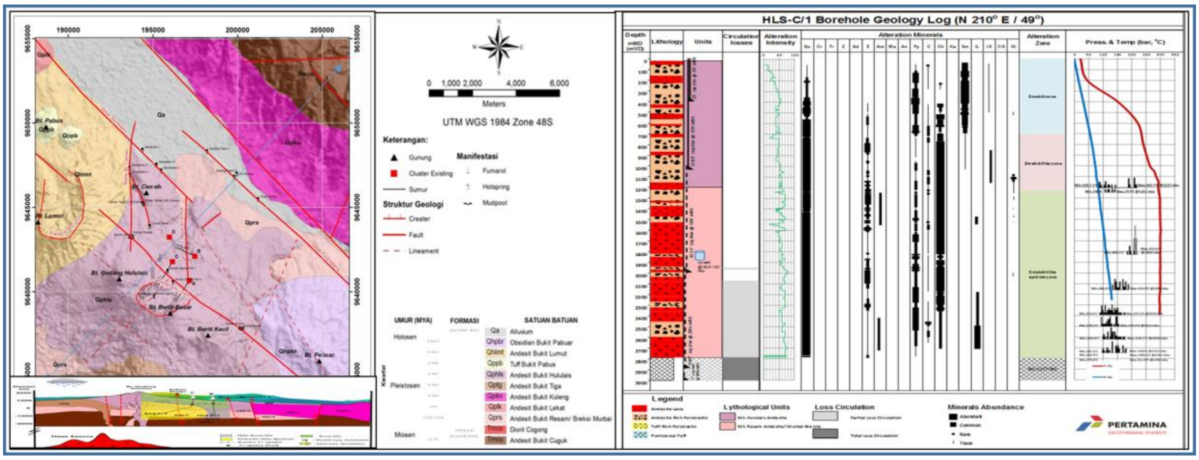


Figure 2: Geological Map of the Hululais Geothermal Area, and Figure 3: Geological Log of HLS C/1 Well completed with fluid inclusion and Pressure Temperature profiles, Hululais Geothermal Area.

The chemical analysis from fluid manifestation and discharged brine from wells was conducted (**Figure 4**), where acidic SO_4 water occurs in several manifestation, indicating high SO_4 and low Cl/ SO_4 ratio, of the acidic water result from the oxidation of H_2S gas contained in the steam that yield the fumaroles or mud pool (Brehme, 2014). Very low Cl cocentration of the acidic water implies that the origin of water is shallow meteoric goundwater and/or steam condensate. For brine from wells, the data plot very close to the full equilibrium curve on the ternary plot indicate that the brine is chemically equilibrated within reservoir. Although the SiO_2 (quarzt) temperature of the brine is calculated to be 250 ^{0}C and possibly the highest temperature at deep levels in reservoir may exceed to 270 ^{0}C as indicated by cation geothermometers.

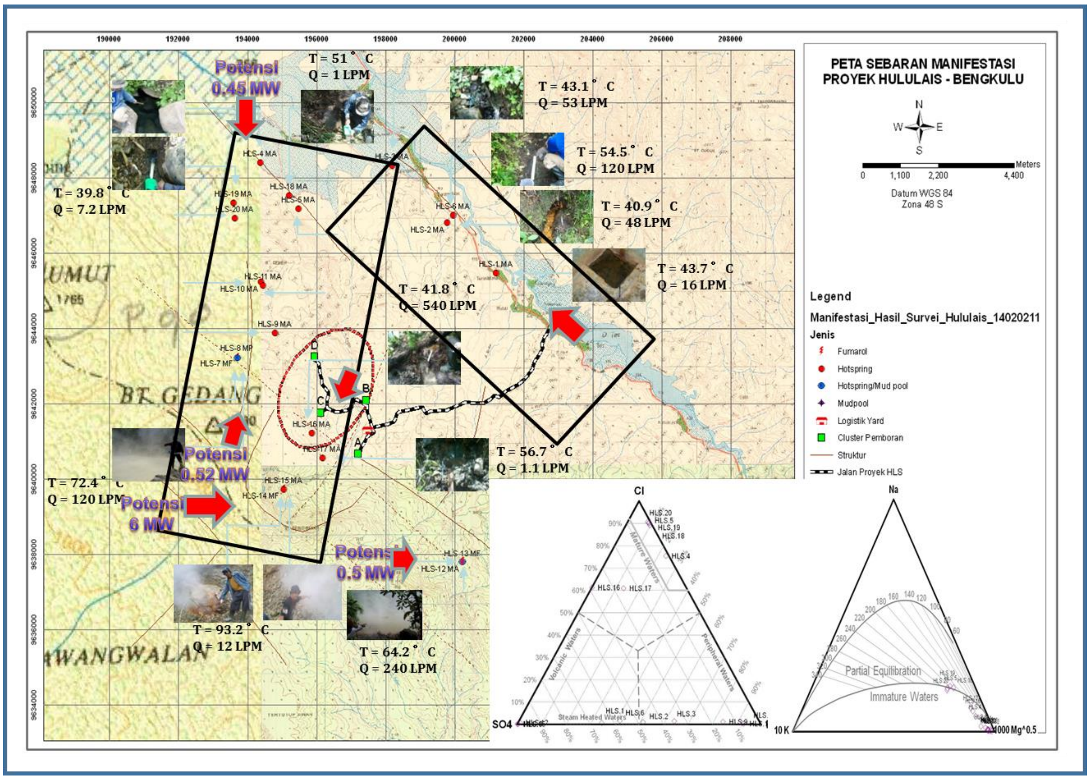
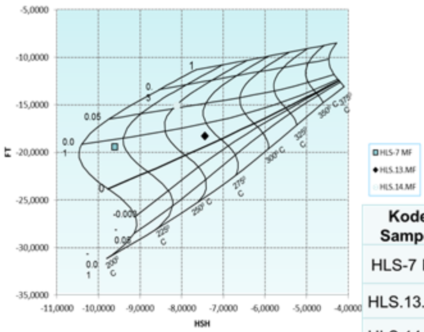


Figure 4: Surface thermal manifestations of Hululais geothermal Field

The Gases from fumarole at several locations is mainly composed of CO_2 as well as the gasses of typical hydrothermal systems. Geothermometries utilizing gas chemical compositions indicate the existence of deep hot reservoir having a temperature of 250-280 ^{0}C. Cross plot of H_2/Ar vs CO_2/Ar suggest the occurence of liquid-equilibrium fluid of reservoir and two phase liquid and vapor (**Figure 5**).



Kode Sampel	Lokasi	H2/Ar	H2S/Ar	CO2/H2	H2S/H2
HLS-7 MF	Suban Gregok	285,9	260,4	251,6	273,4
HLS.13.MF	Suban Nusuk	130,9	156,3	271,2	262,5
HLS.14.MF	Suban Agung	296,2	287,2	271,2	262,5

Kode Sampel	Lokasi	FT (y)	HSH1(x)	y	T	Vv	VL	Sv	SL
HLS-7 MF	Suban Gregok	-19,4067	-9,6192	0,006	**220**	0,0861	0,0012	0,30	0,70
HLS.13.MF	Suban Nusuk	-18,2554	-7,4485	0,003	**269**	0,0362	0,0013	0,08	0,92
HLS.14.MF	Suban Agung	-15,0427	-8,1231	0,060	**251**	0,0501	0,0013	0,72	0,28

Figure 5: Reservoir temperature calculated using gas geothermometry (temperature ranges from 250 to 296°C)

Three-dimensional resistivity inversion analysis from Magnetotelluric Data has been conducted. Frequency ranges from 96 Hz to 0.04688 Hz, rotated direction 45 ^{0}W. Resistivity map results from the three-dimensional resistivity inversion with slice depth start from 75 m depth to 3,650 m depth, in this case we just focused on the conductive layer of reservoir layers (800 m-3000 m depths). The resistivity discontinuity is a structure exhibiting a big lateral change in resistivity and closely correlation with fractures such as fault plan and fractures zone trend. In generally, gothermal fluid is often reserved in fractures zone and surrounding, so detecting resistivity discontinuities is important on studying geothermal structure in this area. In Hululais Geothermal field, five rersistivity discontunuities have been recognized based on the 3D resistivity inversion results (**Figure 6).**

Resistivity discontinuity in the central area roughly aligned trending NNW-SSE and NW-SE direction. Distribution of this resistivity of greater than 100 ohm-m is relatively deep from 1,700-3,650 m depth. In between there is a large scale high resistivity zone distributed in central area (about 25-50 km^2), meanwhile as interpreted as main production zone of geothermal fluid and common rule in this area inform up flow zone where heat source beneath down ward to magma chamber.

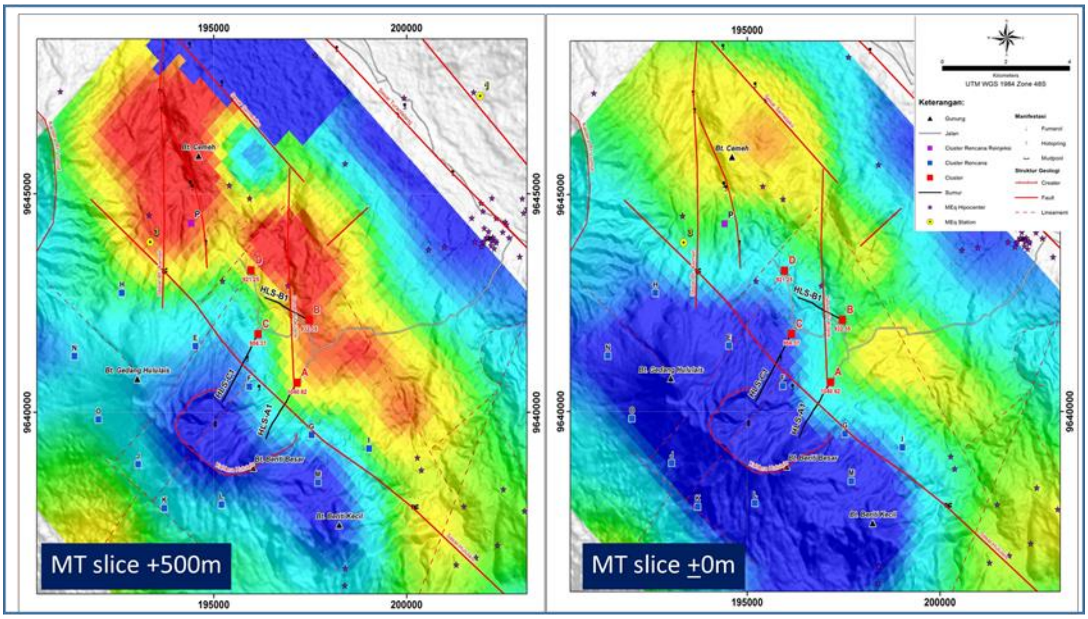


Figure 6. Resistivity distribution Map of sea level and +500 m asl, Hululais Field

Bouger anomaly map (**density = 2.67 gr/cm^2)**, a steep gradient zone of Bouger anomaly values distributes almost paralel to the resistivity trending and fault zonation. So correlation among resistivy, Bouger anomaly and fault fractures as good indicator suporting presense of geothermal active in subsurface, **(Figure 7).**

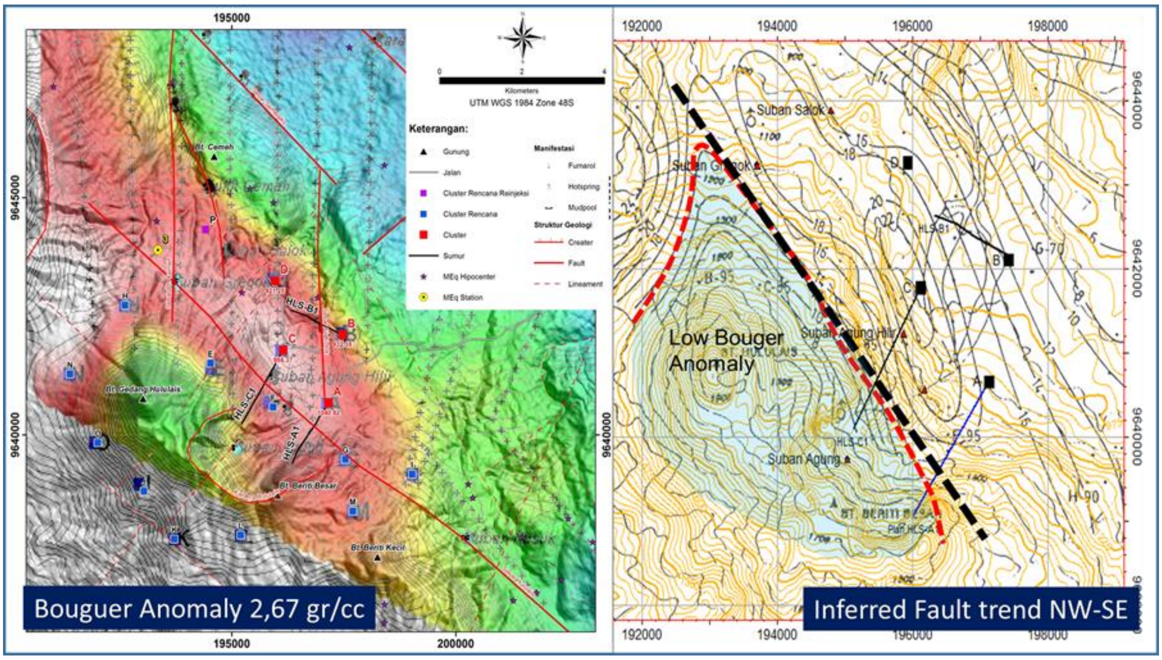


Figure 7. Bouguer anomaly map (∂ 2, 67 gr/cc) with fault trending, Hululais Field

Considering the above mentioned resistivity structure and a fact that Total Loss Corculation (TLC) where centered at explorations wells HLS A/1 and HLS C/1 is situated close to the resistivity discontinuity. Fractures zone controlling geothermal fluid are probably distributed around resistivity discontinuity.

3.2. Subsurface Geothermal Model

Geological site viewing there are nine faults potential as good as permeability for well targetting as production wells or injection wells. Trending faults commonly NW-SE and NNW-SSE parallel with the regional big-fault Sumatra trending NW-SE. Dipping these faults 80-90 degree vertical relatively with open francture to the western. Rim structure or cladera fractures rim is the main controlling fluid up flow zone at the center of Hululais Geothermal prospect area. Inside caldera rim strctures some fumarole and hot springs active fluid flows from bottom trough fractures. Two exploration wells targetted to thus caldera rim and succes reaches 10-20 MW potential capacity for each well. Regarding faults and geothermal activity in Hululais Geothermal field, a large scale high resistivity zone is distributed in central, weastern and southern portions of Hululais working area. The Loss Circulation zone of exploration wells situated inside the main faults zone, (**Figure 8).**

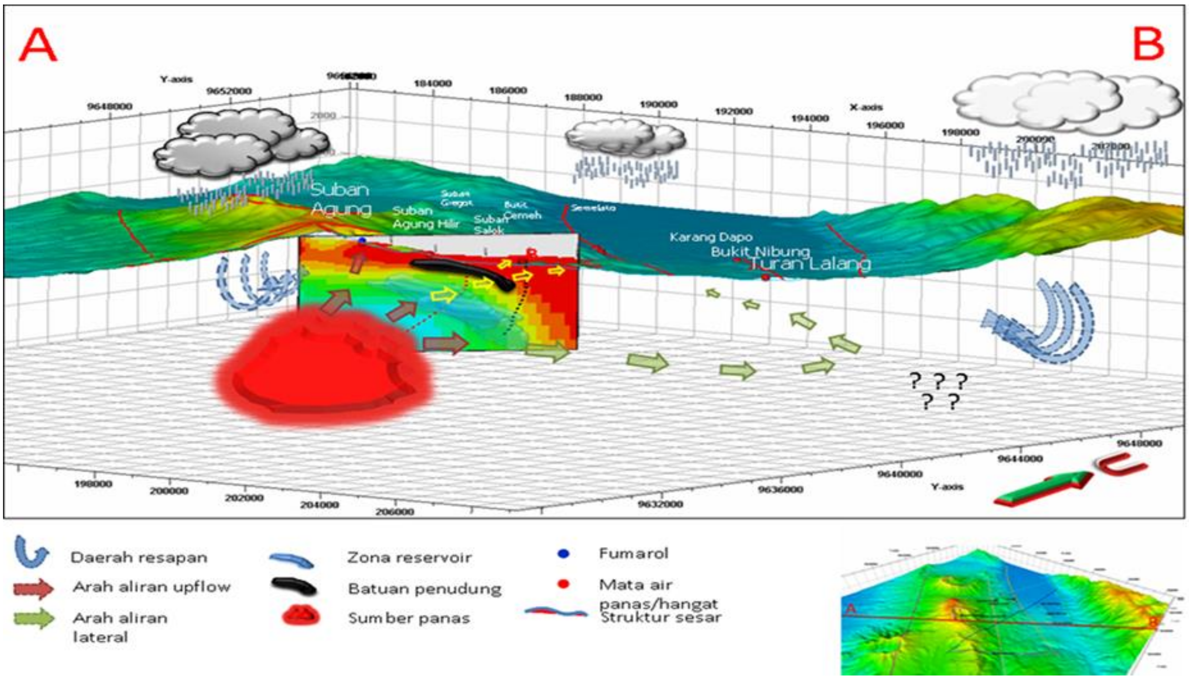


Figure 8. Hydrological model of Hululais Field

Semi circled coollapse structures as rim caldera structure is recognized near Mt. Hululais and Mt. Beriti Besar, when resistivity value was higher than surrounding area. Therefore intensely acidic hydrothermal alteration is supposed to be the reason of the high resistivity in the structure. Geological analysis from cutting and cores occurs. No acidic altered minerals were detected in the samples from exploration wells.

Hydrothermal system in Hululais yields a liquid-dominated reservoir storing typical Cl-type and netral-pH water accompanied by some steam cap at shallow level. Some chloride type spring water in several manifestations derived from dilution and/or conductive cooling of the deep reservoir water, where represented from downhole sample from wells which has a temperature around 270^{o}C and chloride concentration around 4,300 ppm, (**Figure 9).**

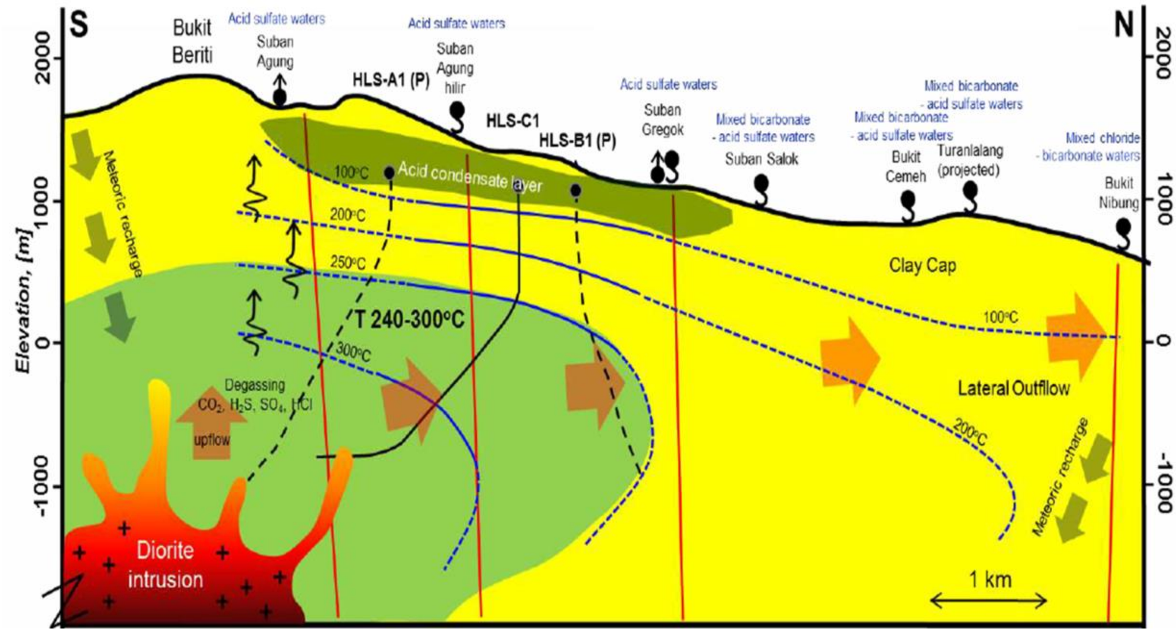


Figure 9. Simplified geothermal model of Hululais Field

Main origin of reservoir fluid is meteoric water infiltrated presumably at the higher elevation around Mt Hululais. The deep circulated meteoric water is heated by conductive heat from magmatic chamber as a heat source. The geothermometers calculated from surface water and gass chemistries suggest that the liquid-dominated geothermal reservoir has a temperature in the range of 200-280 ^{o}C, and this calculating result is similar to the measured temperature in exploration wells.

The main up-flow zone as indicated hottest part of the reservoir in Subang Agung area below Mt. Hululais, above of liquid reservoir, some impermeable layer as a cap rock from clay cup where the reservoir water boils and yields steam-trapped zone and reach the surface and form fumarole. The Northward out-flow from reservoir yielded Cl-type hot spring. Along the outflow water contact with sedimentary rocks, the water content has relatively higher ratio B/Cl (boron/Cloride). The SO_4/ HCO_3 –type spring water is formed separately from the system and local shallow groundwater is heated by conductive heat from the depth and may contact with sulfate minerals such as gypsum in the aquifer zone.

3.3. Calculation of Resource Potential

Geothermal models have been established using real data from various GGGR surface sources and fact subsurface data from three success exploratory wells with output of 10-20 MW each. Same reservoir parameter occure through GGGR data, including temperature, pressure, area dimensional, thickness of reservoir, rock density, fluid density, load factor etc. All parameter were used to calculate the stored heat, as part of a volumetric method. Compared one is Monte Carlo method.

The minimum and maximum area extents is of reservoir within ranges from 25 km^2 to 45 km^2. The ranges determine from result analysis of Resistivity MT (Magnetotelluric). The minimum extent of the reservoir determined since it corresponding to the distribution of relativley high resitivity zone at deeper region of SW area. The maximum area extent was determined based on the distribution of low resistivity cap rocks (**Fig. 10**).

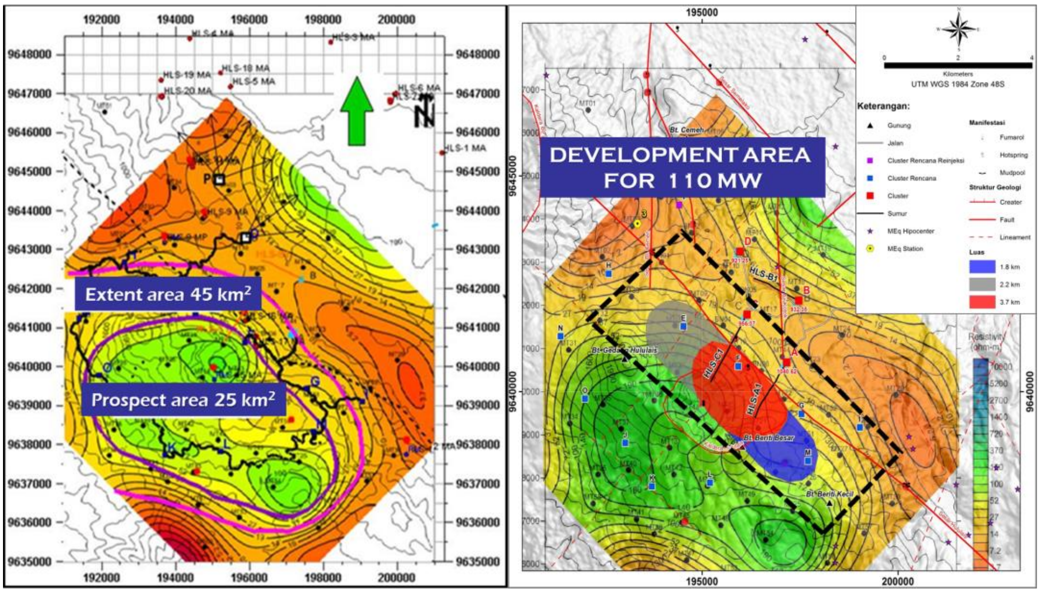


Figure 10. Prospecting priority of Proven and probable Area in Hululais Field

Thickness of reservoir was assumed to be greater than 1.5 km and less than 3 km. Maximum thickness of reservoir was determined because the deep relatively high resistivity spread down to deepest blocks of the inverted resistivity section, exceeds about 3 km. The estimated minimum reservoir volume has ranges from 50 km^3 to 165 km^3.

Average reservoir temperature from exploration wells was assumed to be 270 ^oC, within the range of 200-300 ^oC. Porosity was 5-12 %, and recovery factor was assumed varying within the range 12.5-30 %, corresponding to 2.5 times average porosity (rule of thumb), widely accepted among the wolrd geothermal community. Other parameters such as the abandoned temperature was 160 ^oC and plan life time was 30 years.

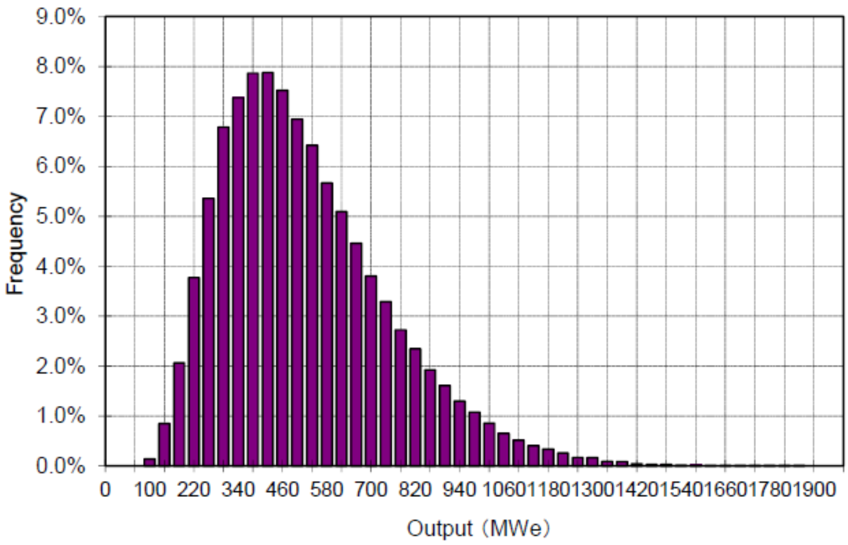


Figure 11. Output and frequency distribution result from Monte Carlo simulation of Stored heat Method

As shown in Figs. 11 and 12, the number of trial calculations in Monte Carlo simulation was 100,000 times. The most likely estimate of resource potential of Hululais geothermal field was around 420 MW. The probability of the resource potential is of 220 MW reaching 90 % meaning that there exists sufficient geothermal resources for current development plan for first stage of 110 MW.

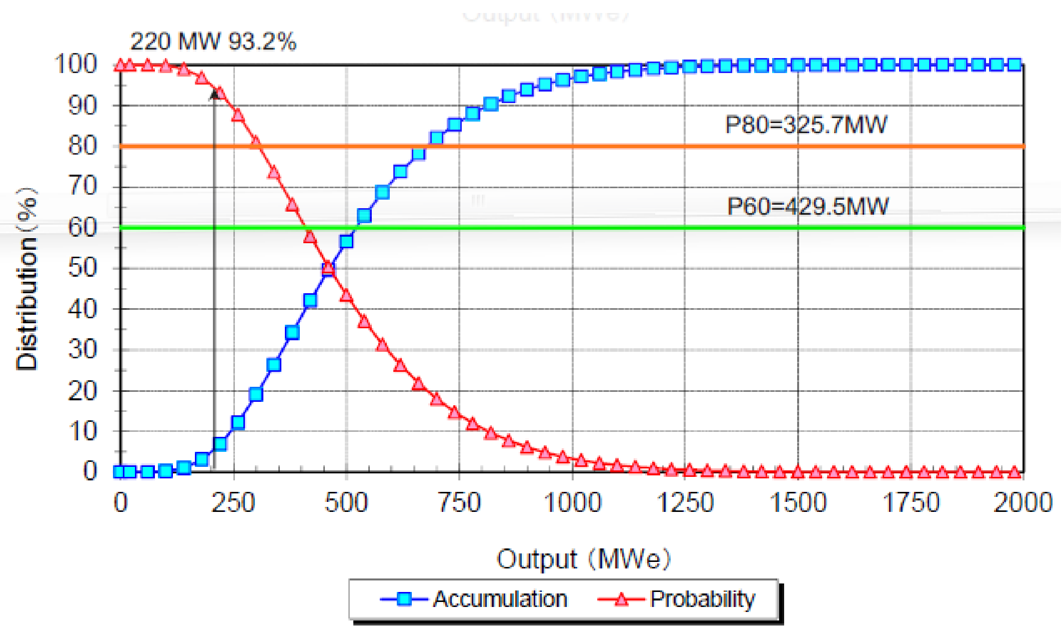


Figure 12. Accumulated frequency (blue) and probability (red) of resource potential estimate in Hululais Field

4. FIELD DEVELOPMENT STRATEGY

4.1. Production, Injection and Drilling Target

Field development strategy at the first stage is starting point from border area of protected forest that means stragey develop from outside to entry upflow region. This strategy based on high dificulty accept permit from government of Plantation department, somehow it need unpredictible time. So establishing production wells and injection wells in the private land area locally is just small effort directly to owners of the land. There were four cellars established at Hululais field outside 500 m away from borderline of protected forest. Additional cellars is still preparing at Northern part of prospecting which located outside forestry borderland.

During preparation of development plan, subsurface well targetting would be with high risk because distance from cellar to up-flow region is more than 2 km displacement. Drilling rig with high performance is needed, capacity ranges 1,500-2,000 HP (Horse power). Deepest wells plan aroud 3000 mMD and inclination angel more than 50 degree. Bench marking this field with other Tompaso Geothermal Field Indonesia, the reservoir carracterism is quite similar, high temperature but high difficulty reach good permeablity fractures (M.Y. Kamah, 2010). Most important thing in subsurface geothermal investigation is result from logging PTS (Pressure, Temperature and Spinner) specially at the exploration stage. The PTS data inform the promise best well targetting and productivity zone for the next development stage, especially at Hululais Geothermal Field (Kamah, 2005).

4.2. Power Generation Capacity of 110 MW

The first stage development scenario was 110 MW in total from 2 X 55 MW. Production per well is 10–15 MW @15ksc that needs thirteen production wells and eleven injection wells. During 30 years power generation, Hululais field still need additional 7 production makeup wells and about 6 injection makeup wells. The steam consumsion estimated for generating one megawatt (1 MW) was determined to be 7.5 ton/hour (t/h), depending on catalogue specification of turbine availabe commercially, JICA, PT.PRTAMINA, (2013).

The case of 110 MW power scenario would need 825 t/h, as a single production well would produce 68 t/h steam and 227 t/h brine. Total amount of brine that will be produced from production wells is 3,600 t/h. The production and injection wells would decline with time. Prepare makeup wells nececsary as big as well production capacity declining. Approximately 7 make up production wells is needed for continuous 30 years operation .

Power generation starts with eleven injection wells for a 3,600 t/h brine capacity. The decline rate is 2 -5% /year aproximatly. Base on many experiences in geothermal field, at early 2 years producing fluid for 110 MW capacity , decline rate would be high, > 5 % due to unstable reservoir condition. Some drilling fluids entries during drilling period and mix with reservoir fluid. After three years continuously producing, fluid reservoir slowly approach to a stable condition and decline rate decrease to about 3-5 %/year.

The injecion wells that planed about eleven wells in some manner will be required after producing fluid in the 4th year, 8th year, 16th year, 20th yrar, 24th year and 28th year of power generation.

5. CONCLUSION

The high-enthalpy geothermal system in Hululais field in Indonesia has been investigated by focusing on subsurface fluid flow and geohydrochemical processes. Detailed analysis of rocks (thin sections, XRD/XRF), wells targetting and fluids (major/minor ions), structural mapping, geothermometer calculations and hydrochemical have been used to provide insights into physical processes affecting the geothermal system.

Results of three exploration wells showed that Hululais Geothermal Filed has big potential capacity aroud 420 MW. The probability of the resource potential is of 220 MW reaching 90 %, which means that there exists sufficient geothermal resources for current development plan for the first stage of 110 MW.

Field development strategy at the first stage start from point of border area of protected forest, which means to develop it from outside to entry upflow region. There were four cellars established at Hululais geothermal field outside 500 m away from borderline of protected forest. Additional cellars is needed at Northern part of the prospecting area where this cellar location is still outside forestry borderland.

The first stage development scenario of 110 MW in total is from 2 X 55 MW. Production per well is 10-15 MW @ 15ksc, it needs thirteen production wells and eleven injection wells. During 30 years power generation, Hululais field still need additional seven production wells and six injection makeup wells. The steam consumption estimating for generating one megawatt (1 MW) was determined to be 7.5 ton/hour (t/h). This depends on the catalogue specification of commercially availabe turbines.

ACKNOWLEDGEMENTS

The support of Pertamina Upstream Technology Center, New Energy and Green Technology Division and Pertamina Geothermal Energy (PGE) is highly appreciated. The authors thank Board of PGE and Pertamina (Persero) for the permission to publish this paper.

REFERENCES

Brehme, M., Moeck, I., Kamah, Y., Zimmermann, G., & Sauter, M. (2014). A hydrotectonic model of a geothermal reservoir-A study in Lahendong, Indonesia. Geothermics, 51, 228–239.

JICA, PT.PRTAMINA, (2013). JICA Data Collection Survey For Kamojang and Hululais Geothermal Power Plant Project, Inodonesia. Part 2 pp 1-165.

M.Y. Kamah, D.B. Hartanto, M.H.Thamrin, (2010), The most evidence for targetting wells in geothermal reservoir by using fractures zonation and erratic structure at Lumut Balai and Tompaso Geothermal Area, Indonesia. Proceeding WGC-2000 Bali Indonesia.

M.Y. Kamah, T. Dwikorianto, A.A. Zuhro, A. Hasibuan, (2005). The productive food zones identified based on spinner data and aplication in the reservoir potential review of Kamojang Geothermal Area, Indonesia. Proceeding WGC-2005 Antalya Turkey.

The Ministry ETI, Ernst & Young S. LLC, JETRO, West JEC. Inc,. (2011): Study On Economic Partnership Projects in Developing Countries FY 2010, Study on Geothermal Power Development Project in Hululais Indonesia. p.165.