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Indonesia Geothermal Drilling History: What We Can Learn from It?

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ABSTRACT

Indonesia is one of the countries that has the largest geothermal energy potential in the world that can be managed to achieve energy security targets in the future. The first recorded geothermal energy discussion in Indonesia was during the Dutch colonial rule, in 1918, by J.Z. van Dijk, which most likely lead to the geothermal exploration project in Kamojang. In the period of 1926-1928, five wells were drilled in Kamojang Crater, West Java, which one of those wells still produces dry steam with a temperature of 140°C until now. Despite the long history of geothermal drilling in Indonesia, which almost reach 100 years, there is no clear indication that shows Indonesia geothermal drilling industry has been established in terms of technology, innovation, and capability. Several indicators that could be used are the widely distributed drilling cost, the absence of integrated drilling database, the absence of personnel certification and the absence of national drilling standard and code for geothermal. This study aims to provide the big picture of geothermal drilling journey in Indonesia that might result one or two useful information for future improvement.

1. INTRODUCTION

1.1 Indonesia's Geothermal Energy History and Target.

Indonesia is an area formed by a series of active volcanoes caused by pacific ring of fire, so this country has huge potential for geothermal resources. Currently, Indonesia is become 2nd rank of top 10 geothermal energy installed capacity worldwide with total gross installed capacity is 2,276 MW in the year-end of 2021 since there was 143 MW were added from 45 MW Sorik Marapi Geothermal Field Unit 2 and the 98 MW Rantau Dedap plants in Sumatra island PLN (2021); Thinkgeoenergy (2021). The detailed data of current installed capacity of geothermal countries power generation by gross intalled capacity is shown in Figure 1.

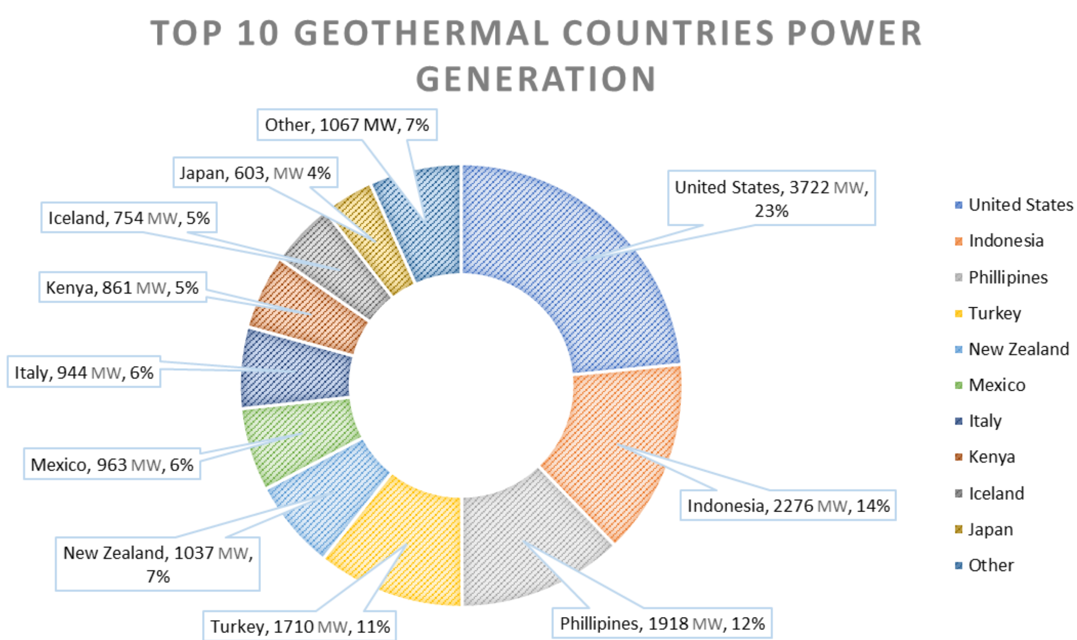

Figure 1: Top 10 Geothermal Countries Power Generation by Gross Installed Capacity in year-end 2021 modified from Thinkgeoenergy (2021).

1.2 Research Background, Objective and Method

1.2.1 Research Background and Objective

The first recorded geothermal energy discussion in Indonesia was during the Dutch colonial rule, in 1918, by J.Z. van Dijk, which most likely lead to the geothermal exploration project in Kamojang. In the period of 1926-1928, five wells were drilled in Kamojang Crater, West Java, which one of those wells still produces dry steam with a temperature of 140°C until now

Then, as stated on EBTKE (2020a) the government hold the vision to utilize geothermal energy as much as possible to become baseload energy supply for future energy security and sustainability. As the commitment to achieve this vision, the national electricity buyer in collaboration with government set the target installed capacity 5,799 MWe in 2030 as illustrated in Figure 2.

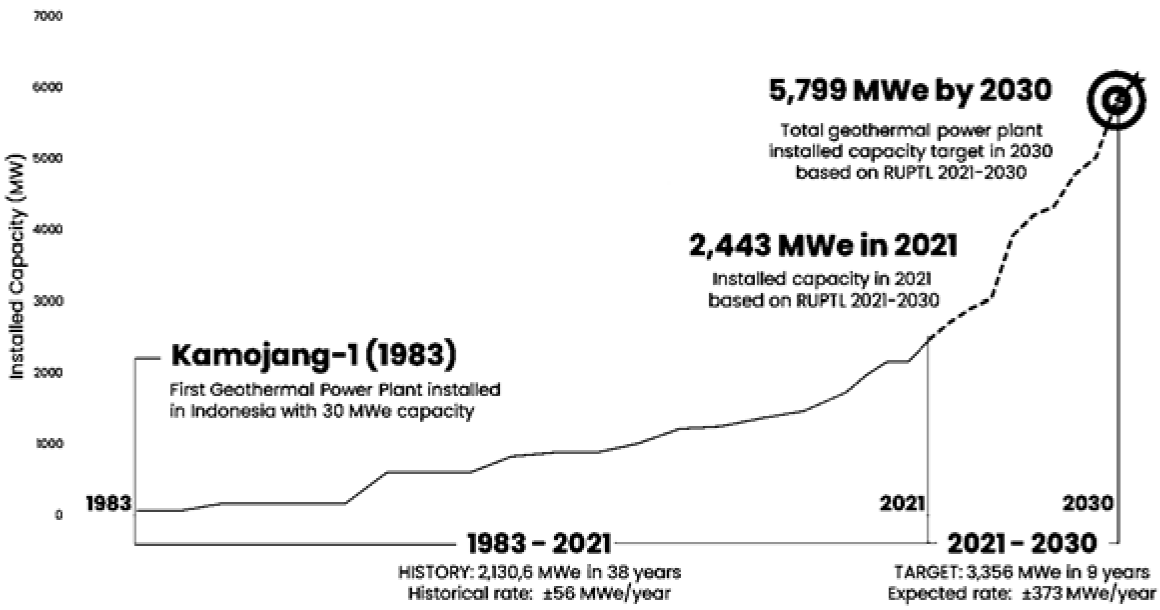

Figure 2: History and Updated Targets of Geothermal Energy Development in Indonesia as RUPTL 2021-2030 by PLN (Modified from Purba et al (2021); PLN (2021))

As the implication of this ambitious target, there will be a lot of geothermal drilling campaign will be conducted to achieve this target. Despite the long history of geothermal drilling in Indonesia, which almost reach 100 years, there is no clear indication that shows Indonesia geothermal drilling industry has been established in terms of technology, innovation, and capability. Several indicators that could be used are the widely distributed drilling cost, the absence of integrated drilling database, the absence of personnel certification and the absence of national drilling standard and code for geothermal.

Ths study aims to provide the big picture of geothermal drilling journey in Indonesia that might result a glimpse of useful information for future improvement regarding geothermal drilling, in Indonesia in particular.

1.2.2 Research Method

The method that use in this study is using literature review regarding geothermal history in Indonesia and summarize all of the information that might be useful for future geothermal development. To achieve the objectives of this research, authors make several breakdown of research question as follows:

1. How was the history of geothermal drilling activity in Indonesia?
2. From the historical of geothermal drilling activities in Indonesia, what kind of typical geothermal well design that frequently used in Indonesia?
3. What kind of operational challenges that most likely be occur during geothermal drilling activity in Indonesia?
4. How about the distributtion of drilling cost in Indonesia? Which cost component that become major cost contributor?

2. GEOTHERMAL DRILLING ACTIVITY IN INDONESIA

2.1. A Brief History on Geothermal Drilling Activity in Indonesia

2.1.1 1918 – 1970 Period: First Attemption of Geothermal Exploration

In Indonesia, the first attempt at geothermal resource exploration for electricity generation was proposed in 1918. Indonesia was still under Dutch colonialism at the time. After the first geothermal development in Italy, geologists in the Indies were inspired to extract geothermal potential in their colonies. Following his experience in Italy, J.Z. van Dijk was the first to suggest that volcanoes be investigated for their geothermal potential. In 1926, the Volcanological Section (now the Volcanological Survey of Indonesia) began investigating geothermal development in Indonesia in Kamojang, West Java. Because the field's surface manifestation is fumarole that intepreted huge potential in subsurface, Dutch Colonial drilled five wells inside the fumarole area to identify subsurface conditions. Up to this point, KMJ-3, which reached a height of 66 meters discharged steam simultaneously. The lip test in 1975 produced a steam mass flow of approximately 10 t/h. The last two holes drilled by Dutch (123 m and 128 m) were capable of producing two-phase fluid periodically. Based on Stehn (1929), unfortunately in 1928 those wells were unable to discharge. KMJ-3 was the only well that could generate dry steam.

Dieng is another geothermal field that has been explored in this phase, specifically in the Sikidang Sector. Beginning in 1928, the UNESCO Volcano Mission (UNESCO Volcanological Mission) drilled an 80-meter deep non-producing hole as stated by Radja (1975). The temperature in the bottom hole could reach 145°C. Until 1972, there was no exploration drilling, but the geoscience survey decided to continue. The survey results had been used to rank various Java prospects for further investigation. As stated in Zen & Radja (1970). Dieng, Gunung Tampomas, Gunung Salak, Gunung Perbakti, K. Kamojang, and Cisolok were among the candidates. Outside of Java, geothermal potential was also investigated, then in 1969 the PLN Power Research Institute conducted an exploration survey in Sulawesi Radja (1970)..

2.1.2 1970 – 1980 Period: Early Exploration for Geothermal Development

In Dieng geothermal field, in 1970 a bilateral assistance project (the United States and France) with the counterpart of VSI/ITB/PLN began geothermal exploration in Indonesia at Dieng, Central Java. To evaluate the prospect and locate drill sites, 3G surveys (geology, geochemistry, and geophysics) were conducted. Based on Radja (1975) actually the deepest exploration drilling (DX-2) reached a depth of 145 meters, but it was unsuccesful. The exploration drilling goals were not met in 1972 due to the inexperience of the drilling contractor. Pertamina later took over the project in Dieng in 1974 and rearranging the reconnaissance survey with the help of BEICIP (French contractor). According to Bachrun, Soeroso, & Suwana (1995).Pertamina's first well, DNG-1, was drilled to a depth of 1900 meters in the Sikidang Sector in 1977. Despite the fact that it had to be abandoned due to corrosion, it was the deepest well drilled in Indonesia at the time. DNG-2, the second well, was drilled in 1979 to a total depth of 1660 meters and was designed to discharge steam (Hochstein, 2008).

Then in Kamojang, in 1971 the Indonesian and New Zealand governments backed a bilateral aid (Colombo Plan) project that conducted prospecting in Bali and four other Java locations, including Kamojang, Darajat, Salak-Perbakti, and Cisolok. The reconnaissance survey in Kamojang, West Java, began in 1974 and resulted in a reservoir with a surface area of 14 km2. KMJ-6 was drilled with a medium rig to a depth of 615 meters. It emits steam and demonstrates the presence of vapor-dominated systems. In this field, other wells such as KMJ-7 (productive); KMJ-8, 8, 9, and 10 (non-productive) were drilled. KMJ-10, with a depth of 760 m, was completed in 1975.

The exploration survey in Kamojang and Darajat showed the evidence of vapor-dominated systems proved by the productivity of 700m drilled wells. The production wells drilled in 1976-1978 were intended to supply a 30 MW Kamojang power plant that already under construction at the time.

Then, continue to Salak area was drilled for exploration by the Colombo aid program in 1975, and the area was turned over to Pertamina in 1977. Pertamina used a consultant from France and Japan to explore a geothermal prospect in Banten between 1975 and 1979. VSI, ITB, and PLN also conducted an exploration survey in North Sulawesi.

2.1.3 1980 – 1995 Period: Second Decade of Exploration Project in Indonesia

The Government of Indonesia issued Presidential Decrees No. 22 in 1981 and No. 45 in 1991, allowing Pertamina to organize their geothermal field activity and form partnerships with local and international investors to develop geothermal areas. It is realized through the Salak-Perbakti Field Joint Operation Contracts (JOC) with Unocal for the joint steam field development. Eight deep exploration wells were drilled after the exploration survey was re-conducted (up to 1830 m). The prospect had 150 Mwe potential and was a liquid-dominated system, according to Pertamina's 1986 exploration drilling campaign. Drilling for further development was halted due to the completion of the first power plant in the third decade (Hochstein, 2008)..

In 1984, another JOC was signed with Amoseas Indonesia to develop the Darajat field. By 1988, five deep exploration wells with a depth of up to 2,300 meters had been completed in this field. Pertamina, like Salak, postponed further drilling due to the power plant's construction.

14 deep exploration wells were drilled in Dieng at Sikidang Sector after being handed over to Pertamina. A detailed survey was carried out in 1985, which led to the drilling of BTN-1. In 1986, a resurvey was conducted at Cisolok, and the CIS-1 deep well was drilled but failed.

In 1981, three slimhole drilling attempts were made at Lahendong, but they all failed. From the request of the Indonesian government to Pertamina in 1983, a deep LHD-1 well was drilled, followed by five more until 1986. To support a 20 MW development, the wells were drilled to a depth of 2,200 meters.

In 1983 and 1988, Kunyit-Lemur Mountain exploration led to the drilling of two deep exploratory wells (1,000 m). The location of the prospect is in a natural park. As a result, VSI did not pursue exploration further.

In 1994, four exploratory drillings were carried out in Sibual-buali and Silangkitang, respectively, until 2,000 and 2,080 meters. 3G surveys were carried out in 35 new prospects across Java, Sumatera, Nusa Tenggara, and Sulawesi, primarily by Pertamina, but exploration drilling was not carried out.

2.1.4 1995 – 2021 Period: Latest Exploration and Development Project

Many geothermal power development projects were halted in 1998 due to the fiscal and monetary crisis. It occurred following the promulgation of Presidential Decree No. 39 in 1998. The state of electricity in Indonesia deteriorated during that period of crisis. From time to time, blackouts occurred across the country. Furthermore, the Indonesian government's revision of geothermal industry regulations, as well as its commitment to develop the industry, influenced the industry's expansion. All geothermal contracts were revived by the government four years later, in May 2002, with the exception of the Karaha Bodas Field, which was canceled due to legal issues (Hochstein, 2008)..

Pertamina and PLN continued to explore four geothermal fields between 2001 and 2010. Ulubelu, Lumut Balai, Kotamobagu, and Tulehu all had exploratory drilling done. Due to unmet permeability and temperature expectations, exploration in Kotamobagu and Tulehu was unsuccessful, while Ulubelu and Lumut Balat were successful.

Twelve preliminary survey assignments, 19 geothermal working areas, and thirteen preliminary survey and explorations were completed between 2011 and 2019. Five geothermal business permit holders have carried out investigations and submitted feasibility studies within their geothermal working areas. By the end of 2014, there were six active geothermal fields and 34 new geothermal prospects with a total potential capacity of up to 4000 MWe. After 6 years until at the end of 2021, now the installed capacity is 2266,9 MW based from EBKE data.

2.2 Future Geothermal Drilling Activity by the government

To attract the investor and adding value for geothermal field auction, the government of Indonesia (GoI) nowadays has strategy to conduct exploration in several geothermal prospect area as listed in Table 1. According to EBKE (2020b) the geothermal prospect area that listed by the government have geothermal resources approximately 1,884 MW and will be plan to be develop 683 MW.

Table 1 Geothermal prospect area list for government exploration drilling program from EBTKE (2020b)

No.	Prospect Area	Location	Region Status	Resources (MW)	Development Plan (MW)
1	Cisolok Cisukarame	West Java	WKP	45	20
2	Jailolo	North Maluku	WKP	75	30
3	Nage	East Nusa Tenggara	WKP	39	20
4	Bittuang	South Sulawesi	Wilayah Terbuka	28	20
5	Ciremai	West Java	WKP	60	55
6	Bora Polu	Central Sulawesi	WKP	123	40
7	Gunung Endut	Banten	WKP	180	40
8	Tampomas	West Java	WKP	100	45
9	Sembalun	West Nusa Tenggara	WKP	100	20
10	Guci	Central Java	WKP	100	55
11	Sipoholon Ria-Ria	North Sumatera	WKP	60	20
12	Marana	Central Sulawesi	WKP	70	20
13	Lokop	Aceh	Wilayah Terbuka	41	20
14	Limbong	South Sulawesi	Wilayah Terbuka	20	5
15	Maritaing	East Nusa Tenggara	Wilayah Terbuka	190	30
16	Gunung Batur-Kintamani	Bali	Wilayah Terbuka	58	40
17	Gunung Galunggung	West Java	WKP	289	110
18	Papandayan	West Java	Wilayah Terbuka	195	40
19	Banda Baru	Maluku	Wilayah Terbuka	54	40
20	Sajau	North Kalimantan	Wilayah Terbuka	17	13
Total				**1.844**	**683**

3. TYPICAL GEOTHERMAL WELL DESIGN IN INDONESIA

The well design utilized in geothermal wells differs in general during the exploring and development stages. Standard hole wells are commonly utilized during the exploration stage, however slim hole wells are widely accepted as an alternate well design for confirming geothermal systems. However, geothermal developers with great confidence in existing geothermal resources can use the huge or big hole option during exploration. This method allows a successful exploration well to be transformed into a production well to sustain production. Geothermal developers frequently use big hole wells to collect geothermal fluids for production during the development and operational stages.

Based on data obtained from 60 geothermal wells in Indonesia across 11 fields in Sumatra, Java, and Sulawesi, it is concluded that 83% of geothermal wells were drilled using the big hole configuration. Figure 3 depicts typical geothermal well designs in Indonesia. Big hole wells, according to Ashadi and Hartono (2020), are more preferable to be used because it requires less amounts of surface casing, allows deeper drilling operations, involves more production hole sections to cover unforeseen events, allows larger down hole tools that have a better temperature resistance and provides a greater number of well outputs. According to report provided by Sveinbjornsson and Thorhallsson (2014), big holes well provide 30-40% greater output compared to standard wells.

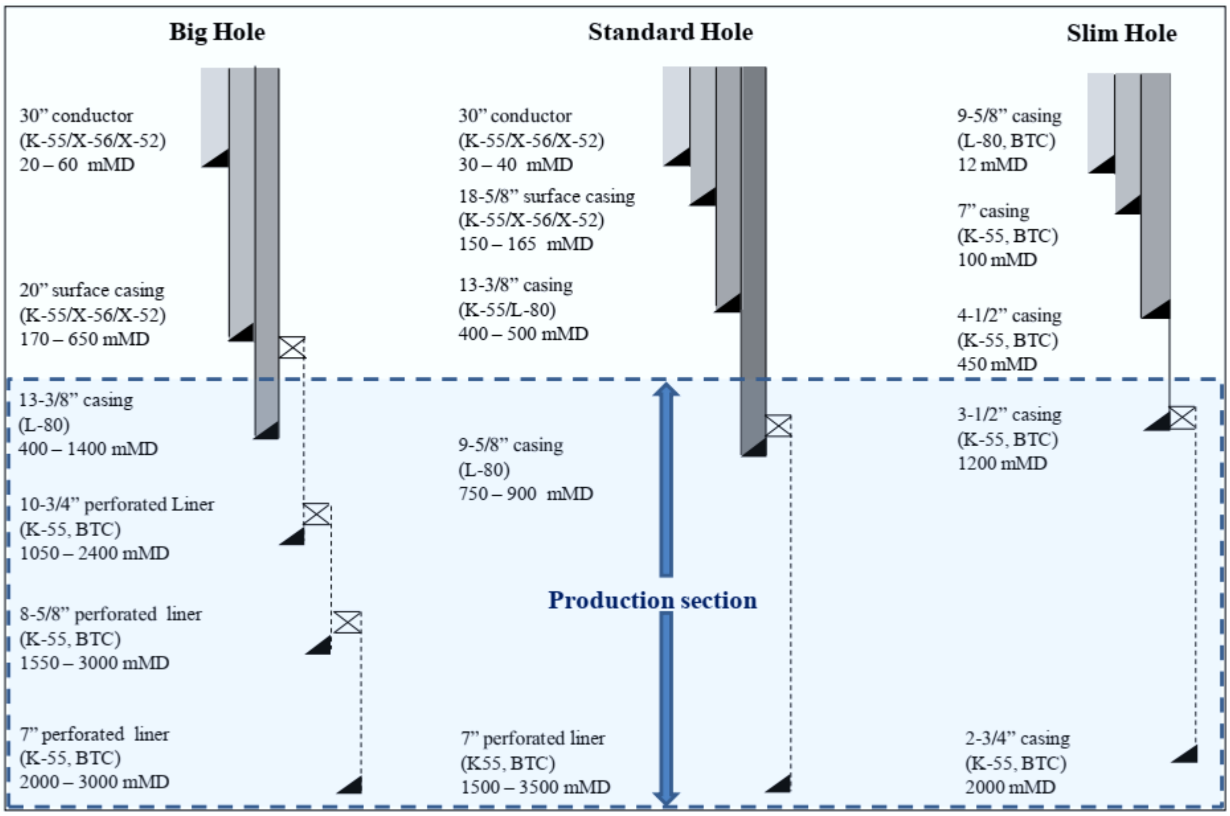

Figure 3: Typical well design and interval depth of 60 geothermal wells in Indonesia (Purwanto, et al, 2020)

The drill hole size should be chosen according to the purpose and phases of drilling to be completed. Slimhole drilling can be encouraged throughout the exploration phase to reduce the risk of failure and increase the likelihood of exploration success. This method could be useful for a geothermal corporation with a high level of resource uncertainty and a budget constraint. The use of slim hole drilling is also preferable in minimising land use while acquiring physical subsurface information through conventional coring. However deep slim hole drilling needs longer drilling time due to technical difficulties encountered during drilling which are mainly caused by lack of deep slim hole drilling knowledge, unsuitable well design and multiple hole problems which eventually leads to cost overruns.

However, if the drilling is for development purposes, the big hole option will be more effective and efficient because, in addition to having a higher steam gain than standard hole and slimhole wells, big hole wells have the ability to reach the planned depth target at a greater depth. This is due to the fact that big hole wells can use a contingency perforated liner three times in the event of complications during reservoir drilling or depth setting.

4. OPERATIONAL CHALLENGES

In general, the concept of geothermal drilling is almost the same as oil and gas drilling, but what distinguishes it from the concept of oil and gas drilling is the design of the well. In Indonesia, geothermal drilling has been carried out since the 1970s in the Kamojang, Dieng and Darajat fields (Hochstein and Sudarman, 2008). Geothermal drilling activities continued until the late 1990s to support the provision of generating capacity from the kamojang, sibayak, Dajarat and salak fields which had produced a total installed capacity of 778 MW by the end of 2000 (Purwanto, et al. 2020).

Geothermal drilling operations are very important in exploring and developing geothermal fields, because the ultimate goal of drilling is to obtain geothermal energy sources below the surface. In addition, the drilling operation is also to prove the potential of the explored field has economic and commercial resources to be developed further. This activity is usually carried out using small wells or core wells. Recent trends indicate that some companies developing geothermal fields carry out exploratory drilling using standard holes with the aim of optimizing production of the well once the desired temperature is proven.

Geothermal drilling also has a considerable risk, the risk here is defined as uncertainty regarding the magnitude of the quality of the geothermal reservoir (Matek, 2014). To reduce the risk of drilling requires an in-depth analysis, and is based on conceptual models and resource risks from 3G studies (geology, geochemistry and geophysics). Operational risk is considered as one of the most important and significant factors that can affect the success rate of drilling. As shown in Table 2, this study already summarize several challenges that most likely occur for geothermal drilling activity in Indonesia.

Table 2: Summary Geothermal Drilling Operation Challenge in Indonesia

Challenge	**Problem keywords**	**Explanation**
Stuck Pipe	Drillstring, bore hole, unconsolidated formation, naturally fractured formation	Stuck pipe in the case of geothermal drilling can be described as a condition where part of the drillstring is trapped in the drill hole, so that drilling operations are hampered or even stopped which can occur due to differential sticking and mechanical sticking. Causes of pipe pinching include Hole Pack off, unconsolidated formations, natural fractured formations, Junk lost in holes, Differential sticking, tectonic compression formations. A jammed pipe can cause additional cost spikes as tools are lost in the bore.
Loss circulation	Fault, fractures, type formation, hydrostatic pressure, formation pressure	Loss of part or all of the drilling fluid circulated into the formation. It is usually lost into caves, faults, fractures, or into permeable layers resulting in partial or complete failure of the mud to return to the surface so that less mud is circulated into the hole. The lost circulation can be caused by the type of formation, namely because of the type of porosity and large permeability as well as the presence of caves and formation fractures. In addition, pressures such as formation pressure and hydrostatic pressure can affect circulation losses. so it is necessary to do countermeasures by doing blind drilling, in order to maintain the reservoir loss zone which is a productive zone so as not to be damaged.
Wellbore instability	Unstable formations, differential stress, natural fracture	Wellbore instability is generally caused by mechanically unstable formations, in addition to expanding/shrunk clay and differential stresses causing drilling obstruction. Apart from being caused by the two things above, wellbore instability is also caused by factors that cannot be controlled, such as: naturally fractured or faulted formations; tectonically stressed formations; unconsolidated formations; naturally over-pressured shale collapse (Pašić, B. et al., 2007).
High-relief Terrain	Slope and contours, alterasion, volcanic rocks	Geothermal in Indonesia is generally in a volcanic environment that has steep contours and slopes. In addition, the lithology of volcanic rocks is not well consolidated. This location is certainly a challenge for companies to drill because the land is unstable. This instability is also influenced by the flow of hot water or steam from below the surface (Purba et al, 2020). Upflow areas in geothermal systems generally have a level of argillic alteration that forms clay minerals, this alteration causes a decrease in rock strength.
Access road	Width road, strength road, land acquisition	Road access is one of the important things in geothermal development projects. Access roads are focused on paving the way to areas that the prospect wants to drill. In general, the land area required for road access in geothermal projects ranges from 8 to 15 meters (Purba et al., 2020). The width of the road must also be considered because it will accommodate the mobility of heavy equipment such as trucks, cranes, graders, etc. In addition, the strength of the road also greatly affects mobility, due to the very large tonnage of drilling equipment which can affect road conditions.

4. DRILLING COST

4.1 Total Well Cost

Associated costs which required for geothermal well generally include well pad construction costs, drilling costs, well completion and testing costs, well hook up, permitting and other supporting costs. Several studies explain the correlation between drilling cost and well depth.

- According to IFC (2013) – single geothermal well may cost between 1 to 7 MUSD per well, depending on the depth and location situation.
- According to Sanyal (2011) – have reported geothermal drilling cost and correlation with well productivity. Depth is main determinant of drilling cost and typically drilling cost in any country increases exponentially with depth.
- According to Lukawski (2014) – geothermal wells require multiplecasings intervals during drilling which resulted in higher drilling time and cost of completions.

The following is the result of an analysis related to the drlling cost data in Indonesia which was carried out by (Purwanto, et al, 2020). The data analyzed is drilling cost data from 203 wells which completed during 2011 to 2019 in Indonesia (Figure 4). Several other factors that are taken into consideration in the analysis of drilling costs include normalized drilling costs, depths, contracts commercial scheme, and activity stages in geothermal projects.

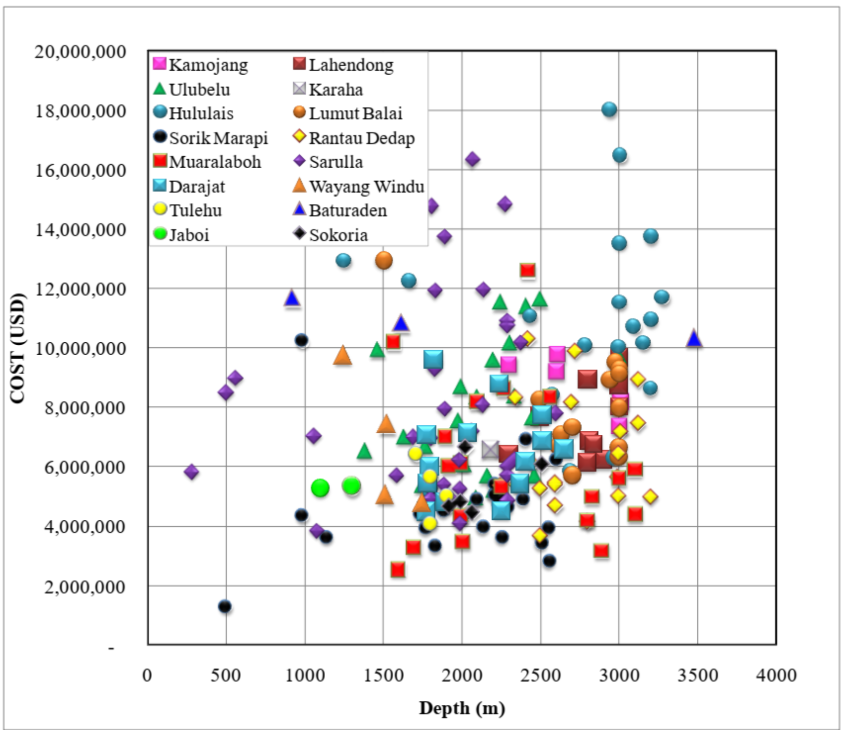

Figure 4: Drilling cost distributions of geothermal fields in Indonesia (Purwanto, et al, 2020)

The result indicates that drilling cost in Indonesia varies greatly from 1.3 to 18 MUSD with mean value at the magnitude of 7.4 MUSD per well (Purwanto, et.al, 2020).

4.2 Geothermal Drilling Cost Component

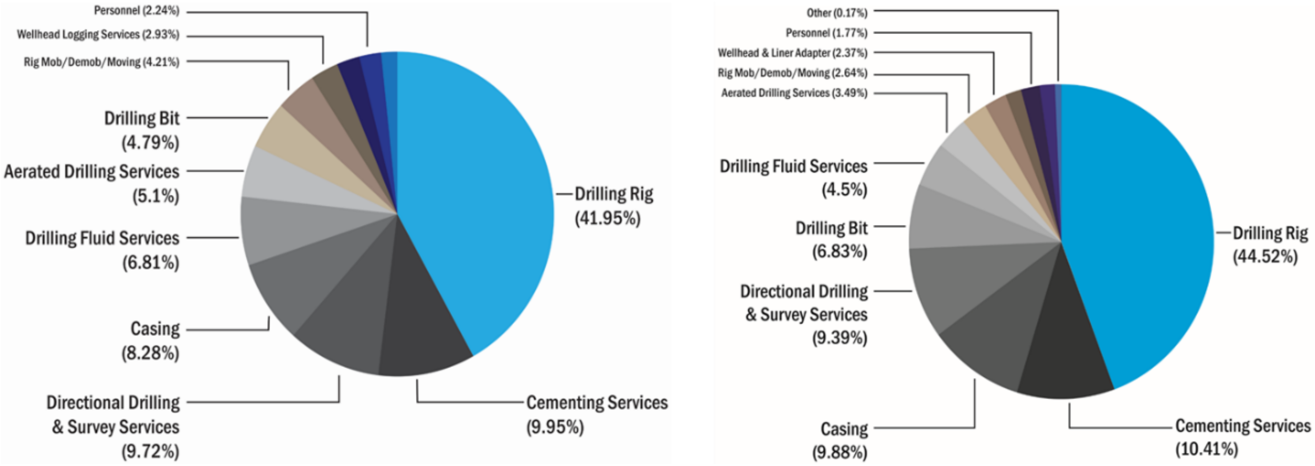

Figure 5: Distribution of drilling costs from two geothermal fields in Indonesia on a field in Central Java (left) and in West Java (right) (Purba, et al 2020).

Figure 5 shows an example of the distribution of actual costs by services of a drilling project. The chart summarizes the actual drilling costs of two geothermal fields in Indonesia summarized by (Purba, et al 2020). The chart shows that both fields have relatively similar drilling cost allocation. The top contributors are drilling rig, cementing, directional drilling, casing, drill bit, and drilling fluid/mud, which in total contribute to roughly 80% of total drilling cost. This is consistent with Pareto law stating that "80% of the effects come from 20% of the causes". If the pattern of this cost distribution is always consistent throughout all geothermal drilling operation in Indonesia, then the drilling team should focus more on managing these six drilling service contracts that influence more than 80% of drilling costs instead of invest equal portion of time and effort to all 25 contracts.

Cost wise, same rules apply for the drilling project, as in any project, that the total cost incurred is the result of multiplication of unit price with quantity. The higher the unit price that we agreed in the contract with our drilling partners, the higher the total cost that will occur. Similarly, with quantity, the more drilling days, tools, equipment, drilling materials, consumables and personnel we consume or utilize, the higher the total drilling cost appears in our project. In this study the authors chose to discuss the top four drilling cost contributors; (1) drilling rig, (2) cementing, (3) directional drilling, and (4) casing, which are responsible for approximately 70-80% of the total drilling cost.

5. CONLUSION

Based on this literature study, we can conclude as following:

- As the implication of latest national geothermal energy update, there will be a lot of geothermal drilling campaign will be conducted to meet 5,799 MW from current installed capacity.
- The typical geothermal well design used in Indonesia is a big hole well with a percentage of 80% of the total 60 wells.
- The operational challenges faced in geothermal drilling is stuck pipe, lost circulation, Wellbore instability, High-relief Terrain, and Access Road.
- The result indicates that drilling cost in Indonesia varies greatly from 1.3 to 18 MUSD with mean value at the magnitude of 7.4 MUSD per well with top contributor is drilling rig.

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