ABSTRACT
After a series of successful drilling campaign between 2007 and 2014, Pertamina Geothermal Energy (PGE) has continued to drill 81 more wells until end of 2018 to support the development and exploration phase of geothermal energy throughout 9 working areas. Various challenges have been mapped and defined, corresponded with the escalation of average Total Depth of the wells around 3,000 meters. Thus, several improvements have been carried out to achieve the good drilling performance based on ROWC (rate of well completion) and GDUC (geothermal drilling unit cost). Another milestone such as Long String Cement, PDC bit and Casing Drive System which has been implemented recently shows a significant impact to resolve some of specific challenges faced by the drilling department in PGE. Those improvements are covered not only for engineering design and proper drilling practices but also comprise the contract scheme for services and materials.

1. INTRODUCTION
The exploration of renewable energy resources is the global challenges for future clean energy supply. One of the most reasonable energy development is geothermal, which is commonly obstructed by the economic challenges. The economic challenges in developing geothermal energy is driven by many aspects, but it is believed to be mainly depends on the drilling well cost. PT PGE, a subsidiary of PT Pertamina as the State-Owned Oil/Energy Company in Indonesia, has becoming one of market leader in developing geothermal working areas, meeting the needs of electrical energy that came from clean source energy across the all country. For the last couple years, there are many geothermal working areas being developed in Indonesia where PGE has been involved in 8 areas with the total target of 632 MW installed capacity. Three areas that have been on production stages (own operation) consist of Kamojang (West Java), Sibayak (North Sumatera), Lahendong (North Sulawesi) and Ulubelu (Lampung). Whereas five areas are being developed namely Karaha (West Java), Lumut Balai (South Sumatera), Hululais – Bukit Daun (Bengkulu), Sungai Penuh (Jambi) and Tompaso (North Sulawesi). These wide-ranging coverages areas means consequently impact the difficulty level and various challenges that has to be controlled.

Between 2014 and 2018, PT PGE has completed the drilling campaign in eight different areas, acquiring more than 81 wells of development and make up well. The drilling performance key indicator are measured in terms of rate of well completion (ROWC) and geothermal drilling unit cost (GDUC), which are fluctuating corresponded with the increasing of Rig Daily Price and total depth. Evaluation for each well has been created continuously to help the engineers analyze the problem thus having the major lesson learned that would be used for the next well. In order to enhance the performance, several improvements have been applied in terms of well engineering design, proper drilling practice and also contractual strategy. By enhancing the performance, PGE is expected to squeeze the overall drilling well cost so that the project will be economically viable. The PGE drilling campaign barchart shows at Figure 1.
2. DRILLING CAMPAIGN PERFORMANCE

The PGE roadmap to achieve 672 MWe has continue in 2014, where PGE has drilled about 17 wells as can be seen in Figure 1. It was started with drilling 15 development wells and 2 exploration wells in Ulubelu, Lumut Balai, Karaha, Kamojang, Lahendong and Sungai Penuh. In the following year, the number of wells was increased when the campaign could finish about 21 development wells that spread across five different fields. In 2016, the number of wells were slightly decreased into 14 wells due to landslide and blowout incident in Hululais and Lahendong field respectively. Between 2014 and 2016, the PGE drilling campaign was dominated by drilling production and re-injection wells in Ulubelu and Lahendong field. The main target was to support the development of new Power Plant in Ulubelu unit III and IV (2 x 55 MW) and also Lahendong unit V and VI (2 x 20 MW). Moreover, PGE could finish 18 more wells in 2018 with the main goals of completing the development wells in Hululais and Lumut Balai project before the project has shifted into FEED and EPCC phase. All these wells are being monitored carefully in terms of performance and operational execution to provide PGE several wells drilled at a minimum cost.

As it mentioned previously in PGE Drilling Campaign (Zuhro et al, 2015), PGE has developed two criteria to measure the drilling performance quantitatively. It is consisting of: rate of well completion (ROWC) to measure the pace of well completion against the total depth in meter/days unit and geothermal drilling unit cost (GDUC) as a result of total overall well cost (exclude site preparation) divided by total depth in USD/meter unit. Both criteria are basically indicating an efficiency of a target depth that can be achieved. The numbers are averagely calculated on an annual basis, showing the performances of each annual drilling campaign. Based on the data between 2014 until 2018, it can be analyzed that both performance criteria are driven by the average total depth. At first glance, the rate of well completion days is increasing in 2014 and 2015 up to 39 m/days compared to 2013 where it only gives 24 m/days. The main challenges in 2014 and 2015 were mostly affected by total overall well cost (ROWC). Although, the GDUC number is considerably increased in 2014, where PGE has drilled about 17 wells as can be seen in Figure 1. It is shown in Figure 2. PGE still having a high price in Rig Daily Rate, possibly caused by the high oil price and term binding contract with Rig Services and other variable aspect that influencing the cost of the geothermal drilling cost. In 2018, the rate of well completion shows an improvement slope (45 m/days) based on the learning curve from the previous years. On that particular year, PGE has established some improvement that would be explained on the next section of this paper. The annual drilling performances shows by the GDUC and ROWC can be seen in Figure 3.

Since all components that formed the drilling cost structure are made in a daily rate basis, the GDUC number is also directly associated with ROWC. Although, there are more external variable aspect that influencing the cost of the geothermal drilling cost. The learning curve in 2014 and 2015 shows a positive slope, where the cost is slightly decrease until 3200 USD/m compare to the cost in 2013. In the following years, the cost is rise exponentially into 4000 USD/m, correlated with the declining of ROWC and the escalation of average total depth. In 2018, the GDUC number is considerably improved into 3200 USD/m. Not only the improvement in terms of engineering design and good operation practices, but also the changes in contract scheme play a big role in affecting the cost. In 2014, PGE still having a high price in Rig Daily Rate, possibly caused by the high oil price at that time with less options of Rig availability in the market. But in 2015 and 2017 along with the falling of the oil prices, PGE has a long-term binding contract with Rig Services with the Rig Daily Rate is reasonably lower than before. Proceeding from the previous years, PGE still using Integrated Project Management (IPM) contract scheme. Although in the mid-semester of 2018, the contract scheme has been modified with all rig and services having a direct and separated contract with PGE. Hence, all daily rates are made as low as possible. The correlation between the rig daily rate and GDUC performances can be seen in Figure 3.

![Image](image.png)

**Figure 2. PGE Drilling Campaign Performances in terms of ROWC and GDUC**
The challenges in terms of minimizing the drilling cost are mainly associated with the number of NPT performances of each well, regardless of contract scheme or any other variables that would influence the drilling cost. In 2014, the highest NPT number is contributed by stuck pipe operations and fishing job, along with the other problems. While in 2016 and 2017, since PGE selected the plug and play method for dealing with loss circulation problem, the combating loss is being the most dominant caused of NPT performances. Figure 4 shows the distribution of highest NPT problems between 2014 and 2018. The identification of subsurface drilling hazard still played the biggest role in causing the NPT performance, whether it caused a stuck pipe operation or combating loss problem in the shallow depth.

For all wells between 2014 and 2018, PGE has a typical well design as shown in Figure 5. The well design is adjustable regarding the formation characteristic in some field, but most of it are using the Big Hole design due to the borehole capacity would allow more steam production/fluid reinjection well with higher water fraction (Zuhro et al, 2015). It was a typical Big Hole design with casing 13-3/8 inch as the production casing, following the previous drilling campaign with some improvement in casing selection/design.
3. LESSON LEARNED & IMPROVEMENT

3.1 Well Engineering Design

In 2018, some of the improvement has been made to solve the problems faced in previous years. Several issues have been mapped, analyzed and to find the best or proper solutions that can be applied with recent technology available in the market. In terms of well engineering design, there are several lessons learned as follows:

a. Long-String cementing design for 13-3/8 production casing
b. Good aerated engineering design to optimize hole cleaning and increase penetration rate
c. PDC bit application for increasing rate of penetration, reducing tripping cost and improved well geometry
d. Casing while Drilling method for reducing casing seat in production casing.
e. Increase combating loss success ratio: stop loss, flow check, foam cement, soft and hard plug, other material
f. Use proper drilling practices to reduce casing seat problem such as high rpm rotation, good hole cleaning circulation (rate and time) and special clearance casing.
g. Optimize sweeps pills properties, volume and frequency according to torque and drag roadmap analysis.
h. Optimize KCL usage by conducting CEC and LSM test for upper section and production section
i. Optimize viscosity material selection through HTHP test for preventing hole permeability damage and waste mud

3.2 Operational Best Practices

On the operational aspect, the proper drilling practices still have a room for improvement in terms of increasing the effective execution. In order to fulfill the cost reduction campaign, some of the improvement has been applied during operation days such as:

a. Stuck pipe prevention program as a campaign for all personnel involved in drilling operation especially for increasing the knowledge and awareness for the rig crew.
b. Prudent quality control and optimum quantity usage control of material and services during operations
c. Optimize number of equipment used such as reduced number of aerated equipment (optimize the usage number of booster and compressor in certain field/Area).
d. Optimize stand by time for services such as reduced stand by time in upper section, cementing equipment and engineer stand by time in lower section, etc.

3.2 Contractual Strategy

Contractual Strategy optimization was delivered with the changing of the contract scenario for several services from Semi IPM Scheme to Individual contract (mud, directional and cementing). It helps PGE to suppress the daily rate of each services without the needs of handling or management fee. In the direct scheme concept, the responsibilities of well design and drilling operations decision are stick to PGE, while each contractor provide the services and material supplies that has been approved by PGE. The risk of operations has been separated on each side, depends on the type of occurrence. On the contrary, the direct contract scheme pushes PGE drilling department to have a prudent supervision for each services and material control. Moreover, in the couple of years PGE has a plan to optimizing the selection of material and services by applying good standard of ISO, API Q1 and API Q2.

4. CONCLUSION

As a conclusion, Pertamina Geothermal Energy has drilled for more than 180 wells continuously between 2007 and 2018. On the period of 2014 and 2018, 81 wells have been drilled with significant improvement has been applied in dealing with wide-ranging and various subsurface challenges spread on 8 different fields. Evaluation has been made in order to have a good learning curve in the next following years based on the ROWC and GDUC criteria. The main goal is to help PGE finished the geothermal project on time, on budget and on schedule (otobosor) and also keep involved in maintaining steam supply for established PGE Area in the future.

REFERENCES