Comparison of Geothermal Well Costs for Slim-hole Exploration wells versus Big-hole Exploration wells

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ABSTRACT

in the geothermal industry in Indonesia, many geothermal operators using big-hole wells for exploration. understand that well and drilling infrastructure costs for standard and big-hole exploration wells are quite high. High exploration costs and the risks of exploration itself are causing the slow development of geothermal fields in Indonesia. Slim-hole exploration wells in geothermal is one option that can be used to confirm the resource in certain geothermal fields.

Two emerging questions are: (i) whether a slim-hole well can deliver the exploration objective and how economic is the cost, (ii) is the use of slim-hole wells an option for exploration planning strategy in the geothermal industry in Indonesia. To answer these questions, we have conducted a literature study regarding the past operation of drilling in exploration projects in Indonesia. We will break down the cost of drilling services and material in the past operations in Indonesia to get the unit rate data and will adapt these data to calculate the cost of current geothermal slim-hole designs. This paper aims to summarize the information in the literature on slim-hole well costs compared with the cost of big-hole wells using the same subsurface data such as lithology, casing setting depth, reservoir zone, etc. This calculation was conducted by authors over the past several months.

Finally, this paper is expected to trigger more discussion among geothermal practitioners about the economics of slim-hole drilling. It is hoped that with the same amount of budget slim-hole wells could deliver more data and increase confidence about the geothermal resource in the area of interest.

1. INTRODUCTION

1.1. Drilling Exploration Objective

Geothermal exploration drilling is one of the important phases in a geothermal project. In this phase the geothermal developer conducts exploration drilling to confirm the geothermal energy source.

The three main parameters that need to be confirmed by exploration drilling are: heat, fluid, and permeability.

a. Heat
Temperatures in the range of 225°C to about 350°C are optimal temperatures, as wells at these temperatures will be self-flowing.

b. Fluid
Good geothermal systems have geothermal fluid in liquid-dominated or vapour-dominated conditions. Exploration drilling and well testing are used to determine the type of geothermal fluid in the geothermal system.

c. Permeability
Permeability will be found just as well with slim-hole wells as with larger diameter wells (e.g., drilling breaks, fluid losses, kicks, etc.). Completion tests can measure injectivity indices, and provide general guidelines for whether good permeability has been found. A normal type of completion test can be run in a slim-hole well, measuring water loss, injectivity and pressure fall off.

1.2. Hole Size Definition and Comparison

For the exploration phase, a geothermal developer can use various types of well depending on the well size. Wells can be categorized based on diameter (big/large-hole, standard/regular-hole and slim-hole) as shown in Figure 1.

Those well categories are defines by the production casing size:

a. Big/large-hole –wells with 13-3/8” production casing size

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b. Regular/standard-hole –wells with 9-5/8” production casing size.
c. Slim-hole – wells with 4-1/2” – 5-1/2” production casing size.

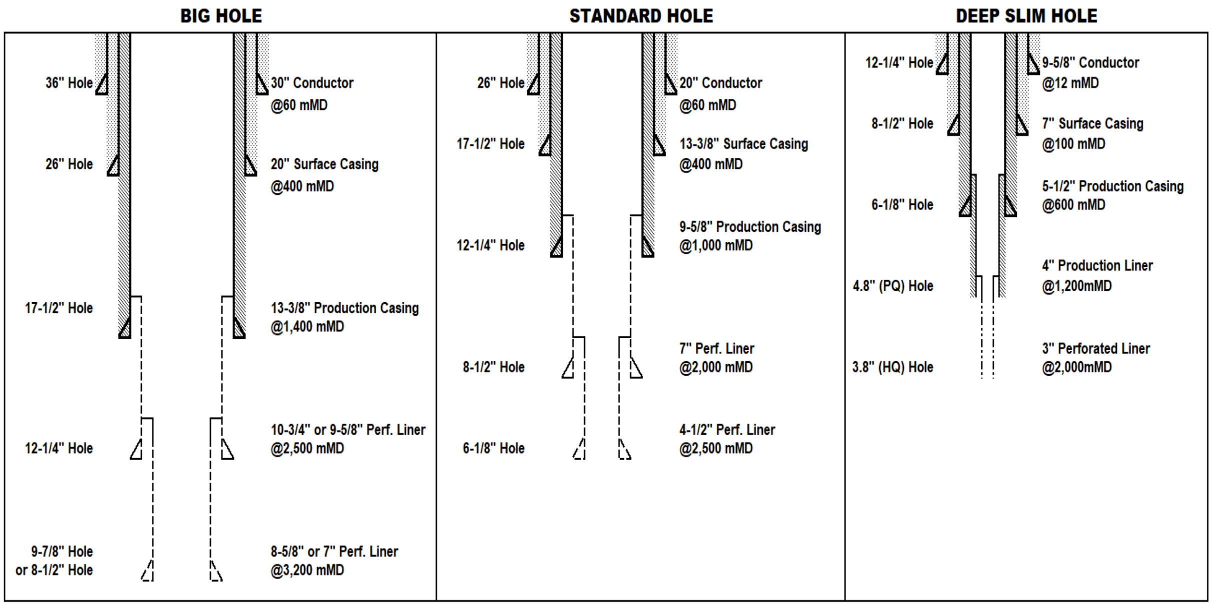

Figure 1: Type of geothermal exploration hole size (modified from Rigsis, 2021)

While based on the type of drilling, those wells can be executed using two methods: rotary drilling and continuous coring drilling. Several important points based on well types are shown in Table 1 They not only differ in diameter size but also require different types of rig, materials, and size of well-pad area.

Table 1: Hole size Comparison (modified from Rigsis, 2021)

	BIG HOLE	STANDARD HOLE	DEEP SLIM HOLE
Production Casing	13-3/8”	9-5/8”	4-1/2” – 5-1/2”
Rig Capacity	1500 – 2000 HP	1000 – 1500 HP	350 - 750 HP or 35 klbs (pull up capacity)
Drilling Method	Rotary Drilling	Rotary Drilling	Rotary – Continuous coring Drilling
Min. Well Pad Area	10k m^2	7.5k m^2	2k m^2
Water Supply	60 – 80 lps	50 – 70 lps	20 – 45 lps
Directional Drilling	✔	✔	✕
Formation Evaluation	Cutting, Conventional/Sidewall Core, Image Logging, PTS Logging, Injection Test, Flow Test		Continuous Core, PTS Logging, Injection Test, Flow Test*
Future Well Usage	Production / Injection	Production / Injection	Monitoring

2. GEOTHERMAL DRILLING COST

The drilling cost is the biggest contributor to the cost of the exploration phase. Because at this stage the construction of the surface facility is not yet required. The main objective in this exploration phase is to confirm the geothermal resource in the area of interest. There is also a risk that the geothermal resource found in the area may not be economical or technical do-able at the later development stage.

We need to identify the services and materials requirements for conducting geothermal exploration drilling. The requirement may vary depending on the drilling exploration objectives, operational constraints such as location, access road, topography, etc. and on the subsurface uncertainties that are difficult to predict.

The risk in the drilling operation at the exploration stage is bigger than at the development stage due to the limitation of subsurface data that geothermal developer has at the exploration stage.

In this study, we will focus on assessing the cost of the geothermal well at the exploration stage. The other cost components such as well pad and access road are also important in terms of project viability, especially in Indonesia, because Indonesian topography may add significant cost for access road and well pad construction. Such difficulties and risks have a significant effect on the cost of exploration.

3. METHODOLOGY

To develop a comparison between drilling costs for slim-hole wells versus drilling costs for big-hole wells, we need to first define the drilling objective. The objective must be similar for both type of well in order get an apples-with-apples comparison. After defining the subsurface objectives, we can start the well design. Based on the well design we try to identify requirements for services and materials. Based on all those requirements we estimate the cost of the well using the market survey or drilling cost data base.

A flow diagram to get the cost comparison of Geothermal Well Cost for a Slim-hole Exploration well versus a Big-hole Exploration well is shown in Figure 2

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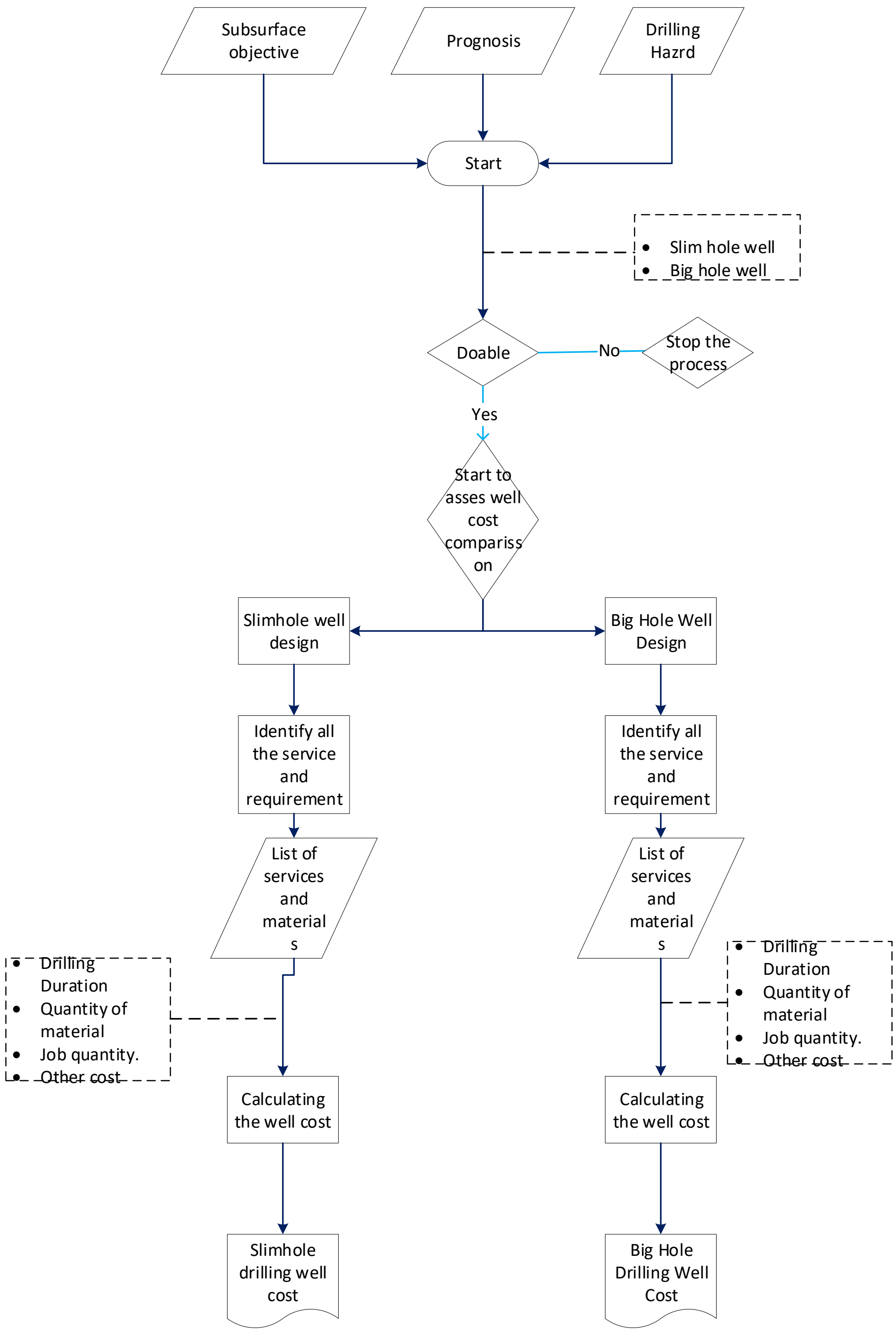

Figure 2: Well Cost delivery process

3.1. Objective

To objectively determine a robust comparison for costs of slim-hole wells and big-hole wells, it is necessary to use the same objective and assumption for the design of both of wells. Therefore in this discussion on developing the well design, we use the same lithology and geological prognosis data.

3.2. Slim-hole Well Design

The slim-hole well design that we use to calculate the cost of the well is shown in Figure 3

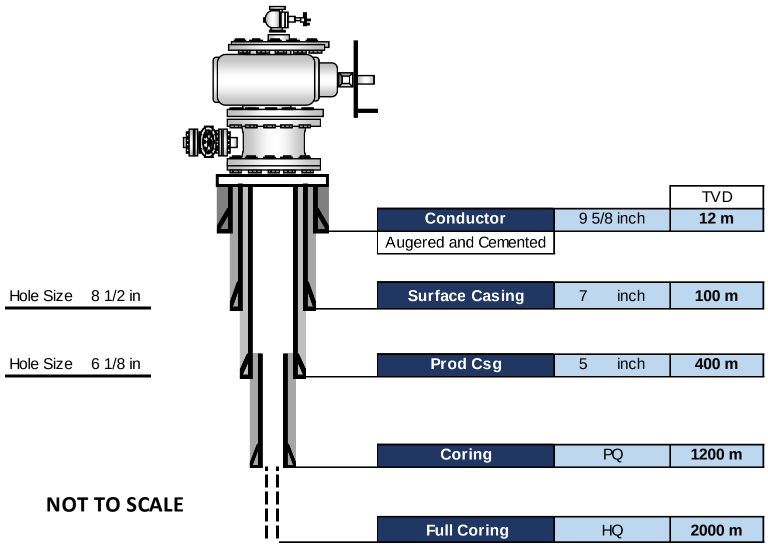

Figure 3: Slim-hole Well Design

3.3. Big-hole well design

The big-hole well design that we use to calculate the cost of the well is shown in Figure 4

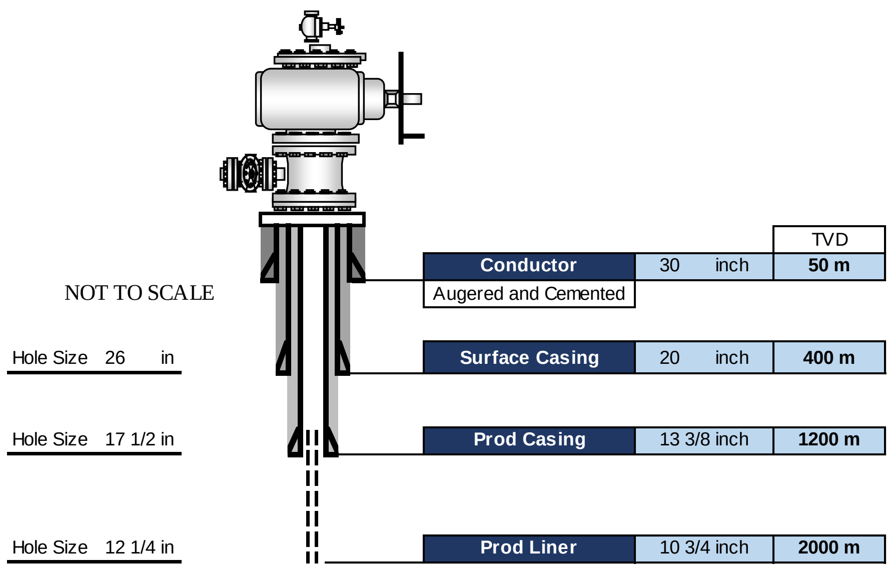

Figure 4: Bighole well design

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3.4. Services and Material Comparisons

Table 2 shows a comparison of the requirements for slim-hole drilling and big-hole drilling.

Table 2: Technical requirements for slim-hole and big-hole wells

	SLIM HOLE	BIG HOLE	REMARK
Drilling Rig	Multipurpose Rig with 50 – 200 Klbs Pull up capacity	Conventional rotary rig – 1500 HP	Multipurposed rig could support both of Rotary and continuous drilling operation
Mud Logging Unit	✔	✔	
H2S Monitoring	✔	✔	
Cementing	Normal slurry	Normal slurry	Difference in quantity
Wellhead and liner adapter	4-1/16” Master valve	12” Master valve	
Casing Supplies	Standard grade, with API connection	Standard and high grade, with semi and premium connection	Difference in size, grade and connection
Drilling Bit	12-1/4”, 8-1/2”, 6-1/8” PQ, HQ, NQ	26”, 17-1/2” 12-1/4”	Slimhole drilling used conventional roller cone for rotary drilling, and core head for continuous coring drilling
Water Transfer Pump	350- 700 GPM	1200 GPM	
Drilling Fluid	KCL Polymer	KCL Polymer	Different in quantity
Well Logging	PT, PTS, Downhole Sampler, Bore Hole Imaging	PT, PTS, Downhole Sampler, Bore Hole Imaging	
Directional Drilling	X	Contingency plan	
Aerated Drilling	X	Loss circulation on reservoir section	

Based on those well schematics, we can identify the service and material requirements for each type of well. With the assumption that duration of drilling for a slim-hole well will be longer than for a big-hole well, due to the nature of continuous coring which has a lower rate of penetration (ROP) compared to conventional rotary drilling. In this scenario, we use the drilling duration estimates based on data from one of the geothermal drilling campaigns in Indonesia to determine the drilling duration for both types of well. Using the ROP data from rotary and continuous coring drilling, we come up with the drilling duration estimate that is 45 days for rotary drilling and 65 days for continuous coring

A conventional rotary rig for big-hole geothermal drilling is quite easy to find in the Indonesian market. Rig equipment for conventional rotary drilling is similar to the equipment for oil and gas applications. The challenge is to find a multipurpose rig. In Indonesia, there is not many drilling contractors that have a multipurpose rig in their fleet because the geothermal slim-hole drilling is currently not very common for Indonesian geothermal operators. Services such as Mud Logging Unit and H2S monitoring use similar equipment with a few modifications that do not much affect the cost.

Since a big-hole well uses a larger size of casing, bit, wellhead, master valve, it will consume more material such cement and drilling fluid. Thus, the cost of material for a big-hole well will be significantly higher than for a slim-hole well. The requirement for a water transfer system is also different due to the differences in flow rate requirements. It will impact the water pump specification and also water line size and rating pressure.

Logging requirements are quite similar since the data that needs to be collected is the same for both slim- or big-hole wells. The important note for the well logging requirement is the size of the liner as some logging tools have a minimum size limitation, which means that we must make sure that the size of the logging tool (outside diameter) will fit into the wellbore.

Aerated drilling is often used in big-hole drilling to support drilling in the reservoir section. The main function of aerated drilling is to help to lift the cuttings from the drill bit area in order to prevent a stuck pipe in the wellbore. On the other hand, aerated drilling for a slim-hole well is not necessary since in slim-hole drilling in the reservoir section continuous coring drilling will be used. This means that almost all the cuttings will be retrieved to the surface using inner barrel inside the string.

Directional drilling will be used for the big-hole drilling only, as currently slim-hole drilling is not supported for a deviated well.

4. RESULT

All the unit prices that are used to calculate the cost estimate for both slim-hole and big-hole wells are from Rigsis's service and material database. The costs shown in Table 3 include a range from the minimum to maximum for each service.

That total cost estimate excludes the mobilization cost. It is difficult to estimate mobilization costs due to Indonesian topography. The well cost also does not include the costs of well-pad and access road construction.

The detailed cost estimate is shown in Table 3.

Table 3: Well cost comparison between Slim-hole and Big-hole drilling

SERVICES	SLIM HOLE	BIG HOLE	REMARK
	USD ($)	USD ($)	
Drilling Rig	**526,500 - 877,500**	**1,350,000 - 1,620,000**	
Mud Logging Unit	**49,400 - 113,425**	**34,650 - 57,600**	
H2S Monitoring	**39,650 - 152,750**	**28,980 - 45,000**	
Cementing	**334,390 - 982,588**	**464,654 - 1,054,678**	
Wellhead, Liner adapter	**95,657 - 229,037**	**384,703 - 423,173**	
Casing Supplies	**128,569 - 210,779**	**767,869 - 809,062**	
Drilling Bit	**116,000 - 199,300**	**301,400 - 353,487**	
Water Transfer Pump	**100,000 - 400,000**	**201,500 - 623,600**	

Drilling Fluid	**108,493 - 541,106**	**301,268 - 861,598**	
Well Logging	**56,000 - 132,000**	**56,000 - 132,000**	
Directional Drilling	**-**	**381,398 - 844,910**	
Aerated Drilling	**-**	**311,500 - 575,830**	
TOTAL	**1,554,660 - 3,838,486**	**3,891,025 - 5,980,198**	

5. CONCLUSION

Defining the exploration objective is the most important step in determining what type of exploration well should be chosen. From the drilling engineering point of view, a slim-hole well is more economical than a big-hole well. Although the big-hole well will give the geothermal developer flexibility to achieve the exploration target.

Also, since slim-hole drilling in Indonesia does not have as much background of experience compared to big-hole drilling, it may increase the operation risk by prolonging the duration of drilling or exceeding targets for material used. A longer duration and larger quantities of materials can lead to the cost of the well exceeding the estimate made by the project owner.

A lot of lessons need to be learned from slim-hole exploration drilling to achieve effective and efficient drilling of slim-hole exploration wells. The two important parameters to define the success of this stage of exploration are cost of drilling (to meet the budgetary target) and the ability of the well to achieve the exploration objective itself. Also needed are fit-for-purpose drilling equipment, especially the drilling rig because the availability of multipurpose rigs on the market is still limited.

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