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Application for Slim-Wells in Geothermal Exploration and Production

Bjarni Richter[1], Sverrir Thorhallsson[1], Thoroddur Sigurdsson[2], Gunnar Skúlason Kaldal[1]

[1]ISOR – Iceland GeoSurvey, Grensásvegi 9, 108 Reykjavík, Iceland,

[2]Mannvit, Urðarhvarfi 6, 203, Kópavogi, Iceland

br@isor.is, s@isor.is, thoroddur@mannvit.is, gsk@isor.is

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ABSTRACT

Over the last few decades, geothermal development has repeatedly been hampered due to lack of funding when it comes to drilling exploration wells in green geothermal fields. Financial institutions and banks find the risk, involved in the first stages of development, too high to invest or issue loans. Therefore, the developers must finance the exploration stage with own assets or find financiers that are willing to take higher risk. Over the last few years, developing agencies have focused on assisting with financing this part of the geothermal development, offering grants and soft loans to bridge the gap. One option in lowering the initial financial risk is to use deep slim wells (small diameter) for the exploration. This has advantages when keeping the initial budget lower and easier to arrange. This can be more easily implemented, especially in areas that are considered riskier, resource wise, than better known areas due to indecisive surface exploration data. This approach can lower the cost of confirming or not the potential resource in question. In general, the smaller the diameter, a smaller drill rig is required, which translates to lower drilling costs, less infrastructure and smaller environmental footprint. It has been shown that slim wells can be tested, even though the diameter is small. They can provide similar information as the conventional geothermal wells, such as the reservoir temperature and pressure, chemical composition of geothermal liquid, gas content of the steam, reservoir permeability as well as information on the hydrothermal alteration of the geological formations. If well temperatures are high enough, discharging can be initiated and the well output measured which can be scaled up to estimate output of larger diameter wells. They may even sustain production over a longer period of time and be utilized as small producers or be used as observation wells for reservoir monitoring. Drilling slim wells may benefit the developers in de-risking their projects so that financing of the next steps of development becomes easier. If an exploration well does not prove the existence of a resource, the investment lost is less with slim wells than if larger wells were drilled. If a resource is identified and measured using slim wells, the risk of further drilling and development will be reduced significantly which simplifies decision making for developers, banks and investors.

1. INTRODUCTION

Normally, when drilling full size wells during the exploration phase, anywhere from 2-6 exploration wells may be needed to confirm, test and measure the resource. This can be extremely costly since each standard geothermal well usually costs several million US dollars, not including high infrastructure cost and the environmental footprint of large drill rigs. Therefore, the total cost of exploration drilling can easily add up to tens of millions of US dollars before the geothermal field can be considered a measured resource. Using deep slim wells (small diameter) for the exploration, can lower the cost considerably (McKenzie et al. 2017, Nielson and Garg, 2016), both for drilling and infrastructure, e.g. roads and access to water to the drilling site.

Here, slim wells are defined as wells drilled with the final diameter of ~ 6″ or smaller or a liner under 5". Such wells can either be drilled with tri-cone bit or cored, or combination of both. In general, the smaller the diameter, a smaller drill rig is required. Same as for regular size wells, slim-wells are designed according to requirements of structural integrity and safety during drilling. The New Zealand Standard "Code of Practice for Deep Geothermal Wells" NZS 2403:2015 and a version of it published as "The African Union Code of Practice for Geothermal Drilling" 2016 are widely used. According to the geothermal reporting codes (Australian Geothermal Reporting Code Committee, 2010, Canadian Geothermal Code Committee, 2010), certain steps are needed for bringing the knowledge on a specific resources from being inferred to a measured resource (Figure 1).

Bringing the knowledge from being inferred or indicated to a measured resource can be done through slim wells. In Figure 2, the most common geothermal casing programs/well designs are presented. The regular geothermal well is the most common (even as the first exploration well), but the large design is also common especially within fields that are already proven and are being developed. The slim and cored are much less used, and mainly as the first exploration wells within an undrilled geothermal area.

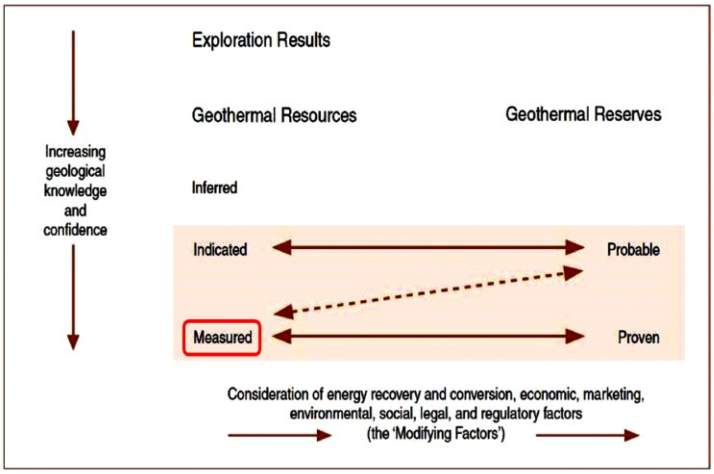

Figure 1: From the Geothermal Reporting Code (2010),

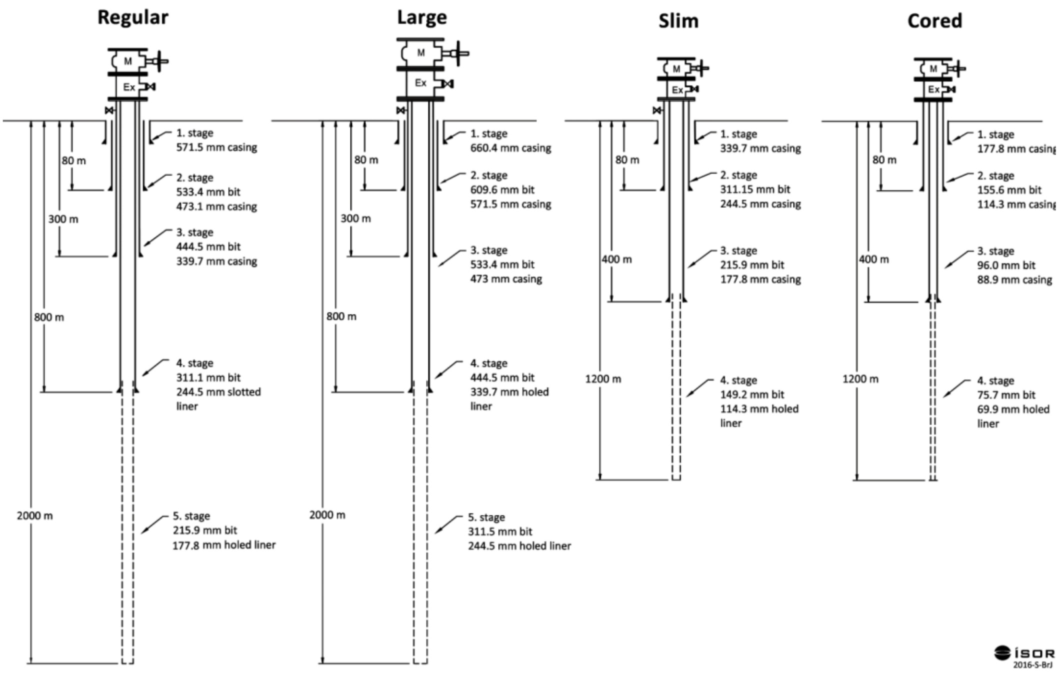

Figure 2: The most common casing programs for geothermal wells.

2. WHY DRILL SLIM-WELLS?

The following are some reasons why slim-wells may be preferred over drilling full size holes:

- High cost of drilling is a barrier to exploration of subsurface resources.
- Slim-well drilling can reduce costs up to 25-75% compared to larger wells (Garg et al. 2000, Nielson and Garg 2016, Mackenzie et al. 2017).
- Remote or sensitive locations with difficult access. Easier transportation. Less infrastructure cost.
- The reduction in bulk allows even helicopter transport or small trailer mounting.
- Reduced size of required well pads and roads. Smaller footprint and more easily removed afterwards.
- Drilling license for slim wells may be easier to acquire.
- The power required for drilling is lower, saves fuel and minimizes CO_2 emission.
- Usually less water demand during drilling, which makes drilling in arid areas easier. If drilled by coring the water demand is even less. Aerated drilling can also help mitigate with rotary drilling if the water supply is scarce.
- Cheaper drilling tools, casing, cement jobs, smaller crew, less materials, smaller waste disposal.
- Shorter rig mobilization and de-mobilization time. Coring, however, may be more time-consuming.
- Provide same/similar information as larger wells on resource temperature, pressure, composition of brine, gas and steam, as well as indications of permeability and output.
- Continuous cores provide high definition stratigraphic information and samples for determination of formations, hydrothermal alteration and other reservoir properties.

- If successful in proving a geothermal resource, the risk of drilling sequential full-size wells has greatly decreased and financing of the next steps of the development becomes easier and less expensive
- If not successful in proving a geothermal resource, the financing lost is much less than if drilled with full size wells.
- Successful slim wells drilled, but not suitable for production, may serve as monitoring wells or small-scale injection wells for further development and utilization.
- Successful slim wells drilled and suitable for small production, can replace diesel generators both during further development of the field as well as provide energy to local communities.
- Small scale production gives information on reservoir response and sustainability for further development

3. TYPES OF WELLS CONSIDERED SLIM WELLS.

3.1 Slim-Well, 6 1/8" open hole section

This type of a slim-well (Figure 3) can be drilled with rigs with 60 to 100 ton hook load capacity (Figure 4). Such rigs are truck mounted or on a trailer and require a substructure or alternatively a deep cellar for the blow-out preventers. All sections of the wells are drilled with conventional tri-cone bits. Such wells can reach 2000-2500 m, depending on the drill string and hook load rating of the rig and pump size.

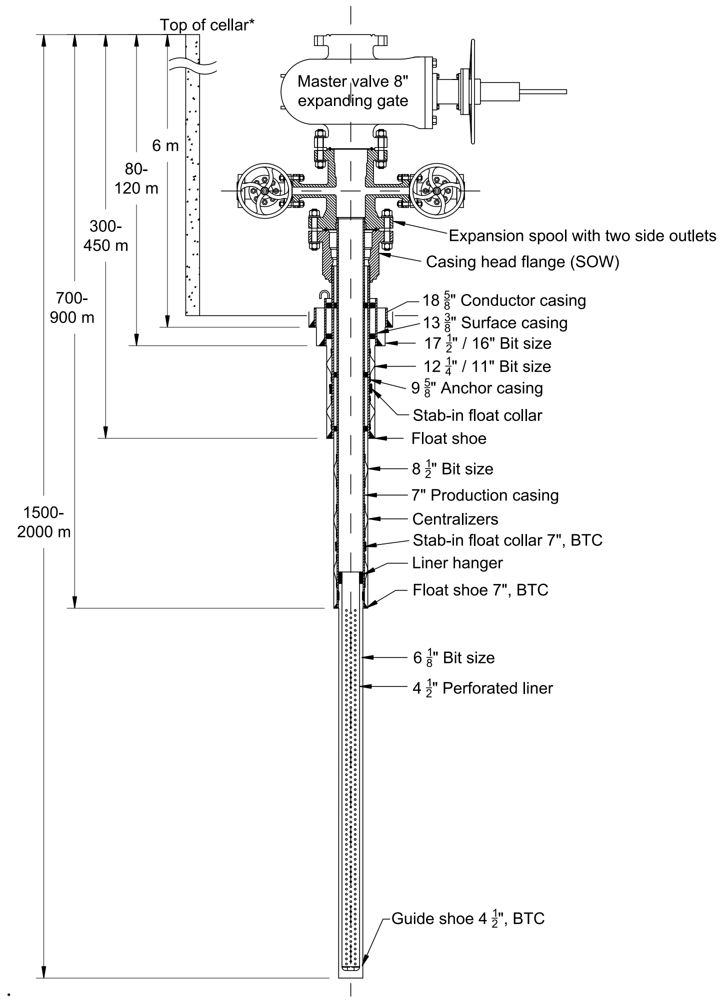

Figure 3: Design for a rotary drilled, 6 1/8″ open hole section, slim-well.

Figure 4: A 100 ton hook load drillrig (Sleipnir, Iceland Drilling), drilling a well with 6 1/8" open hole section in Dominica. Three wells were drilled to 1600-1800 meters.

3.2 Hybrid Slim-Well (cored and rotary), with HQ and NQ open hole section

This type of a slim-well (Figure 5) can be drilled with truck mounted coring rigs, typically having a hook load capacity of about 20-30 ton. Such truck mounted rigs require a substructure and/or a deep cellar (Figure 6). This type of wells are drilled with tri-cone and coring bits. Such wells can reach up to 2000 m.

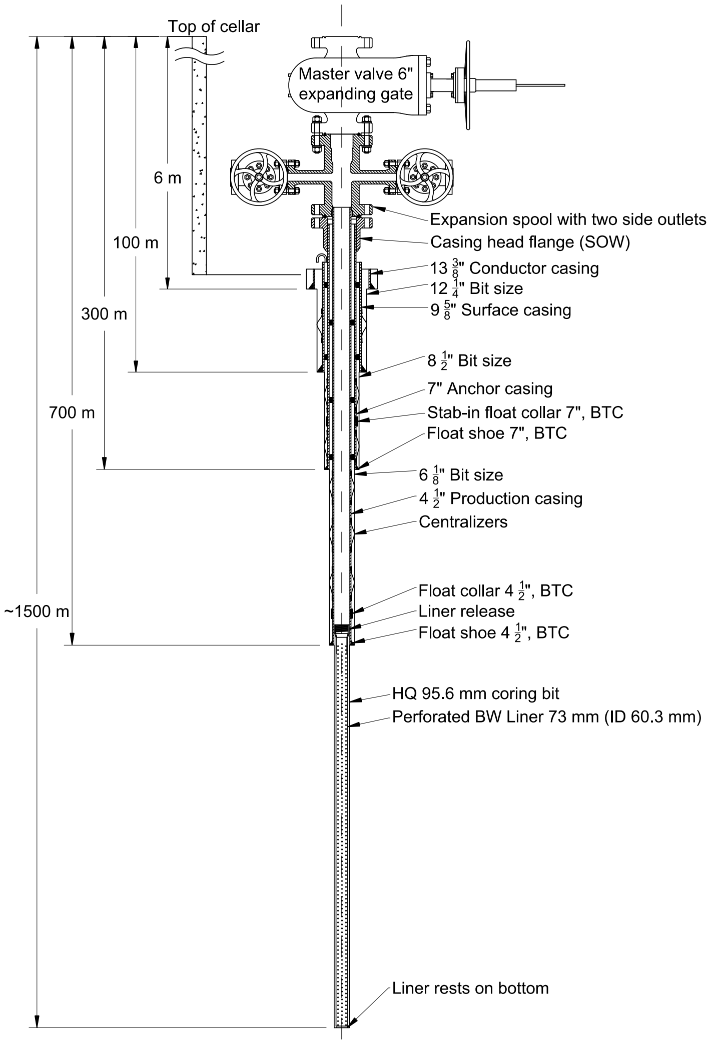

Figure 5: Design for a hybrid well where the first sections are rotary drilled, and the last section is cored with HQ.

Figure 6: A ~ 20 ton hook load, truck mounted coring drillrig drilling a hybrid well in Chile.

3.3 Cored Slim-Well

The slimmest well types (cored HQ/NQ) can, be challenging to drill to depths beyond 1500 m and into high temperatures (Figures 7 and 8).

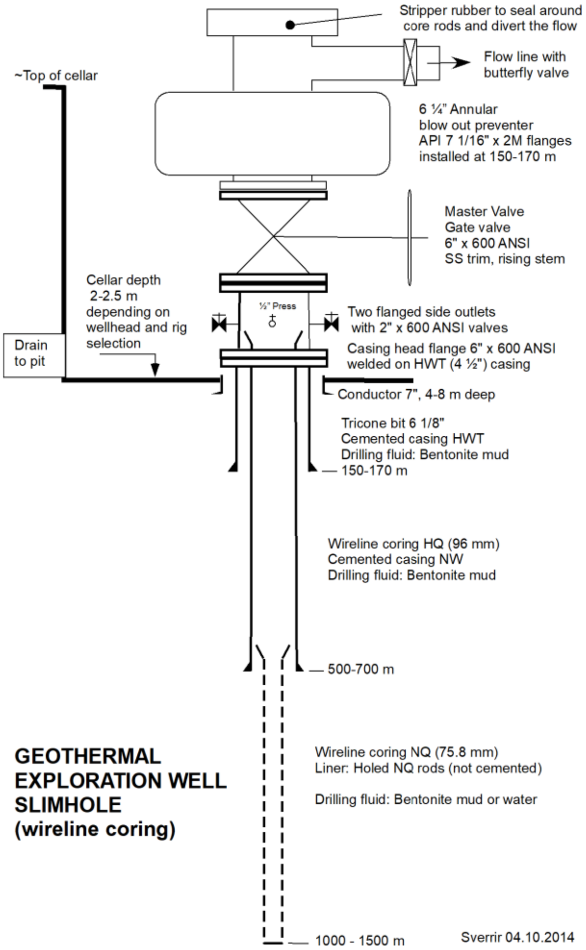

Figure 7: Design for a cored geothermal slim-well.

Figure 8: A small coring rig drilling with HQ to depths of 1250 m into temperatures beyond 200°C.

All these wells can be geophysically logged with high temperature tools, using more or less the same equipment as for larger types of wells. Therefore, as mentioned earlier, the data collection from such wells are at par with full size wells.

4. FLOW RATES FROM SLIM-WELLS

If well temperatures are high enough, self-flowing can be initiated and the output measured, which can be used to estimate output of larger diameter wells. These wells can also be used directly for small scale power production over extended period of time.

According to Garg et. al., 2000, the output of slim-wells can vary significantly, based on the actual design of the wells. Garg et. al. carried out simulations for maximum well output for four different slim-well completions (to 1500 m) in high temperature regime.

Slim well completions from Garg et.al, 2000.:
Type 1) Uniform inside diameter of 100 mm to 1500 m.
Type 2) Inside diameter of 104 mm from 0 to 1000 m, 100 mm from 1000 m to 1500 m.
Type 3) Inside diameter of 154 mm from 0 to 500 m, 104 mm from 500 m to 1000 m, and 100 mm from 1000 m to 1500 m.
Type 4) Inside diameter of 154 mm from 0 to 1000 m and 100 mm from 1000 m to 1500 m.

The following temperature assumptions were used:
10°C at 0 m,
100°C at 200 m,
230°C at 1000 m and
250°C at 1500 m.

Below are calculated values for maximum discharge rates (Table 1), as well as plots with estimated enthalpies and output curves for the four different scenarios (Figure 9).

Table 1. Maximum discharge rate calculated from different well completions (Garg et.al, 2000).

Completion	Maximum discharge rate
Type 1)	9.6 kg/s
Type 2)	10.7 kg/s
Type 3)	18.4 kg/s
Type 4)	27.8 kg/s

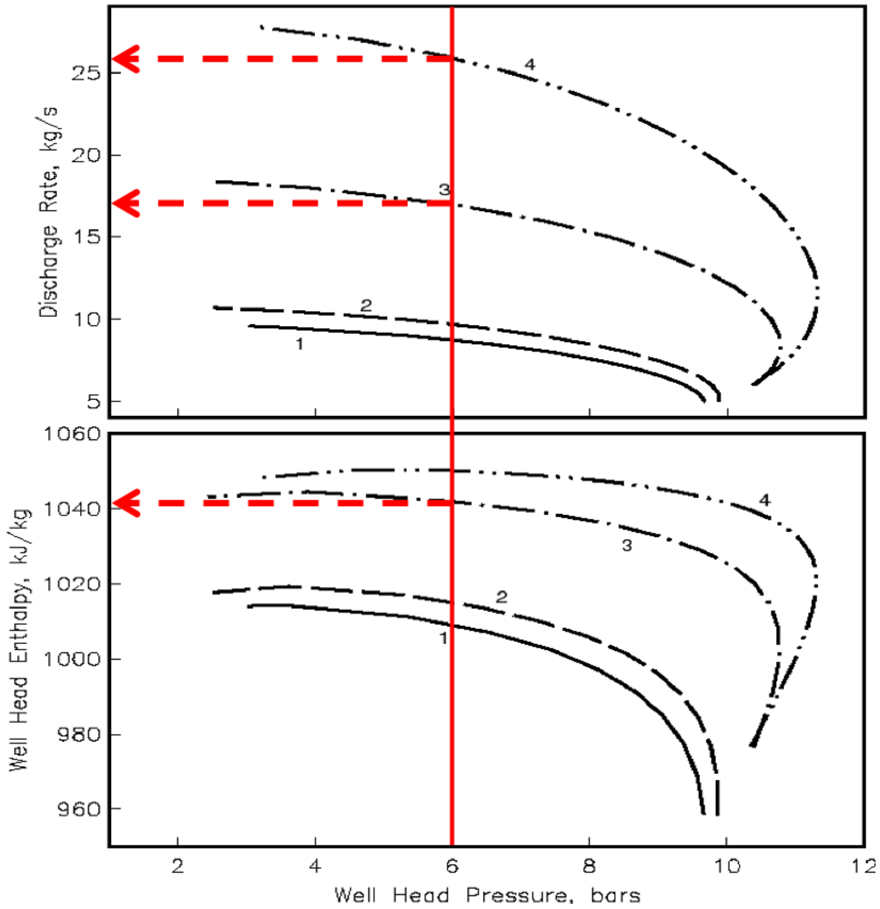

Figure 9: Output curves from Garg et.al. 2000. Red lines and arrows how input figures were derived for the examples of flowrates and power output.

Example of estimated power output (MWe) through a condensing flash plant, based on aforementioned calculations:

Assumptions: Well Head Pressures at 6 bar, indicates enthalpy of ~1040 kJ/kg and ~18% steam. About 2 kg/s of steam is needed to generate 1 MWe.

Example 1: Well example type 3: Total flow rates of ~ 17 kg/s, thereof ~3 kg/s steam. Such a well may therefore produce up to 1.5 MWe, if the permeability is good.

Example 2: Well example type 4: Total flow rates of ~ 26 kg/s, thereof ~4.6 kg/s steam. Such a well may therefore produce up to 2.3 MWe, if the permeability is good.

By using the total fluid from wells (through binary units), the power output may even be somewhat higher.

5. DISCUSSION

Using slim wells for exploration purposes has been known for some time during the last few decades. Such wells can in most cases reach deep enough to penetrate through clay caps, often found in connection with high temperature geothermal reservoirs. In any high temperature geothermal development, the need to drill for confirmation of a resource is inevitable. The slim wells can offer a less expensive approach, to the standard well, in the first phase of geothermal development. The exploration information gained are similar to using a full size well.

A properly designed and located slim wells may also be used for power generation on a small scale, both for use at development site as well as to local communities. This possibility may be of interest when developing high temperature geothermal resources, close to isolated and populated areas with relatively low power demand. A few MWe produced from such geothermal resources can lower cost and carbon emission by replacing diesel generators, often used by small, off-grid communities.

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