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Geothermal drilling and well completions in comparison to oil and gas practices in low temperature (<170°C) sedimentary basin reservoirs

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Summary

In Canada's Western Sedimentary Basin (WSB), a number of significant factors must be taken into consideration in order to develop a commercially viable geothermal project, most of which center around drilling and well completions. Within Canada, Alberta has particularly significant areal extent where temperatures are high enough to extract for direct-use applications and, in some locations, power production (Wiedes and Majorowicz 2014). In addition to a suitable temperature differential between the surface and subsurface, there must also be a permeable reservoir. Alberta has a significant and extensive history in the production of oil and gas resources and has been a leading innovator in drilling technology. This background is an excellent framework for geothermal development and understanding the differences is an important principle for successful geothermal development.

To exploit the subsurface heat resources of the WCSB, there are four main factors necessary for creating an economic geothermal well and ultimately a commercially viable development: (1) Well bore diameter (deliverability); (2) Pump size (capacity); (3) Pump setting depth (parasitic load); and (4) Power plant efficiency (alcohol/modular plants vs Organic Rankin Cycle (ORC) units) for electricity production. The following summary has been derived from the experience of the authors and drawn from the cumulative expertise of professionals, for example, Capuano (2006, 2010, 2014), Petrowiki (2015), Teodorui and Falcone (2008), Anderson and Petty (2006), among others. These papers outline the differences between drilling and well completions for oil and gas (O&G) versus geothermal resources. These differences are sometimes subtle, but nevertheless critical for project success. An often-contemplated geothermal development plan in Alberta is utilization of old O&G wells. That topic is beyond the scope of the paper, but readers are referred to Sanyal and Butler (2010) for a realistic review of potential issues.

Mass flow and enthalpy: The lower the temperature, the more fluid (mass) that must be pumped to get the same enthalpy value. Enthalpy is the measured energy contained in water or steam (kJ/kg). Steam has significantly higher enthalpy than water, hence high temperature geothermal systems are more efficient than low temperature ones; i.e. less water (or steam) needs to be produced to create a MWe of power (Figure 1). As a result, larger well bores and large pumps are a necessity for economic utilization of systems below 170°C (338°F).

Heat Transfer: Heat energy can be transferred by conduction (direct heating), convection (brine circulates the heat upward) and/or counter-flow (steam condensation/phase change). In the WCSB, it is assumed most heat transfer is via conduction from the Precambrian basement rocks. There may, however, be some convection within porous reservoirs contained in both the basement and sedimentary sequences, as well assome trapping of heat by low conductivity sediments within the sedimentary sequence (for example tight shale horizons). These heat transfer mechanisms are also a major difference from O&G reservoirs. In typical O&G reservoirs the fluid is static (not moving), whereas in a geothermal reservoir the fluid is convecting.

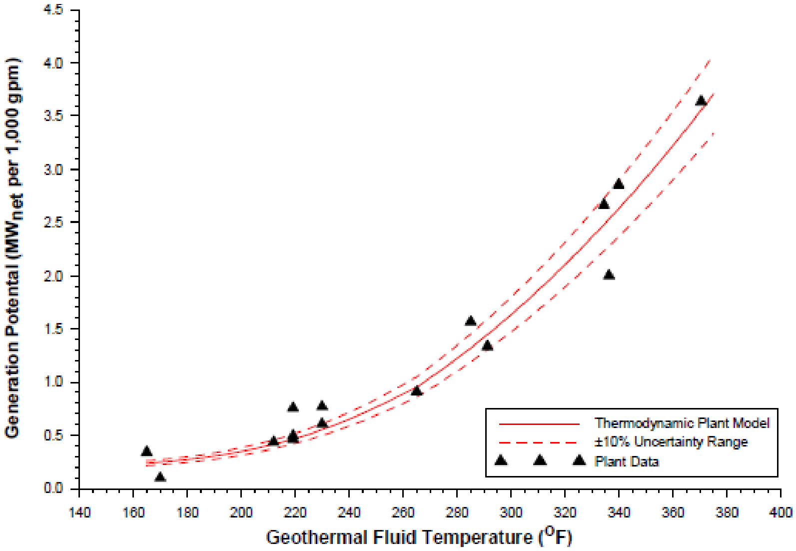

Figure 1. Generation potential vs. fluid temperature (Sanyal and Butler 2010).

Completions: Completions of a geothermal well are significantly different than those of O&G wells. Figure 1 illustrates why large diameter wells are required. Figure 2 schematically shows the difference in the completions between three well types (Teodoriu and Falcone 2008). Additionally, there are often large segments of open hole (or slotted/perforated liner) in geothermal wells. The targeted formations are either completed open-hole or slotted/perforated liner hung or set on the bottom (not cemented). In contrast, the producing zone in O&G wells is usually confined to a small, well-defined, vertical interval, and tubing is cemented in place and perforated. The open-hole section in geothermal wells may be as great as 2000 m and in the WCSB could be hundreds of meters. This long, open-hole section allows for communication between the well and the formation in locations where a fractured zone is intersected. Further, where several permeable zones are encountered, there are usually interzonal flows.

Mass Flow and Longevity: Geothermal wells must fundamentally flow significant volumes of brine, especially in low temperature systems as shown in Figure 1. The decrease in enthalpy with decreasing temperatures must be compensated for by mass flow. Additionally, unlike O&G reservoirs, produced hot brine is replaced by cooler surrounding brine (recharge) which is then heated by the reservoir rocks. Management strategy must balance the input and output and match them to the heat loss. Injection is critical for maintaining this mass balance and is often difficult to achieve. Drawdown and lack of pressure support can significantly impact a geothermal resource, shortening the lifespan of a project by decades. When appropriately balanced, however, geothermal reservoirs can produce for decades.

Well Longevity: Because resource extraction can be sustained for decades, geothermal wells need to be designed, and good management practices followed, to keep the installation in use over generational time spans. In O&G projects, 5-15 years is a more typical design lifespan. Issues such as corrosive fluids, erosion of casing due to high production rates, and damaged casing due to thermal cycling must be taken into consideration to ensure well longevity.

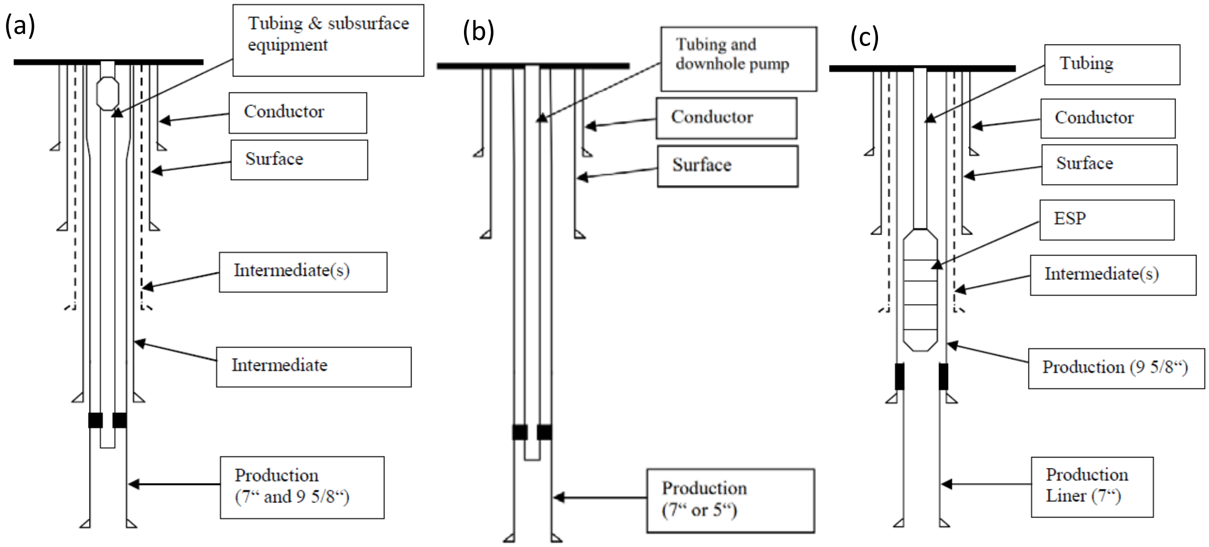

Figure 2. (a) Schematic representation of a larger than average gas well completion; (b) heavy oil completion; (c) a smaller than average geothermal completion. (Teodoriu and Falcone 2008).

Cementing: Geothermal well casing must be cemented across the entire length from the casing bottom to the surface. This results in much higher volume cement jobs than is typical in O&G drilling. Uncemented voids in casing annuli will result in casing failure; this is also true for brine-filled voids. Precision in cementing is key to the longevity of the well and to avoid casing damage during drilling. The major modification in composition of geothermal cement is the addition of retardants and approximately 40% silica flour to standard Class G cement. Requirements for steam-assisted gravity drainage (SAGD) wells is similar.

Lost Circulation (LC) Zones: Geothermal wells are potentially drilled with long segments of lost circulation. LC creates drilling problems including complete loss of drilling fluids and blind drilling, where stratigraphic information typically gleaned from cuttings is unavailable. Drilling fluid loss can be massive, requiring pumping rates of hundreds of barrels per hour and resulting in underbalanced drilling. Underpressurized formations aggravate differential sticking. LC also makes casing cementing difficult. Precision cementing is more challenging because large diameter casing/ hole sizes require large amounts of cement and placement becomes critical.

High Temperature Adaptations: In the WCSB, some of the adaptations for drilling in high temperature fields are not applicable as temperatures are well below 200°C. In fields where temperatures exceed 200°C, modifications of mud coolers, the necessity to have high temperature electronics, specialized high temperature cements, and high temperature mud additives are the norm.

Well Testing: Production fluid temperatures within the WCSB will likely be below <140°C, so standard downhole tools can be utilized. However, because of the amount of open hole in geothermal wells, testing tools are different and the results require differing interpretations. For example, downhole pressure-temperature data is impacted by interzonal flows within the wellbore. These circulation patterns are impacted by a combination of well completion design (variation of casing size and perforation details) and the diameter of the drilled hole (Allis and James 1980; Lund 2010).

Fluid Production: Fluid (brine) is often produced "open hole" or slotted/perforated liners utilized to filter large formation debris. Typically, O&G is produced up tubular completions. In geothermal wells, wellhead completions are large diameter master valves through which the well was drilled. Caution must be exercised as fluids could be corrosive, which impacts the choice of well heads.

Formation Rocks/Drilling Risk: In the WCSB, a notable geothermal target is the lowermost sedimentary sequences and the top of the Precambrian basement. These units could be hard (240+ MPa compressive strength) and abrasive (quartz content above 50%). Additionally, unlike O&G production, geothermal production in crystalline basement rocks is most likely from fractures and fissures, rather than open pore space as in a sedimentary sequence. Drilling is often slow and bit life typically low. Roller-cone bits with tungsten-carbide inserts are most often used. Additionally, polycrystalline diamond compact (PDC) bits are an option, but there have been reports that PDC bits do not perform well due to air/aerated drilling, fractures and increased temperatures. Reports of lemon-shaped or sub-round holes is not uncommon; these types of holes complicate setting of packers and testing the well.

Drill Pipe Pressure Class: In a depleted O&G field, the static pressures may have declined and an argument could be made for a lower pressure class than for O&G, but this is likely not universal and would have to be made on a case-by-case basis. The pressure class rating would have to consider the O&G and geothermal implications of the target strata, and potential to drill through over-pressured zones and above the geothermal resource. In addition to defining the completion, the short wellhead piping will have to meet the wellhead pressure class rating with a pressure relief system. This pressure class flows through the testing piping as well as the production piping. Choices here have a significant effect on casing costs as well as surface piping costs.

Economics: Value of heat is significantly lower than hydrocarbon values. Therefore, cost cutting measures are necessary to improve the economics of the project. Maximizing flow with a minimum number of wells is an important consideration, but well bore size, casing program, pump size, pumping costs, cementing, and testing are all more expensive compared to O&G projects. If high temperature connections are required, costs increase significantly. Well depth is also a very important cost factor for these systems. Deep wells in the WCSB are significantly more expensive to drill. Figure 4 is illustrative of the increasing costs with depth (Anderson and Petty, 2006). Anderson and Petty (2006) also report findings that geothermal well costs were 2-5 times higher than typical O&G costs.

Well Control: Pressures in oil and gas drilling situations are controlled by three methods: drilling fluid density, well head pressure control equipment, and well design. The most significant well design change when comparing geothermal costs to O&G costs is that extra casing strings are added to shut off high pressure zones in oil and gas wells (Anderson and Petty 2006). While over-pressure is very common in oil and gas drilling, geothermal wells are most commonly hydrostatic or under-pressured. The primary well control issue is temperature. If the pressure in the well is reduced suddenly and very high temperatures are present, the brine in the hole will boil, accelerating the fluid above it upward. The saturation pressure along with significant water hammer can be seen at the wellhead. Thus, the most important method for controlling pressure in geothermal wells is to cool through circulation.

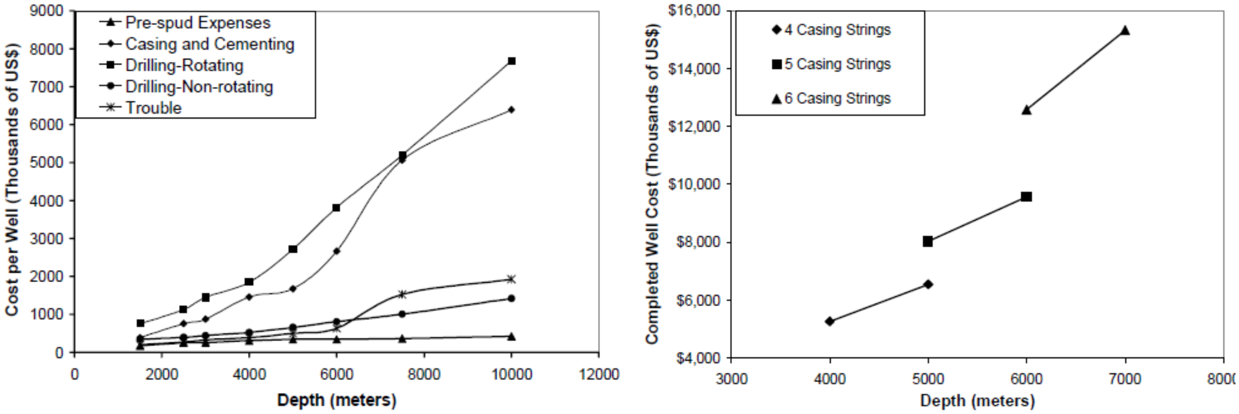

Figure 3. Well costs as a function of depth (Anderson and Petty, 2006).

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