Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Optimization of Geothermal Borehole Diameters

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Keywords: geothermal borehole diameters, Turkey.

ABSTRACT

Geothermal wells are drilled with standard and non-standard diameters. These non-standard diameters are mostly big diameter ones, which might sometimes cause serious cost overruns in some geothermal fields. On the other hand, sometimes big diameter wells create disappointments due to highly exaggerated expectations when the limited permeability is found. This study is conducted to define the optimum well diameters for geothermal wells depending upon the depths. With this aim, deterministic and stochastic studies are carried out trying to find suitable diameters. Moreover, in order to assess better the underground uncertainty, a risk analysis study is conducted, and the results for different depths are presented. Besides, some recommendations are given for selection of most suitable well diameters.

1. INTRODUCTION

Geothermal well diameters have always been a hot topic and debated in geothermal industry since 1960's. Since geothermal wells are produced through casings instead of tubings in oil and gas wells, casing diameter designs have always been a discussing issue.

As known, early geothermal wells used to be cased with standard $9^{5/8}$" and non-standard $8^{5/8}$" production pipes. In geothermal steam fields like Larderello larger diameter pipes ($13^{3/8}$") had been utilized with the aim of controlling of frictional losses during the fluid flow and consequent increase in production. In Turkey, different diameters have been used without any scientific and technological basis.

On the other hand, geothermal fluid rising from wells tapping water dominated geothermal systems flashes into two-phase because of lowering hydrostatic pressures in the wells. Increasing frictional losses within this two-phase zone of wellbore introduced the agenda for larger diameter wells.

This subject is first introduced by James, (1970). He showed through the calculations that production increases with larger well diameter, especially in the upper part of casing where two phase flow is formed. Later, in early 1970s large diameter ($13^{3/8}$") production casings were used for few wells in a water dominated system of Ahuachapan Geothermal Field-El Salvador. However, drilling in low permeability zones and obtaining lower or no production from those large diameter wells in this geothermal field resulted in turning back again to the standard ($9^{5/8}$") casings.

The debate about well diameters in our country-Turkey has been raised for another reason. There is plenty of CO_2 gas in Turkey's geothermal systems. The flashing of CO_2 gas within the wellbore during the fluid flow triggers $CaCO_3$ precipitation. After some time (generally 6 months) $CaCO_3$ precipitation diminishes the well diameter and reduces production rate because of throttling. Production flow rates have declined by time. Precipitated $CaCO_3$ had to be mechanically cleaned nearly every 6 months. In order to alleviate this problem specific for our country, and extend the periodical cleaning, production casings with larger diameters were planned. For this purpose in Kızıldere geothermal field-Turkey, a well had been drilled with a diameter of ($11^{3/4}$") production casing in 1970s. Later, Serpen (2000) reviewed the subject of well diameters and presented some recommendations.

In the recent years after 2000, a significant increase in productions has been observed with larger well diameters in Rotokawa Geothermal Field-New Zealand (Bush and Siega, 2010). Moreover, drilling problems in deeper zones obliged the drillers to drill larger diameter wells and completing them with $9^{5/8}$" blank and $7^{5/8}$" slotted pipes. It seems that this sort of wells is made in Philippines (Sarmiento, 2007).

2. WHY DRILLL BIG DIAMETER WELLS?

The most obvious reason for drilling big diameter wells is increased flow rate expectations. This evident for two reasons: (1) bigger pay zone diameter, (2) lower frictional losses in wellbore where two-phase flow occurs, This in turn results higher bottom-hole pressures. In the first case if we take Darcy's radial flow equation, increasing pay zone diameter from 8½" to 12¼" results only 3.5% of increase in flow rate to the well.

On the other hand, the second reason has more influential one. We have made several runs in a wellbore simulator for 1000 m and 2000 m deep wells. Keeping constant the wellhead pressures and flow rates we calculated the frictional losses in Table 1.

As seen in Table 1, with increasing casing diameter, frictional losses decreases substantially, and with increasing casing lengths, frictional losses increases as expected. On the other hand, for deeper wells the effect of bigger diameter on pressure drop decreases. Therefore, higher pressure losses throttle the flow rates. If a well diameter is increased in a well with high bottom-hole pressure, the production would increase.

On the other hand, the behavior of a producing well is resultant of well and reservoir characteristics. The most important well characteristics are: (1) bottom-hole pressure, (2) productivity index, (3) gas content of geofluid, (4) depth, (5) casing size, (6) type of reservoir mechanism.

Table 1: The effect of well diameters and the depths on frictional losses

q_{steam}=50 t/h +q_{water}=250 t/h=q_{total}=300 t/h					
1000 m			2000 m		
Casing OD $9^{5/8}$"	Casing OD $11^{3/4}$"	Casing OD $13^{3/8}$"	Casing OD $9^{5/8}$"	Casing OD $11^{3/4}$"	Casing OD $13^{3/8}$"
Δp (bar) 53.6	Δp (bar) 32	Δp (bar) 4	Δp (bar) 138	Δp (bar) 115.2	Δp (bar) 105

So there are several other factors affecting flow rate of the wells apart from casing size, depth and bottom-hole pressure that are above examined. The most important is productivity index. If the field has high productivity wells with high bottom-hole pressures then big size wells could be feasible. Otherwise that would be a waste of money. Recently in Turkey, several telescopic wells have been drilled in different fields with upper sections completed by large size ($13^{3/8}$") without taking into account the above mentioned factors; all have failed sometimes even with zero production.

On the other hand, in a field with moderate productivity, a similar telescopic well produces about 400 ton/h. Other wells with standard casing sizes and similar fluid reservoir characteristics also discharge similar amounts, and sometimes better. It seems there is no clear advantage.

In the light of above mentioned and uncertainties involved underground, an economic analysis is conducted.

3. METHODOLOGY

Selection of geothermal well diameters for the completion of wells is studied in this section. The results will be presented in tables, and the suitable sizes will be chosen using these tables. Shallow and deep geothermal systems are assumed, and hot water and deep thermal reservoirs with respective 1000m and 2000m depth wells are modeled. Related production and cost values in these wells are either estimated or calculated. Drilling costs are adapted to be compatible with world prices and given in Equation 1 (Edwards et al., 1982).

$$\text{Cost} = 120000\ (1.0014)d,\ \text{US\$} \qquad (1)$$

where; d= well depth

Costs for different diameter wells are determined with the exponential relation of cost and well diameter.

A well with a scaling tendency is assumed. As the production decreases during the period of precipitation, productions are estimated for the different well diameters by considering the average productions of different diameter wells before clogging. Furthermore, annual power generation is calculated. Annual revenues are calculated assuming the electricity sales price as 10 cent/kwh and from the obtained value 40% corporate and other taxes together with operational and mechanical cleaning costs are deducted. Moreover, a well life is assumed to be 12 years and in 20 years economic analysis, drilling of a new well in the 12th year is presumed, then net present values are calculated. All calculated values are given in Table 2.

Table 2: Revenue and investments for various well depths and well diameters

Depth	1000 m			2000 m		
Diameter	$9^{5/8}$"	$11^{3/4}$"	$13^{3/8}$"	$9^{5/8}$"	$11^{3/4}$"	$13^{3/8}$"
Revenue, $/year	910500	1290000	1798500	799800	1131600	1561500
1st Well Drilling Investment, $	486148	772925	1302876	1969497	3072415	5100997
2nd Well Drilling Investment, $	154901	246293	415137	627542	980535	1625335

4. ANALYSIS OF RESULTS

The results of the economical analysis using the data given in Table 2, is shown in Table 3. For 1000 m deep wells when ROR is considered, ($9^{5/8}$") well diameter seems to be more suitable in economical perspective and ($13^{3/8}$") comes after. Here it has to be noticed that the ROR values in these evaluations seem to be exaggerated. The reason for this can be explained with the annual revenues that are more than the investments in the early years, so instead of ROR values, the evaluations has to be considered in terms of NPV.

Table 3: Economic analysis for various well depths and well diameters

Depth	1000 m			2000 m		
Diameter	9 5/8"	11 3/4"	13 3/8"	9 5/8"	11 3/4"	13 3/8"
NPV,$	6464137	9051657	12750263	3829190	5073635	5622261
ROR, %	142	123	140	31	28	22

Actually, for the 1000 m deep the (13 3/8") well diameter seems to be the most appropriate diameter in terms of NPV values. On the other hand for 2000 m deep wells, while (9 5/8") well diameter seems to be the most appropriate in terms of ROR, it is observed that (13 3/8") well diameter gives the highest NPV. But it is noticeable that calculated NPV values do not differ so much for 2000m deep wells and the investments are higher for larger diameter wells. Considering these two criteria, it can be concluded that ROR values seem more reliable.

The above economic analysis is a deterministic one. But, we all know that the data of flow rates and well costs involve some sort of uncertainty. In order to minimize the effects of uncertainty, a risk analysis study is conducted implementing risk weighted ROR method. As it is known, probabilities are not taken into account for the profitability criteria. In risk weighted ROR method, to consider the risks in the analysis, a pseudo investment concept given by the following equation, developed by Newendorp, (1975).

$$Pseudo \quad investment \quad (present \quad time) = Y_o + Y_d (1 - p) / p \tag{2}$$

where;

Y_o: Production well cost, $

Y_d: Dry well cost, $

p: production probability, %

Calculated economic analysis by risk weighted ROR method results implementing pseudo investments are given in Table 4.

For both 1000 m and 2000 m deep wells, (9 5/8") well diameter seems to be the most economic one in terms of risk weighted ROR values. In the previous section analysis, increased well diameters and increased extension of cleaning period resulted in higher productions. Although deterministic economical analysis is valid in terms of NPV for 1000 m deep wells, opposite results obtained in risk analysis study.

Table 4: Risk analysis results for various well depths and well diameters

Diameters	9 5/8"	11 3/4"	13 3/8"
Depth	1000 m		
Probability, %	70	60	50
Risk weighted ROR	99	72	52
Depth	2000 m		
Probability, %	60	50	40
Risk weighted ROR	18	13	6

3. DISCUSSION AND RESULTS

Selecting big (13 3/8") casing diameters instead of standard (9 5/8") diameters has again come to agenda in the last 20 years. The reason for selecting larger sizes is to obtain more production with less number of wells. But, the underground uncertainty prevents making such kind of selection.

Selection firstly has to be dependent on / (or related with) the nature of geothermal system. For instance, due to high pressure drops in dry steam geothermal fields, selection of big casing diameters is advantageous. Moreover selection of big diameters becomes much more advantageous when there are multilateral holes providing the fluid flow into a single production casing.

In water dominated geothermal systems, the flow regime in the wellbore becomes important in the selection of casing sizes. Although standard casing diameters are adequate for single-phase fluid flow, selection of bigger diameters for two phase fluid flow might be needed due to higher frictional losses. For this type of systems, selection mostly depended on permeability, non condensable gas content and bottom-hole pressure.

The above conducted risk analysis study points out that drilling with standard diameters is more advantageous compared to non-standard big diameters. On the other hand selection of bigger diameters is expected to be advantageous in such fields where productivity indexes and reservoir pressures are higher.

To reduce frictional losses and increase productions, using standard ($9^{5/8}$") diameters in the production zones and then switching into larger diameters in the upper part of casing where two phase flow is formed can be an alternative option. Although this option is preferred and applied in some of the geothermal fields in Turkey, it brings together a further risk. The reason for this risk is the failures of liner cementing that occurs in the "overlap" zone, between the two casings ($13^{3/8}$" – $9^{5/8}$"). Geothermal fluids having high CO_2 gas content with very high partial pressures (sometimes over 2000 psi) might cause fluids leakage to surface from these not-well cemented zones.

In making suitable well diameter decisions for our country-Turkey, an important parameter, permeability, has to be taken into consideration. For instance, standard diameters have to be chosen in the Gediz Graben as the reservoirs have limited permeability in this region. On the other hand, in Buyuk Menderes Graben, selections have to be determined according to permeability values for each resource. The permeability values of this region points out the selection of standard type diameters.

Making big diameter wells in Turkey to alleviate scaling problems are not necessary anymore because inhibitor usage has solved this problem. The telescopic wells with big diameter in the upper part is dangerous in Turkey since high CO_2 content create very high pressure gas accumulations at wellheads.

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