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Improvement in Drilling ROP with Real Time MSE Monitoring in the Salton Sea Geothermal Field

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ABSTRACT

One of the biggest handicaps of the Geothermal Drilling industry is the poor performance on rate of penetration (ROP) when compared with the Oil and Gas Industries; most geothermal wells lack proper data collection while drilling, data integration, and analysis of such data. This lack of essential engineering, well planning, and construction tools seemingly adds a significant amount of time to the industry average of 12-days non-productive time (NPT) per geothermal well, as compared to oil and gas wells, therefore, leading to higher well costs. Geothermal Resource Group (GRG) has recently been involved in the drilling of two wells at the Salton Sea Geothermal Field (SSGF), utilizing real-time monitoring of MSE (Mechanical Specific Energy) and achieving ROP like those of oil and gas wells, cutting drilling time by 15 days and 25 days respectively, when compared to average drilling time in the SSGF. The formulas for computing MSE and the step-test procedures for MSE optimization are given as part of this paper.

1. INTRODUCTION

Today's technology has brought improvements to the data acquisition systems for both surface and downhole drilling data, helping to identify major dysfunctions while drilling and how to correct them. The use of these tools opens up an opportunity to save significant time and money on a particular well, as well as improve organizational cohesion, therefore proper data collection and real time analysis should be standard operating procedure. Having these data available for analysis afterward has proved beneficial for research and development notably in bit technology, and further ROP gains in subsequent wells have been documented.

Mechanical Specific Energy (MSE) has been utilized in the oil and gas industry for the past five decades in various forms and flavors. Simply stated, MSE is conservation of energy, which mandates that the amount of energy and work expended to cut a volume of rock should be equal to the rock compressive strength and conserved throughout a closed system of the drilling rig/equipment doing the work. However, the energy required to drill a volume of rock is not conserved due to several factors and therefore, doesn't necessarily translate into the net effective rate of penetration. Optimizing MSE has the effect of increasing the ROP. If the parameters used to calculate the MSE are recorded/available while drilling, there is an opportunity to adjust operations to determine the effect on MSE and to correct operational factors to increase ROP. With today's technology and downhole sensors, MSE is widely used in the oil and gas industry to improve performance and provide real-time feedback loop to the driller on downhole formation transitions. The adoption of this strategy has not been widespread in geothermal due to several factors that include: perception that the technique is not applicable in geothermal drilling because the rock type is not comparable, geothermal requires drilling of less wells, so the additional cost for the monitoring and oversight would not reap enough gains in a small drilling program, rigs are not equipped with the required instruments, personnel not trained in the use of MSE, and the additional cost of monitoring and supervision.

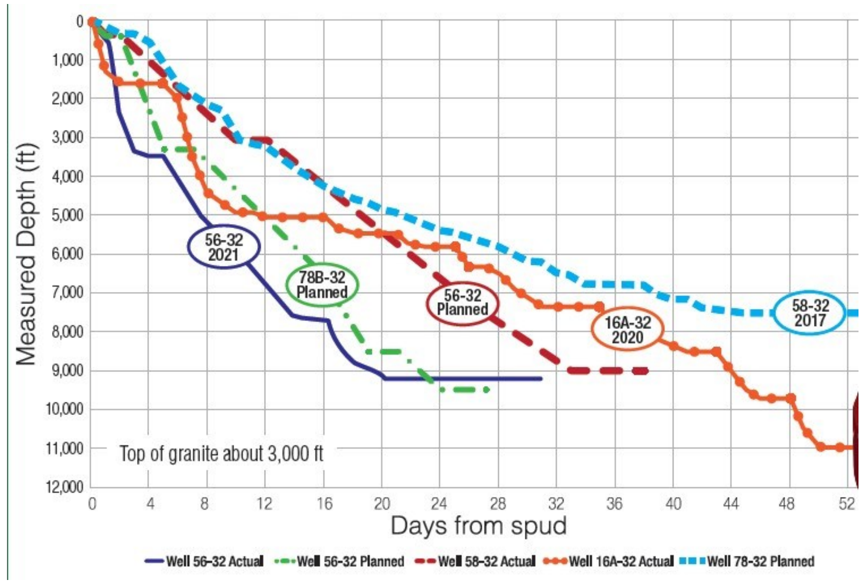

Figure 1: Well over well improvements in ROP and decreased estimated and actual completion time in wells drilled at the Utah FORGE site (data available from 2021).

Recent demonstration of these improvements in ROP at the Utah FORGE experimental site (Figure 1) and now application at the SSGF prove that this technique is valuable in geothermal drilling as well. The recent SSGF drilling that is it the topic of this study showed that the gains can be achieved in reducing well completion time using the techniques (even in part) on the first well where they are tried (in comparison to previous wells in the field). The SSGF wells are considered similar to the lithology found in 'typical' O&G fields, being mostly basin sediments (and altered sediments), and so this seems a logical field in which to document the improvements possible through MSE in geothermal drilling, and maybe applicable in other fields where O&G wells may be drilled or repurposed as geothermal wells. There are quite several wells drilled in the area for comparison, so the ROP improvements within field are remarkable, though more analysis is possible if privately held drilling data were made available. Additional challenges faced in SSGF includes potential unstable ground, surface CO_2, high temperature, faults and fractures resulting in partial to total lost circulation, and high TDS, corrosive reservoir fluid.

By setting up a MSE real-time monitoring and analysis of the data, Geothermal Resources Group (GRG) was able to document comparable rates of penetration (ROP) to what is reported from the O&G industry, this in turn has reduced the required (planned) drilling days by up to 50% of the time required to drill similar wells in the area, with a cost reduction of at least 30%.

2. MECHANICAL SPECIFIC ENERGY (MSE)

MSE is a numerical value used to understand how efficiently a system is drilling and it has been widely used to reduce drilling days by as much as 50% and therefore lower drilling costs at least by 30%. In this paper, we explore the use of MSE real time monitoring and emphasize how real-time drill-off tests and qualitative trending tool can be used to improve ROP. Reacting to MSE is also a common method to reduce drilling costs and is being widely applied to infer rock characteristics in the unconventional industry, such as geothermal, where logging might be done less frequently. With the acquisition and analysis of data, the interpretation of MSE can be a very powerful tool helping driller to improve ROP, by optimizing the energy expended at the bit.

The formula for calculating MSE incorporates pertinent drilling parameters being input into a system (WOB, RPM, TQ, etc.) and relates it to the performance output of the given system (Figure 2). The lower MSE value, the more efficiently the drilling system is removing rock. Thus, there is less energy being expended (wasted) by something other than rock-removal. Real time monitoring of MSE is vital to identify the presence of drilling disfunctions that contribute to reduced ROP.

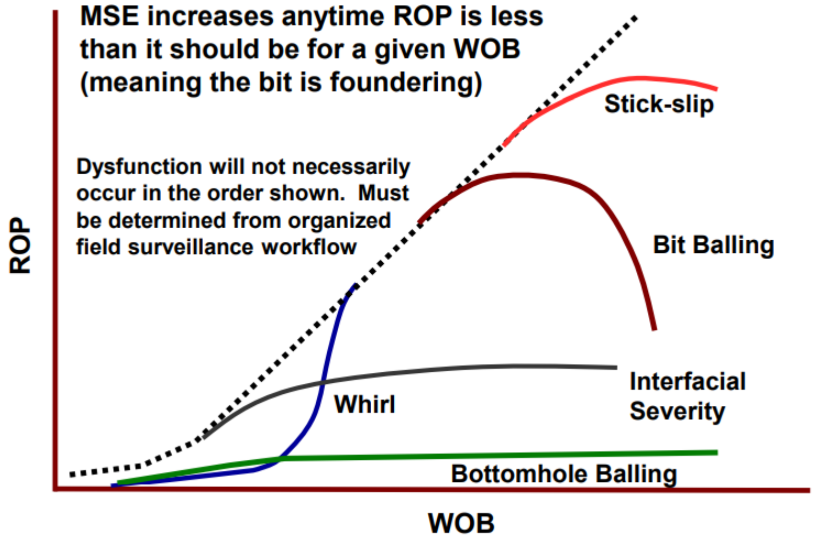

Figure 2: Identifying the presence of dysfunction. Figure credit: Harold Vance Department of Petroleum Engineering, TAMU.

Calculating MSE requires certain appropriate input data, however, to understand WHY it changes and HOW to improve the operational response (for example, adjustments to WOB, RPM, etc.) and design going forward, more data is better. Parameters such as pump pressures, differential pressures, temperatures, vibration, Gamma Ray, and other logs, even auto-driller settings, such as ramp rate, can be important. It really depends on the situation and dysfunction encountered in a particular interval. A dysfunction should be considered when the bit is not drilling efficiently, i.e., MSE is higher than rock strength. (Ideally, rock strength is known before drilling the interval, but that is not really the case. At the FORGE wells the rock strength was determined with a post-mortem calculation. In practice, a step-rate test is completed to determine the optimum MSE as the base line for that interval.)

Two formulas were used for the monitoring of MSE at the SSGF wells: $MSE_{Downhole}$ and MSE_{Total} (Figure 3). The separation between these two in the plots should be the energy lost in the drill string. This gap increases with loss of weight or torque transfer (e.g., stabilizers hanging up).

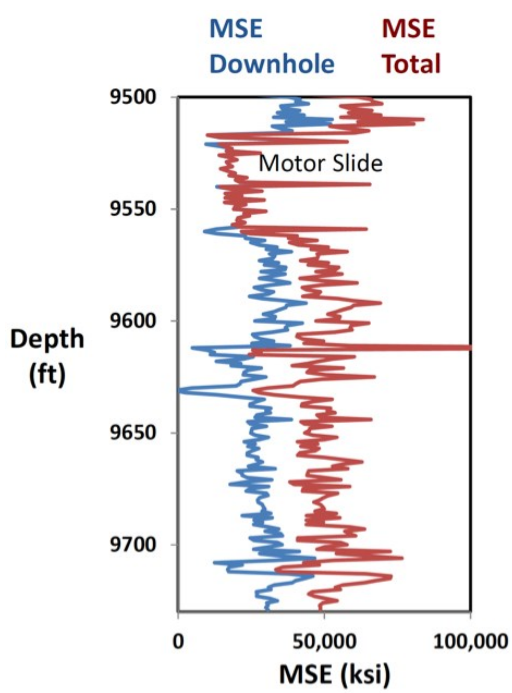

Figure 3: $MSE_{Downhole}$ vs MSE_{Total}. Figure Credit: Harold Vance Department of Petroleum Engineering, TAMU.

The (well known) original formula for MSE (Teale's Original Lab Equation) is:

$$MSE = \frac{4\,WOB}{\pi D^2} + \frac{480\;x\;TQ\;x\;RPM}{D^2\;ROP} \tag{1}$$

The equation for Downhole MSE (also called bit MSE or Motor MSE) is as follows:

$$MSE_{downhole} = \frac{4\,WOB_{surf}}{\pi\,D^2} + \frac{480\,(K_t\,\Delta P)(\,RPM_{surf}+K_n\,Q\,)}{D^2\;ROP} \tag{2}$$

And for Total MSE this formula is used:

$$MSE_{\text{Total}} = \textbf{Axial Work} + \textbf{String Rotational Work} + \textbf{Bit Rotational Work}$$

$$MSE_{Total} = \frac{4\,WOB_{surf}}{\pi D^2} + \frac{480\,(\,TQ_{surf} - TQ_{mm}\,)\,RPM_{surf}}{D^2\;ROP} + \frac{480\,TQ_{mm}\,(\,RPM_{surf} + RPM_{mm}\,)}{D^2\;ROP}$$

$$MSE_{Total} = \frac{4\,WOB_{surf}}{\pi D^2} + \frac{480\;TQ_{surf}\;RPM_{surf}}{D^2\;ROP} + \frac{480\;(K_t\,\Delta P)(K_n\,Q\,)}{D^2\;ROP} \tag{3}$$

2.1 Real Time MSE monitoring.

A real time monitoring system was set in place from the start of drilling, using PASON instrumentation and data system and using the MSE formulas 2 and 3, as described above. The calculated MSE was available for real time viewing in the PASON data stream and is plotted in with ROP and WOB in Figure 4.

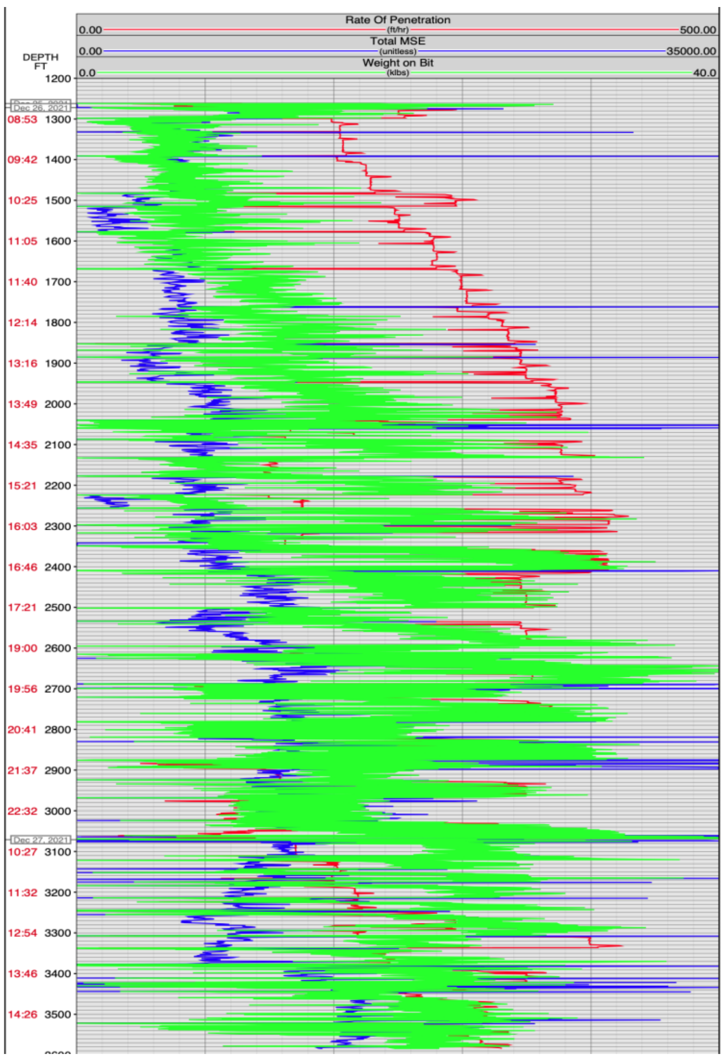

Figure 4: Example of GRG's real time MSE monitoring, with time/depth shown on lefthand side.

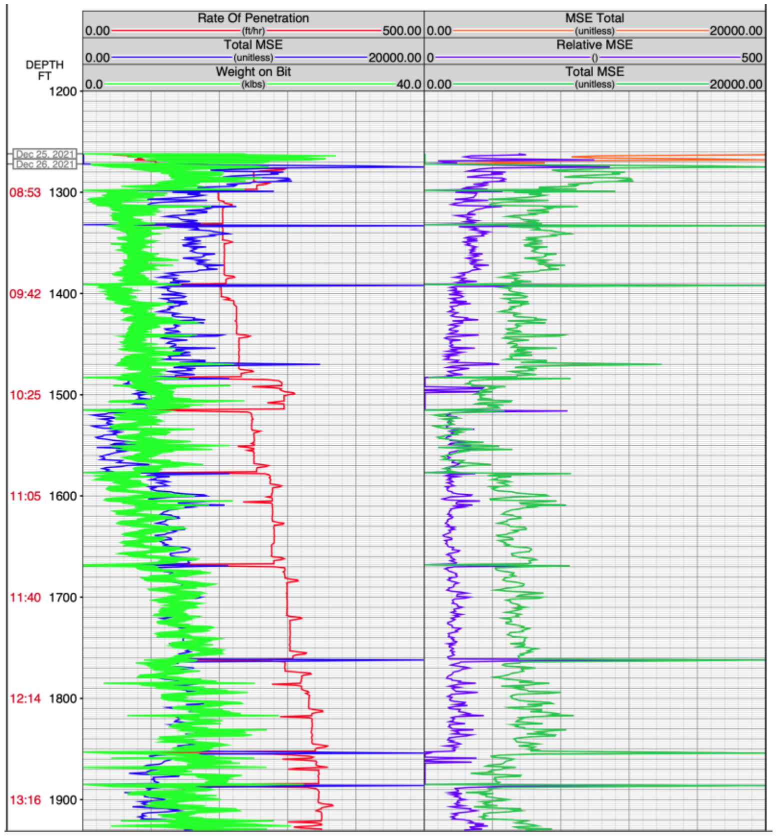

Figure 5: Example of GRG's real time MSE monitoring, showing the gap between $MSE_{Downhole}$ and MSE_{Total}.

Figure 4 shows the inverse relationship between ROP and MSE. With a lower MSE value a higher ROP is achieved and a higher WOB is used to get more indentation of the bit in the rock. Figure 5 shows the separation between MSE_{Total} and $MSE_{Downhole}$, which correspond to energy lost in the drill string. Utilizing these plots, better drilling parameters can be achieved, or BHA design adjusted, to minimize this gap.

2.2 Parameter Step-Test for Optimal MSE

As part of the overall performance improvement effort, several parameter step-tests were performed throughout the well drilling, to ensure that dysfunctions were minimized thus efficiency was maximized. A step-test is performed by methodically varying a specific parameter in incremental steps and watching for changes in MSE. The parameters are changed during a step test included top-drive RPM or WOB. The fundamental strategy during a step test is to change one parameter, wait a few seconds, and see which direction MSE moves. If MSE is reduced after the parameter step change, then the system has begun drilling more efficiently and the new parameter value should be preferred over the old value. If MSE increases after the change, the system is drilling less efficiently, and the parameter should be returned to the original value or changed to another step to further check for optimal parameters.

An active drill off test was performed at every bit change and as needed while drilling with the objective of keeping MSE at minimum:

2.2.1 WOB Step Test

- After a connection, re-establish the previous parameters and observe the base line trend.
    - If the system is efficient, the MSE will approximately equal rock's compressive strength.
- Increase WOB in increments of 2-5 Klbs and observe MSE at each step, for a minimum of 5 minutes.
- Continue increasing WOB until the MSE jumps (focus on MSE, not ROP).
    - A significant increase in MSE will occur if the bit founders, usually by more than twice the initial value.
        - Note: Keep in mind to limit WOB to the bit's structural limits provided by the vendor, not the recommended operating limit.
- Drill ahead with the WOB equal to or less than the founder point.

2.2.2 RPM Step Test

- After WOB is optimized, increase bit RPM incrementally by a minimum of 20% and observe the MSE at each step, for a minimum of 5 minutes.
  - Smaller RPM changes will not have a detectable effect.
- Continue increasing the bit RPM in 20% increments, until founder is observed, or equipment's limit is reached.
- Drill with a bit speed just below the observed founder point.
- Repeat the WOB step test after any significant increase in RMP or change in flow rate.

The results of these tests will provide an optimized MSE value, that should be used as baseline to determine when MSE deviates from it. This is actually very important, as most of the time, the rock strength is unknown in geothermal drilling, so a baseline value provides the best approximation to rock strength, given current drilling conditions and a starting point to monitor MSE.

3. RESULTS OF REAL TIME MSE MONITORING

Though the use of real time MSE monitoring and operations adjustments, drilling time was reduced by up to 50% of the time usually spent to drill to around 8,000 ft. (See Figure 6 and Figure 7) in the two SSGF wells in the campaign. Application of the technique in future drilling campaigns would further solidify results. The wells used for comparison are similar to the GRG wells with similar hole sizes drilled in similar formations in the SSGF in recent years and are representative of average to good drilling performance in the SSGF.

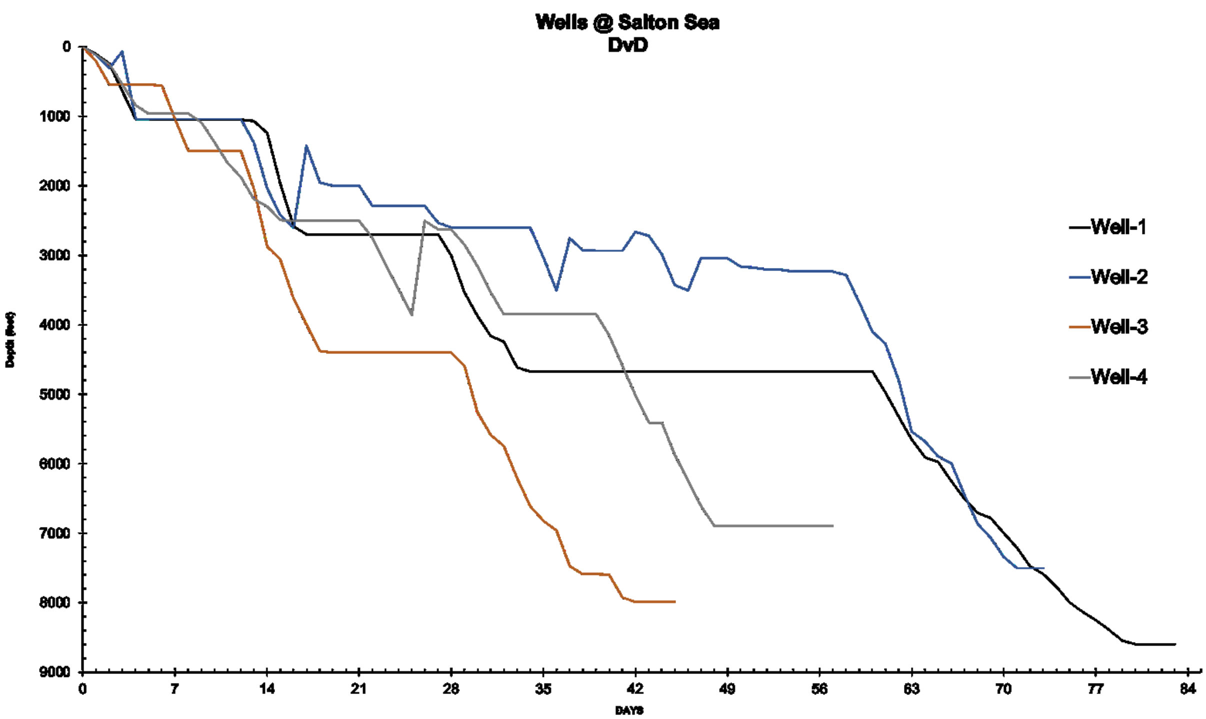

Figure 6: Drilling days for offset wells at the Salton Sea drilled between 2005 and 2015.

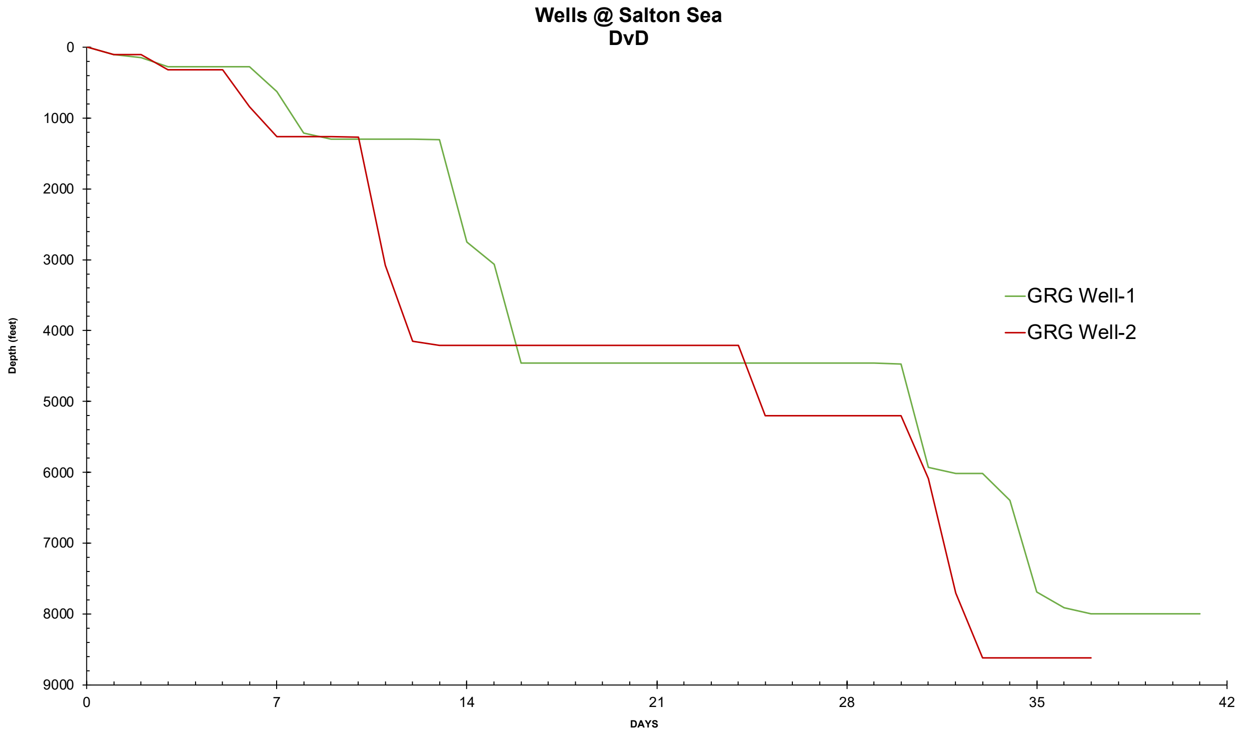

Figure 7: Drilling days for HK-1 and HK-2, new SSGF wells drilled in 2021 and 2022, using real time MSE monitoring.

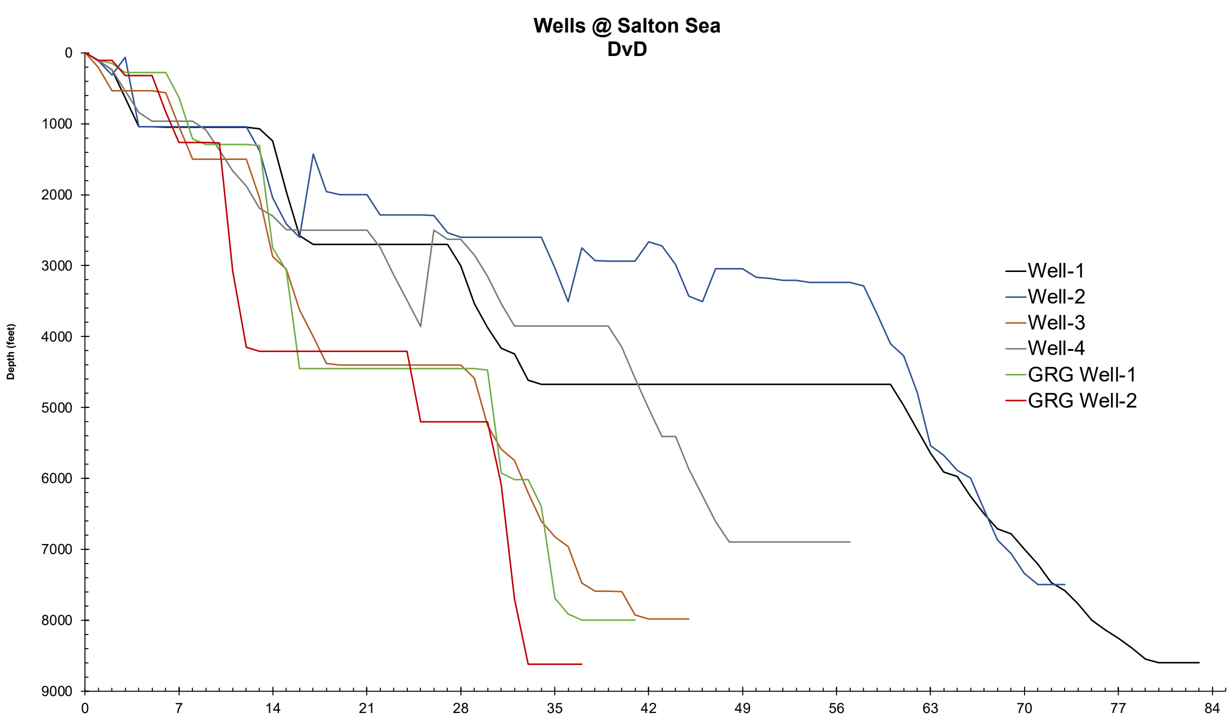

Figure 8: Comparison of DvD for GRG wells and offsets wells at Salton Sea

4. DISCUSSION

Establishing a real time MSE monitoring system and utilizing the latest in PDC cutter technology have allowed a significant reduction in the time required to drill well by up to 50% when compared to offset wells, highlighting the improvement in drilling performance.

This improvement in performance can significantly reduce the required days to drill a geothermal well and therefore will lower the cost for future geothermal projects. This is technology transfer from O&G, which is directly applicable, because the drilling parameters monitoring required are the same. The solutions to drilling dysfunction may be unique to each field. This study consists of analysis of data for two wells, but the gains are significant. Further data analysis and application of the MSE techniques suggested should be implemented elsewhere to further refine the techniques and substantiate results. Geothermal developers should include the data collection, monitoring and analysis in the drilling program. Implementing operational changes suggested through use of the data and analysis is crucial to realize of the gains possible, which involves the collaboration with the rig company, subcontractors and on-site personnel.

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