Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

# Cashing In on Marginal Production Wells Using High-Temperature Downhole Pumps

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**Keywords:** marginal well, downhole pump, electric submersible pump, ESP

## ABSTRACT

The inability of some geothermal wells to attain or sustain commercial wellhead pressures are often documented because of various factors that include subsurface resource characteristics, reservoir response to long-term utilization and wellbore conditions. This paper investigates a database of drilled and completed production wells that are unable to contribute to power generation despite sufficient downhole temperatures and evident permeability. Detailed study, wellbore diagnostics and theoretical modeling of two priority candidate wells were conducted to match with the design of high-temperature downhole pumps that aim to provide additional lift and deliver the downhole fluids to the surface facilities at 7 to 10 bar conditions. The methodology developed by the collaboration of the two industries provides a new option for reservoir management strategies and development of growth areas in addition to the opportunity for return of investments from idle to underutilized geothermal wells.

## 1. INTRODUCTION

The well drilling program comprises one of the major investments in any geothermal project. A high utilization of these drilled wells, originally programmed to be good producers or injectors, will ensure returns on these investments. However, a significant number of completed wells fail to deliver their objectives. Some wells encounter inherent permeability issues or aggressive conditions (e.g. corrosive fluids) after well completion. In other cases, online production or injection wells decline in performance after impacted by either reservoir response to field utilization or blockages within the wellbore (e.g. Salonga et al., 2004). Eventually, the severely affected ones, despite interventions like workovers and acidizing, end up shut and underutilized assets.

Gonzalez et al. (2005) demonstrate various field strategies to optimize existing assets such as matching well utilization with the proper facilities. Recently, newer technologies are also made available to squeeze more contribution from underutilized and unused wells (e.g. Muir et al., 2019). This work has a similar objective of turning wells from idle to useful. Specifically, focus is given to a group of marginal production wells--- those that have proven permeability and sufficient enthalpy and yet are unable to either develop or sustain discharge wellhead pressures to satisfy the interface pressure requirement of installed geothermal power plants.

## 2. SUBJECTS OF STUDY

An inventory of all geothermal wells in Energy Development Corporation (EDC) provides the following general categories shown in Figure 1. An ambitious fleetwide program, coined Lazarus, is envisioned to “resurrect” the idle wells in the chart which may involve combinations of proven and non-conventional technologies. For this study, the Offline/Idle/Production Wells/Low Pressure group poses interest as considerable time and resources are often spent in discharging and commercializing these wells. Another motivation of this work is a significant number of Online Wells, are already showing marginal characteristics---they intermittently cease to contribute and are sensitive to either surface facility movements or changes in reservoir conditions such that online monitoring systems are installed for immediate revival. Thus, finding a solution to achieve a sufficient and sustainable discharge condition in these wells provide system stability and better planning perspective.

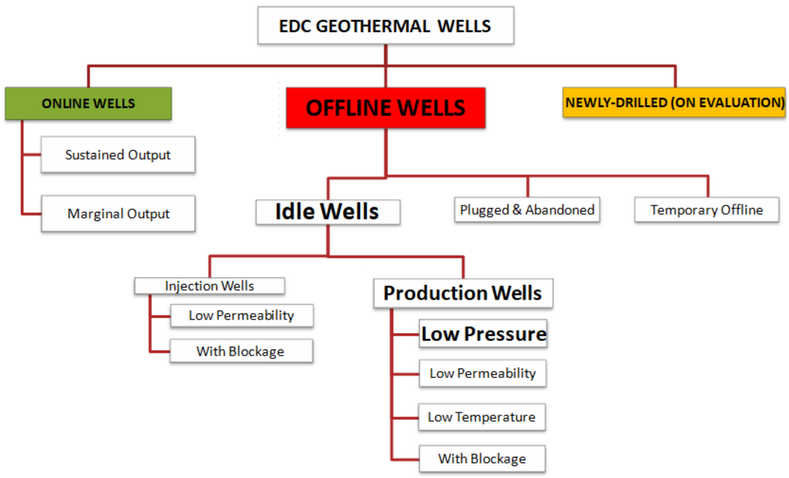



**Figure 1: Category of geothermal wells in EDC showing various status and major factors causing well subperformance. Emphasis is shown in the idle production wells that can have sustainable discharge but at pressures lower than power plant interface requirement.**

When productivity of wells are impaired, they end up shut for a prolonged period and are usually deprioritized in the revival program in favor of wells that have higher probability to succeed. At best, the lower cost option for the sustaining wells will entail re-aligning them from high pressure (~1 MPag) to low-pressure (~0.7 MPag) steam gathering system. If the well discharge is not sustainable, Figure 2 illustrates the process flow where additional investments and potential innovations are considered for further evaluation. Updated discharge data, well chemistry and shut surveys provide important information to allow matching with appropriate, available and viable technologies in the market.

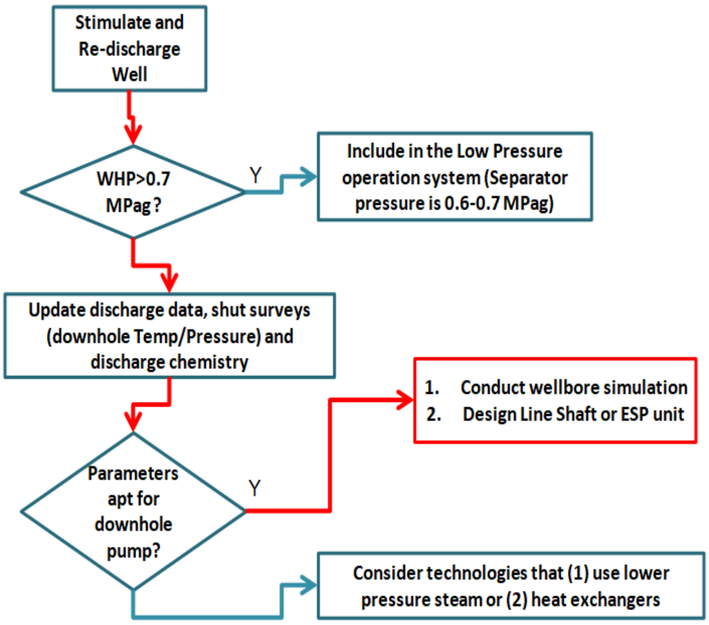



**Figure 2: Process flow to revive idle and marginal production wells. The red arrows indicate the conditions that lead to further study of downhole pump applications in consideration of lower and/or unsustainable discharge pressure.**

### 2.1 Well Selection

Among the idle EDC production wells, recent field activities provided opportunities to update data of wells A1 and B1. Both wells are located in an area encroached by cooler fluids as inferred from physical and geochemical monitoring data plus injection tracer tests. It has been about a decade since these two wells were cut-in and contributing into the steam gathering system. Figure 3 shows encouraging leads from the May 2019 shut surveys that both wells have sufficient clearance to set equipment <7.5-in diameter below the static water levels of ~800m (A1) and ~1150m (B1). Excluding other factors, shallower water levels are generally preferred in the context of lower head and lesser power requirement to lift the water into the surface.

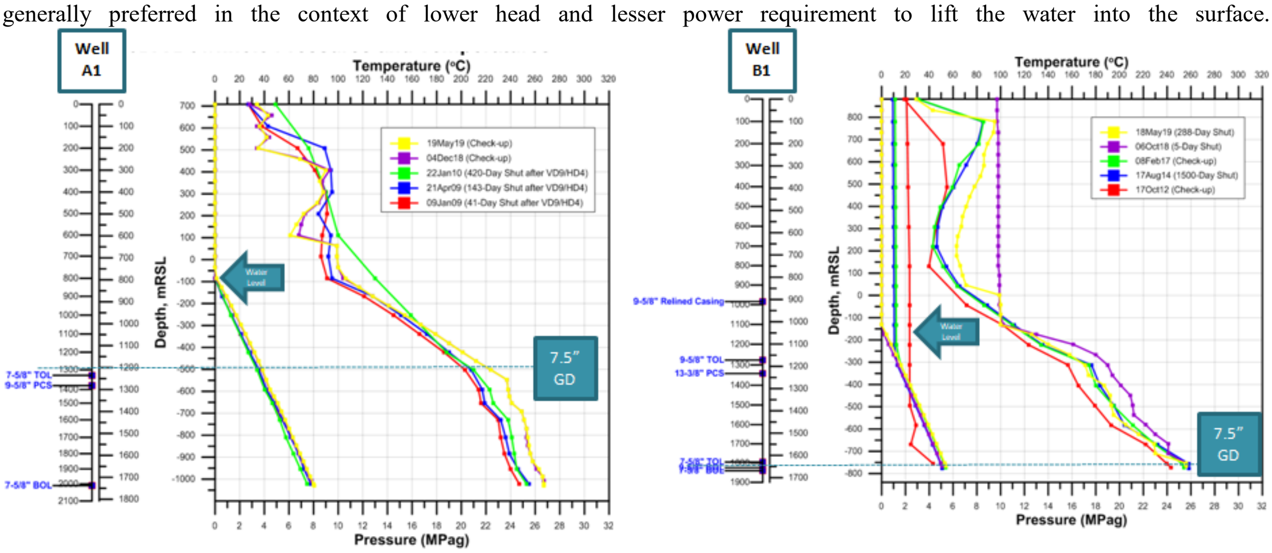



**Figure 3: Shut survey data (temperature, pressure) of candidate wells A1 and B1 showing sufficient clearance to run-in a downhole equipment well below its static water level.**

Despite the cooling effect of peripheral or injected fluids, Figure 3 also shows that downhole temperatures of both wells are still significantly high for utilization. Another vital information in Figure 3, that will later factor in the pump selection, is at potential pump setting depths, the liquid temperatures are >170°C (i.e., sufficient enthalpy to flash the fluid at surface pressure of 0.7 MPag) yet do not exceed 250°C (reasonable limits of downhole pumps in the industry). The two candidate wells are also located in developed sections of the steam gathering system (e.g. near power sources, with available branchline) providing the opportunity for quick hook-up and contribution.

Well B1 was re-discharged in 4Q of 2018 to attempt commercialization but only reached a maximum wellhead pressure of 0.6 MPag (Table 1).

**Table 1: Updated discharge data of well B1 which only managed to reach maximum discharge pressure of 0.6 MPag.**

| Opening | Stable WHP (MPag) | Mass Flow (kg/s) | Enthalpy (kJ/kg) |
|---|---|---|---|
| FO | 0.51 | 40 | 1,324 |
| 3" | 0.55 | 35 | 1,372 |
| 2-3/4" | 0.58 | 34 | 1,349 |
| 2-1/2" | 0.59 | 33 | 1,303 |
| 2-1/4" | 0.59 | 30 | 1,361 |
| 2" | 0.60 | 30 | 1,361 |
| 1-3/4" | 0.60 | 25 | 1,369 |
| 1-1/2" | 0.50 | 20 | 1,411 |
| 1-1/4" | 0.43 | 17 | 1,610 |
| 1" | Collapsed | | |

## 2.2 DOWNHOLE PUMP SELECTION

In Mar 2017, a landmark workshop was jointly held by the Geothermal Resource Council (GRC) and Society of Petroleum Engineers (SPE) in San Diego, California to explore synergies between the geothermal and oil and gas industries, respectively. One of the highlights showed the potential of using downhole pumps (Figure 4) as a standard compliment in geothermal conditions.

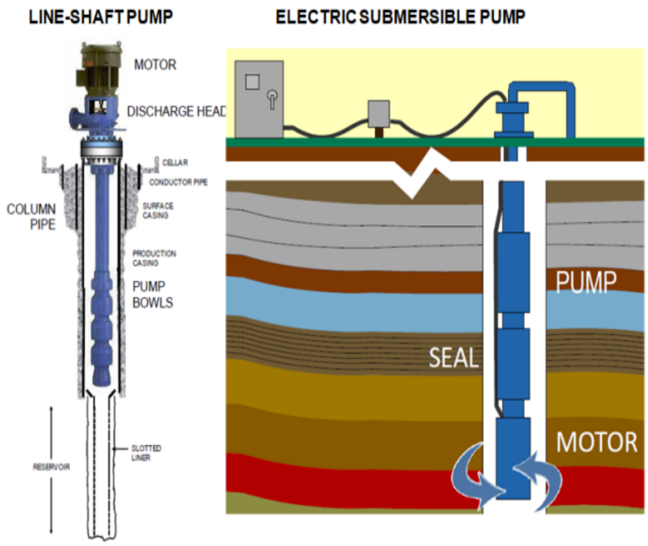



**Figure 4: Typical diagrams of a line shaft pump (adapted from Weinberg, 2017) and an Electric Submersible Pump, ESP (adapted from Adams et al., 2017).**

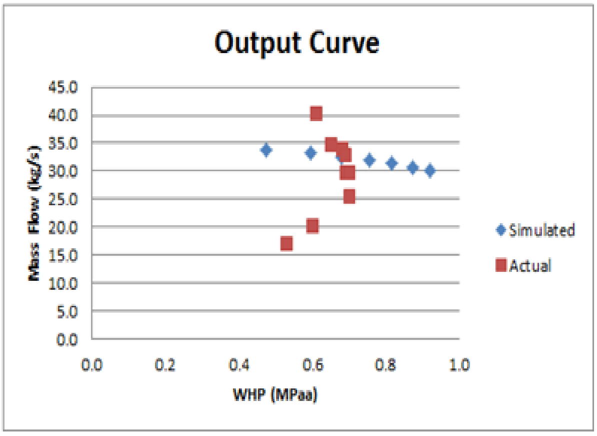
The idea of potentially using a downhole pump to provide the necessary lift to high-temperature downhole fluids in some relevant idle EDC wells was then conceived. Two considerations were initially considered that favored the use of ESP than the Line Shaft variety: (1) the depth and deviation of the drilled wells and (2) temperature limits of the pumps. Adams et al. (2017) pointed that ESP units have high-temperature applications in Steam-Assisted Gravity Drainage (SAGD) wells that are used in some oil and gas fields to aid in the extraction of challenging oil reserves in places like Canada.

## 3. RESULTS AND DISCUSSION

### 3.1 Candidate Wells' Simulation

Considering the insights from Figures 2 and 3 plus available discharge data, the permeability of wells A1 and B1 and their ability to be recharged at the desired conditions at the wellhead are investigated in this section. Wellbore simulation was done to estimate the productivity of the well that serves two main purposes: (1) to simulate the total mass flow that can be extracted by the pump and (2) to design how many stages are needed to lift the fluid to the wellhead. Well calibration was done by changing the permeability indices (PI) of the feedzones to match the actual mass flow and enthalpy data at different wellhead pressures.

Well B1 is a deviated and big-hole well which was completed in 1996 to a total depth of ~1850 m then eventually relined with a 9-⅝" material in 1997. The calculated injectivity index of the well during completion test is 13 L/s-MPa. Calibration was done using the updated discharge data in 4Q 2018 (Table 1) with results summarized in Figure 5 and Table 2.



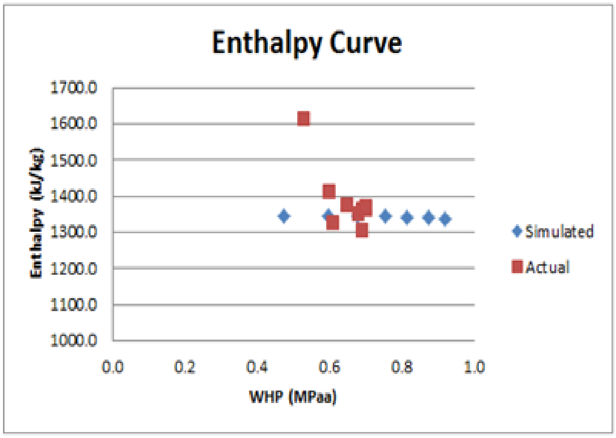




**Figure 5: Output curve and enthalpy curve match of Well B1 calibration.**

**Table 2: Calibrated productivity index of well B1.**

| Feed zone | Zone Type | Calibrated PI (kg/s-MPa) |
|---|---|---|
| FZ 1 | Minor | 3.9 |
| FZ 2 | Major | 13.6 |
| FZ 3 | Minor | 7.6 |

Well A1 is a deviated and regular-hole well which was completed in 1997 to a total depth of ~2030 m. The calculated injectivity index of the well during completion test is 11 L/s-MPa. In contrast, well A1's last discharge data was still in 2009 and has not been updated since. In Figure 6, the data in blue circles correspond to the Oct-Nov 2008 Bore Output Measurement (BOM) data in which the mass flow is around 20kg/s with an enthalpy of around 1200 kJ/kg. A two-feed model was used to calibrate the model and the results are presented in Table 3. In order to match the Maximum Discharge Pressure of the Bore Output Curve, it was required to lower the simulated pressure equal to the saturation pressure with respect to the December 2018 temperature survey shown in Figure 3.

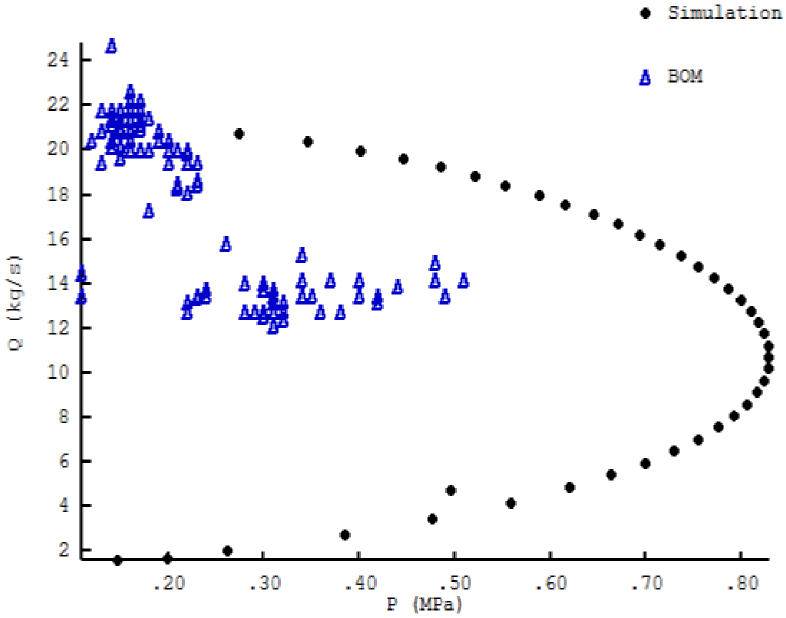



**Figure 6: Output curve and enthalpy curve match of Well A1 calibration using actual Bore Output Measurement (BOM) data obtained in 2009.**

**Table 3: Calibrated productivity index of well A1.**

| Feed zone Depth, mMD | Zone Type | Calibrated PI (kg/s-MPa) |
|---|---|---|
| 1450-1550 | Major | 11.2 |
| 1850-1950 | Minor | 1.8 |

### 3.2 Downhole Pump Design

The operating philosophy for this innovation is to use an ESP to lift the hot downhole liquid from the wellbore and then allow the hot liquid to flash in the surface at a specific system pressure. For demonstration purpose, a modest requirement of 5 kg/s of 0.7-1.4 MPag steam can be set as a target. Based on thermodynamic calculations, a delivery rate of 25-30 kg/s total mass flow should satisfy the requirement. The combination of high temperature (max 250°C) and high pump power requirement to achieve the required flow rate makes this application challenging. ESP's with these capacities are available in the market which can deliver a Total Dynamic Head profile shown in Figure 7.

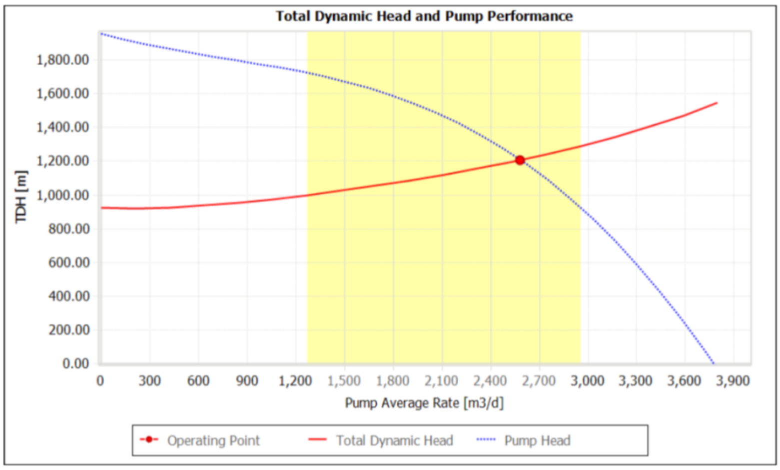



**Figure 7: A total dynamic head and pump head curve to satisfy a flow requirement of ~30 kg/s at the surface.**

The ESP may also need capability to handle some gas content as a portion of the downhole liquid may flash when drawing the well down to very low pump intake pressures (Figure 8).

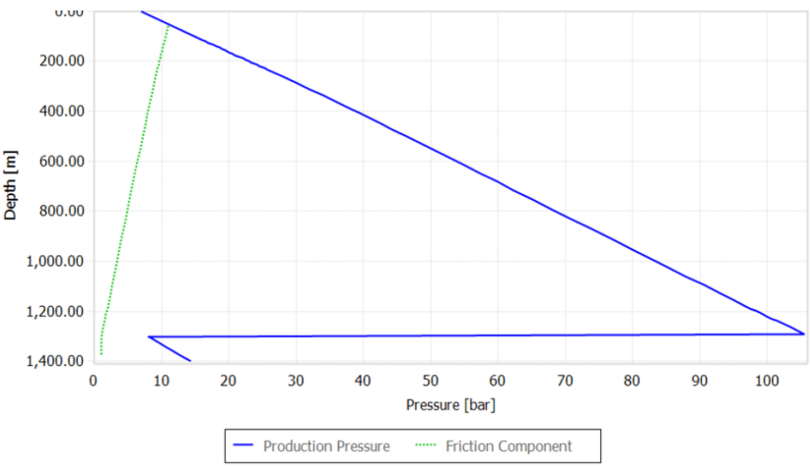



**Figure 8: A potential pressure profile of the liquid as it is pumped from ~1300m depth and into the surface with discharge pressures of ~1 MPag. Note the inflection at the suction portion that lowers pressures to <10 bars.**

The system also has to be carefully designed with sufficient lift provided by the pump and at the maximum flow potential but not leading to loss of water level or intake fluid. This can be addressed by installing a high-temperature gauge to ensure real-time intake pressure readings are obtained at surface for monitoring, evaluation and appropriate adjustments. To increase reliability, the temperature gauge can also be used to monitor motor internal winding temperatures to ensure it doesn't overheat. The use of a Variable Speed Drive to control the speed of the ESP's rotation will provide flexibility to increase or decrease drawdown depending on actual intake pressures. Figure 9 is an illustration where the desired flow rate of ~30 kg/s and total dynamic head requirement is achieved by operating the motor at 60 Hz. All these will help ensure the well is pumped down but not pumped off.

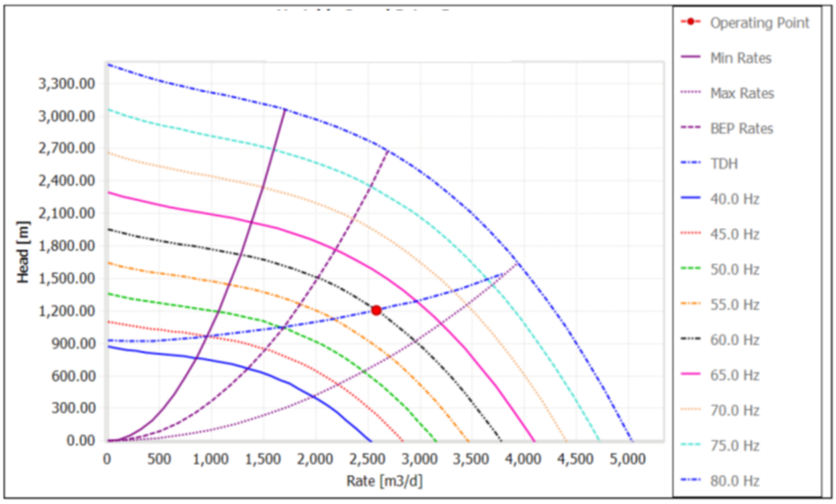



**Figure 9: A potential variable speed drive curve of an ESP to achieve the ~30 kg/s flow requirements and discharge pressures at the surface.**

## 4. CONCLUSION AND FUTURE WORKS

This work has demonstrated that it is theoretically possible to match downhole pump technology with high-temperature geothermal reservoirs. The relative ease of installation, a smaller footprint and minimal modification to typical steam gathering systems make downhole pumps a viable innovation to sub-par production wells. But in spite of the technical feasibility and promising outlook on the use of ESP's in the idle and marginal production wells of EDC, Adams et al. (2017) provided early red flags of typical problems encountered during ESP operations involving massive scaling and accelerated material damage due to combined actions of erosion and corrosion. It is also important to note that proven ESP units in geothermal applications (Binary Plant systems) varies significantly with the intended applications in deeper and hotter production wells of EDC as summarized in Table 4.

**Table 4: ESP key parameters in Binary Plants and EDC's marginal production wells.**

| | Binary Plants | EDC Application |
|---|---|---|
| Bottomhole Temp, C | 140 to 165 | 250 max |
| Setting Depth, m | ~500 | 1200-1300 |
| Total Mass Flow Rates, kg/s | 130 to 160 | ~30 |
| Discharge Pressure, MPag | 0.92 | 0.7 to 1.0 |
| Process | Liquid brine fed to Binary Heat Exchanger | Liquid brine flashed in the surface to produce LP or HP steam (~1.5 MWn) |
| Motor, hp | 1500 | 750 |

Stronger collaboration between downhole pump manufacturers and mid- to high-enthalpy geothermal developers and operators can open up new markets to increase geothermal power generation. Improvements in the ESP technology to withstand aggressive wellbore conditions (>200°C temperatures, erosive solids, acidic fluids, supersaturated brine) can increase pump utilization period and equipment reliability, providing more development options aside from conventional flash-type or binary generation units.

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