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Geothermal Applications of Electric Submersible Pumps (ESPs) in the USA and Turkey

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ABSTRACT

Geothermal developers have been expanding their use of electric submersible pump (ESP) technology in recent years. This paper provides a comparison of ESP technology with line-shaft pump (LSP) technology, which has historically dominated the market for artificial lift in geothermal production wells. The paper then compares typical characteristics of ESPs in geothermal applications in the USA and Turkey, with respect to production temperatures, production rates, pump-setting depths, and run times. ESPs in the USA are operating at production temperatures up to 168°C (334°F) and at production rates up to about 635 tonnes/hour (tph) (1,400 thousand pounds per hour, kph). Pump-setting depths for ESPs in the USA are typically less than 530 meters (1,740 feet). Run times for ESPs in the USA have typically extended to 2-3 years (in one instance, over 7 years), and improvements in ESP designs and attention to power quality appear likely to increase run times in the future. In Turkey, the market for ESPs in geothermal applications is relatively new, and run times for these ESPs are typically shorter by virtue of shorter operating histories. For the Turkish ESP installations considered in this paper, the maximum production temperature was 162°C (324°F), and the maximum production rate was 410 tph (904 kph). These values are somewhat lower than in the USA, but the differences appear to relate more to resource characteristics than to ESP capabilities. In contrast, ESPs in Turkey have been set at much greater depths (up to 979 meters / 3,212 feet). Moreover, ESPs in Turkey have been adapted to allow scale inhibition down-hole, which is not usually necessary in the USA. Significant advantages of ESPs in comparison to line-shaft pumps (LSPs) include: (1) ESPs can be installed in deviated wells; (2) ESPs can be set at greater depths; and (3) ESPs do not require injection of lube-oil that can contaminate both reservoir zones and surface facilities. As ESP technology improves, there is considerable potential for use of this technology to rejuvenate output from formerly self-flowing wells in pressure-depleted fields.

1. INTRODUCTION

Geothermal developers have been expanding their use of electric submersible pump (ESP) technology in recent years. In particular, new projects Turkey have taken advantage of the ability of ESPs to handle deviated wells and greater pump-setting depths. Turkish projects have also adapted ESP installations to incorporate down-hole scale inhibition to deal with higher concentrations of non-condensable gas (NCG) and gas break-out down-hole. In the United States of America (USA), operators have improved their understanding of the importance of the quality of the power supplied to ESPs through Variable-Speed-Drive (VSD) equipment, in order to extend ESP run times (Heninger et al, 2019). This paper begins with a comparison of ESP technology with line-shaft pump (LSP) technology, which has historically dominated the market for artificial lift in geothermal production wells. The paper then compares typical characteristics of ESPs in the USA and Turkey, with respect to production temperatures, production rates, pump-setting depths, and run times (quantified as Mean Time Between Failures, or MTBF). The data for this paper derives primarily from ESPs supplied by the Artificial Lift division of Schlumberger (SLB), as well as data on non-SLB ESPs provided by certain operators. The Turkish data set comprises 15 wells from 7 fields, and the USA data set comprises 17 wells from 7 fields. Appendix 1 provides a listing of the wells in both data sets, ranked by temperature. This data set is by no means exhaustive, but it is large enough to identify important characteristics in the ESP markets of Turkey and the USA, with implications for expanded use of ESPs in other geothermal markets as well.

2. COMPARISON OF ESP AND LSP TECHNOLOGIES

Artificial lift has historically been used in moderate-temperature geothermal wells (below about 180°C or 356°F) that do not sustain production at sufficient rates under self-flow. The earliest applications of artificial lift in geothermal projects date from the mid-1980s, at binary power plants in Nevada, USA. The early geothermal production pumps were adapted from agricultural applications and involved the use of a rotating shaft ("line-shaft") powered by a motor at the surface to drive a pump assembly down-hole. After an initial period of high failure rates, these LSPs gradually became more reliable, such that run times averaging 5-6 years became common (sometimes reaching 10 years or more). LSPs had certain features that operators liked, especially the fact that the motor was located at the surface; this meant that the motor could be repaired without having to pull the entire pump assembly. The LSPs were usually operated at conditions that allowed the production fluid to be kept above the gas break-out pressure from the formation all the way to the power plant, so scaling was not a concern. The pumps required injection of a small amount of lubrication oil ("lube-oil") for the down-hole assembly, delivered through a tube attached to the column pipe that supported the pump. This lube-oil was discharged at the bottom of the tube and was typically produced back to the surface and injected along with geothermal brine at injection wells. Because the wells were generally completed in a way that protected shallow aquifers (and also because the geothermal plants were typically located in remote areas), contamination of the formation by the oil was not considered a significant issue.

Certain shortcomings of LSPs have prompted the introduction of ESPs into the geothermal industry. ESPs put the motor down-hole (below the pump), thereby eliminating mechanical limitations of a long, rotating shaft. The pumps can be set in deviated wells (very desirable if a directionally-drilled production well has become depleted in pressure), and there is no theoretical limit to the depth at which the ESP can be set. The motor is self-contained with respect to lubrication, so contamination of the reservoir by lube-oil injection is eliminated. Like the early LSPs, ESPs initially had shorter run times, particularly because of the ampacity threshold of electrical components exposed to high temperatures in the wellbore, as well as mechanical damage to the electrical cable and the motor-lead extension (MLE) at the junction of the cable and the motor during installation. Improvements in the design of cables and MLEs (such as Schlumberger’s Trident Technology) have made them much less susceptible to mechanical damage. Temperature tolerance has also been improved, such that certain models can now operate at production-fluid temperatures of up to 250°C. ESPs are often used with VSD units at the surface to regulate the speed at which the pump operates. In recent years, poor power quality supplied through VSD units has been identified as a significant contributor to degradation of ESP components (e.g., bearing fluting; feedthrough and penetrator arcing; stator end-turn failures; skin-effect heating of cables; and MLE, pot-head, and splice insulation failures) (Heninger et al., 2019). The use of sine-wave filters to correct poor power quality, together with improvements in mechanical designs, have allowed significant improvements in ESP run times. Figure 1 illustrates the basic ESP components. Table 1 summarizes the pros and cons of ESPs and LSPs in the current state of the technology.

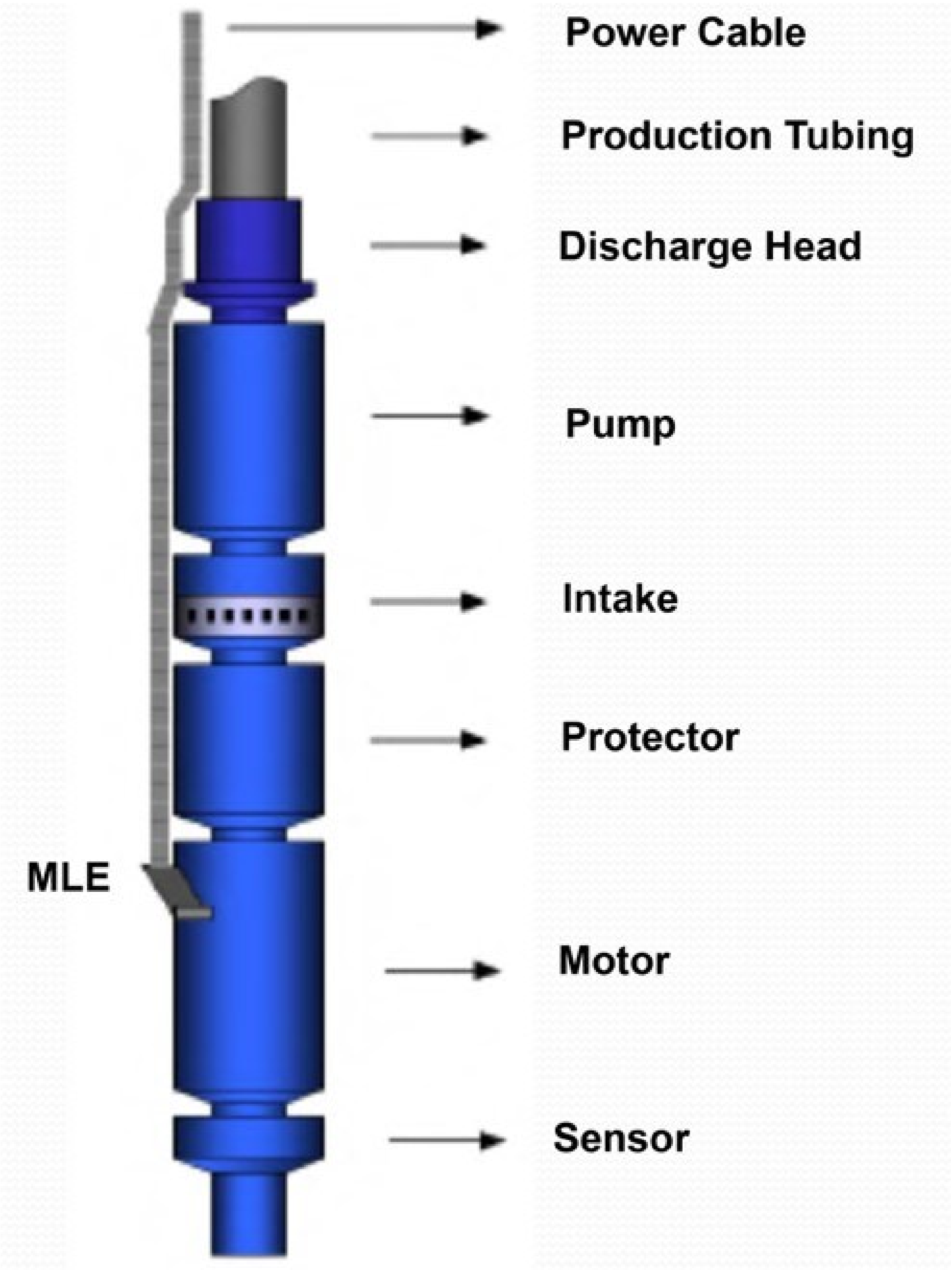

Figure 1: ESP components (adapted from Lobianco and Wardani, 2010).

Table 1: Pros and Cons of Electric Submersible Pump (ESP) and Line-Shaft Pump (LSP) Technology

	Electric Submersible Pumps	**Line-Shaft Pumps**
Pros		
	Can be installed in deviated wells	Longest-established technology for pumping geothermal production wells (about 4 decades)
	Can be installed at any depth (no rotating shaft from the surface)	Motor is at surface, so motor repairs do not require pulling pump
	Compatible with scale-inhibitor tubes	No electrical components down-hole, so can accommodate high temperatures
	Operating temperatures up to 165°C for rates up to 600+ TPH (assuming adequate permeability).	Average run times are on the order of 5-6 years. Run times of 10 years and more have been documented.
	Operating temperatures up to 250°C for smaller-diameter pumps (lower flow rates)	Cost per pump may be lower than for ESPs (assuming conditions are suitable for LSPs)
	Reduced installation time due to factory-prepared, modular components	
	No loss of lube-oil to formation due to self-contained lubrication	
	Reduced manpower requirements for motor maintenance	
Cons		
	Cost per pump may be higher than for LSP (though they are comparable in many circumstances)	Cannot be used in deviated wells (rotating shaft must be vertical)
	Relatively new in geothermal applications (within the past 2 decades or so)	Practical limit for pump-setting depth is about 700 meters
	Repair of motor requires pulling pump	
	Historical issues with shorter run times (though current models have been re-designed and are more reliable)	Longer installation times to accommodate thermal expansion
		Requires injection of lube-oil (about 2 liters/day/pump), which contaminates the formation
		Higher labor requirements for motor maintenance

3. ESP CHARACTERISTICS IN THE USA

ESPs in geothermal wells in the USA are routinely operating at production temperatures up to 168°C (334°F). Production rates range up to about 635 tonnes/hour (tph) (1,400 thousand pounds per hour, kph); in volumetric terms, this is approximately equal to 190 liters per second (L/s) (3,000 gallons per minute, gpm). Figure 2a shows a cross-plot of production temperatures and production rates for the ESPs reviewed in this study. The ESPs with the highest rates in this data set have relatively low temperatures (around 130°C (266°F)), but wells producing in the upper cluster of rates (around 600 tph) range in temperature up to 156°C (313°F). The hottest well (168°C / 334°F) is producing at a relatively low rate (136 tph / 300 kph), but the second hottest well (165°C / 329°F) produces 454 tph / 1,001 kph. In short, this data set suggests that ESPs can operate effectively at any combination of temperatures and rates within the observed ranges.

Figure 2b shows a cross-plot of pump-setting depths and production rates. The highest-rate wells also have some of the shallowest pump-setting depths (about 120 meters or about 400 feet). However, wells in the upper cluster of rates range in setting depth up to 445 meters / 1,460 feet, and the well with the greatest setting depth (551 meters / 1,808 feet) produces at a rate over 400 tph (about 900 kph). Again, this data set suggests that ESPs can operate effectively over the full range of rates from any pump-setting depth within the observed range. The data set also suggests that ESPs in the USA are generally set at depths no greater than about 530 meters / 1,740 feet.

Figure 2c shows that ESP run times in the USA have ranged to over 7 years. Run times in this study have been quantified as mean time between failures (MTBF), defined as

$$MTBF = \frac{T}{(R+1)}$$

where T = time in days between the initial ESP installation and the current date (taken as 27 July 2019 for this paper)

R = number of ESP replacements since the initial installation

For purposes of plotting, MTBF values in days have been converted to years. The ESP with a run time of 7.2 years is clearly an outlier. Still, over half the ESPs in the USA data set (9 out of 17) have run times greater than 2 years. Not all the wells in the USA data set had actual installation and replacement dates available (just MTBF values were provided). For the subset of wells with known replacement dates (11 out of 17), it is possible to consider another metric of run time, i.e., the longest time that any ESP has operated in a given well. This subset of data is plotted in Figure 2d, which shows another well with a maximum ESP run time approaching 5 years (the most recent ESP replacement in this well was 1.3 years ago). The well with the longest run time is toward the cooler end of the temperature spectrum (135°C / 275°F). However, the rest of the wells in the data set show no clear correlation between production temperature and run life. The improvements in ESP design and the enhanced understanding of the importance of power quality are still relatively recent. Even in the relatively mature geothermal ESP market of the USA, there has not yet been time for the improvements to fully manifest themselves as longer run times in this data set.

Figures 2e and 2f show cross-plots of run time (MTBF) versus production rates and pump-setting depths, respectively. Again, the well with the 7.2-year run time is toward the lower end of the spectrum for these parameters. However, the remainder of the USA data set shows no clear correlation between run time and either production rate or pump-setting depth. Wells with production rates of about 600 tph have MTBF values ranging from less than a year to over 3 years. Similarly, wells with the greatest pump-setting depths (about 530 meters / 1,740 feet) have MTBF values ranging from 1.2 to 3.7 years. Longer run times seem possible for ESPs currently in operation, but they are not yet fully reflected in this data set.

The subset of 11 wells with known replacement dates also had data regarding causes of ESP failure. Of this set of wells, 4 had failures attributed to poor power quality, 3 had failures associated with other problems in the ESPs (pumps and motors), 2 had cable/MLE failures, and 3 had no failures at all. (The sum of these is greater than 11, because one well had failures for more than one reason.) None of the wells had failures due to down-hole scaling, because wells with ESPs in the USA have relatively low NCG concentrations (in comparison to Turkey) and can generally be operated at pressures above the gas break-out point.

4. ESP CHARACTERISTICS IN TURKEY

The use of ESPs in Turkish geothermal fields is relatively recent, and the earliest installations in the data set considered in this study date from December 2016. Therefore, the data sets for the USA and Turkey are not really comparable in terms of run times. However, it is possible to make comparisons in terms of production temperatures, production rates, and pump-setting depths. As shown in Figure 3a, the ESPs in Turkey are similar to the ESPs in the USA in terms of production temperatures (up to 162°C / 324°F). The maximum production rates to date are somewhat lower (up to 410 tph / 904 kph); this appears to be a function of the wells in which the ESPs have been installed, rather than a limitation of the ESP technology. Figure 3b shows that the ESPs in Turkey have a much greater range of pump-setting depths (up to 979 meters / 3,212 feet). Moreover, many of the deeper ESPs in Turkey are installed in deviated portions of the wellbores, often to boost production from wells originally intended for self-flow.

As shown in Figures 3c-f, the run times for the data set of ESPs in Turkey extend up to just 2.6 years. Again, the shorter run times primarily reflect the fact that the market for ESPs in Turkey is relatively new. Four of the wells have MTBE values over one year, and 7 wells have had their longest ESP run times exceed one year. Over half the ESPs in this data set (8 out of 15) have never had a failure, and none of the ESPs have been replaced more than once. Among the failures that have occurred, there is no clear correlation with production temperature, production rate, or pump-setting depth. Failures have been attributed to cable/MLE problems (4 cases), motor/pump problems (2 cases) and scaling problems (3 cases) (two of the failures have been attributed to more than one cause). None of the failures has been specifically attributed to power quality, either because this is not an issue or because the issue has not been fully recognized. The scale-related failures for ESPs in Turkey highlight an important difference from operating conditions in the USA. Because the wells in Turkey have higher NCG concentrations, it is often not practical to operate these wells at pressures that keep NCG in solution, and gas break-out can lead to calcite scaling either above or below the pump. The adaptation of ESPs in Turkey to include scale-inhibitor tubes has been an important contribution to artificial lift technology.

5. POTENTIAL FUTURE ESP APPLICATIONS

As mentioned above, certain models of ESPs can operate at production temperatures up to 250°C (482°F). These high-temperature ESPs have been developed for oil production from tar sands using steam flooding, and thousands of ESPs are currently in service for this purpose in Canada. However, these ESPs are designed for relatively low flow rates (up to about 150 tph / 330 kph). Research is continuing on development of high-temperature ESPs that will be capable of the higher flow rates more typical of geothermal wells used for power production. The combination of higher rates with adaptability to wellbore deviation and greater pump-setting depths holds the potential to a significant expansion of ESP use in high-enthalpy fields that have historically been self-flowing but are now pressure-depleted. This technology could allow existing wells that no longer meet line pressures to be put back on production.

6. CONCLUSIONS

ESPs in geothermal applications in the USA have demonstrated the capability to handle production temperatures up to 168°C (334°F) and production rates up to 635 tph (1,400 kph) (in volumetric terms, approximately 190 L/s, or 3,000 gpm). Run times for ESPs in the USA have typically extended to 2-3 years (in one instance, over 7 years). In Turkey, run times to date have been shorter, primarily due to shorter project operating histories (over half the Turkish ESP installations considered in this paper have experienced no failures to date). ESPs in Turkey have been installed to greater depths than in the USA (up to 979 meters / 3,212 feet). Moreover, ESPs in Turkey have been adapted to allow scale inhibition down-hole, which is not usually necessary in the USA. Significant advantages of ESPs in comparison to line-shaft pumps (LSPs) include: (1) ESPs can be installed in deviated wells; (2) ESPs can be set at greater depths; and (3) ESPs do not require injection of lube-oil that can contaminate both reservoir zones and surface facilities. As ESP technology improves, there is considerable potential for use of this technology to rejuvenate output from formerly self-flowing wells in pressure-depleted fields.

7. ACKNOWLEDGEMENTS

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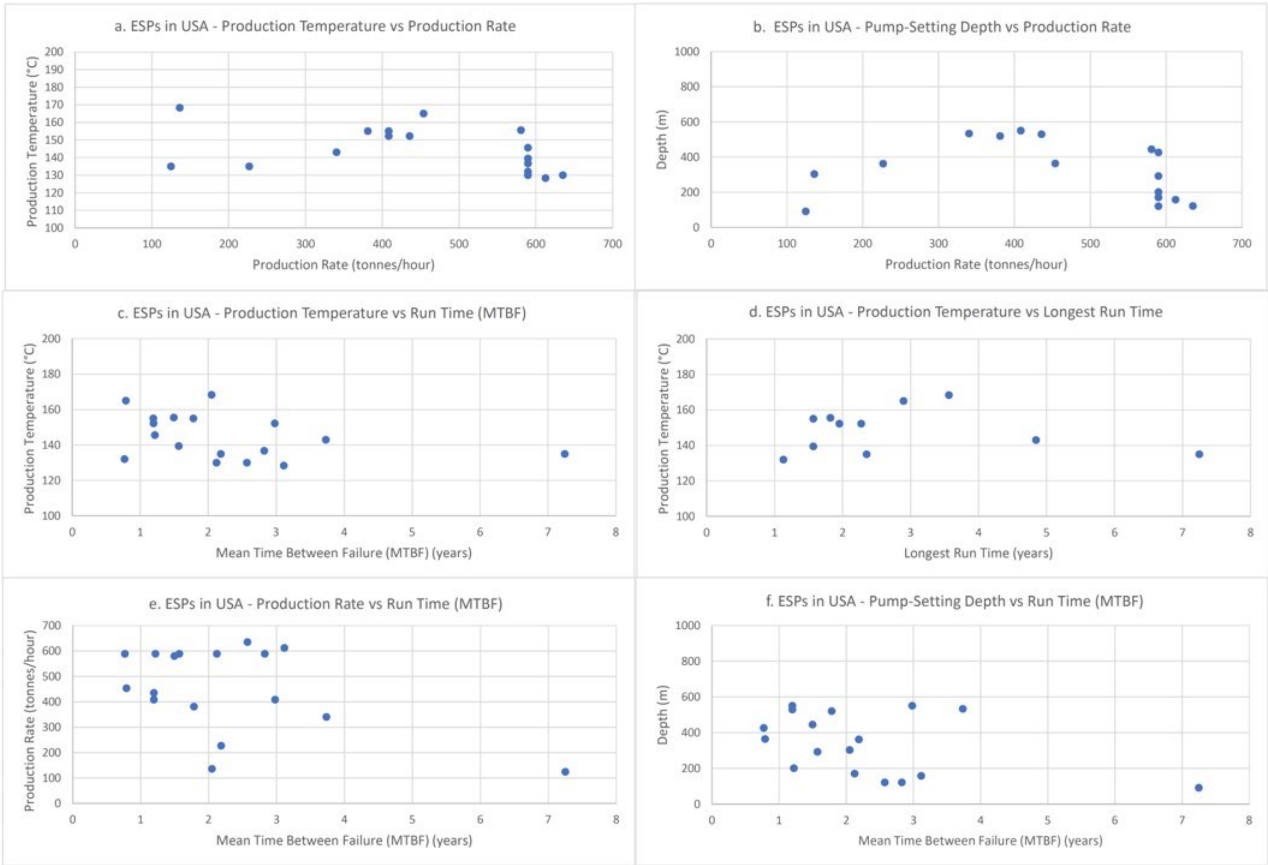

Figure 2. Characteristics of ESPs in USA

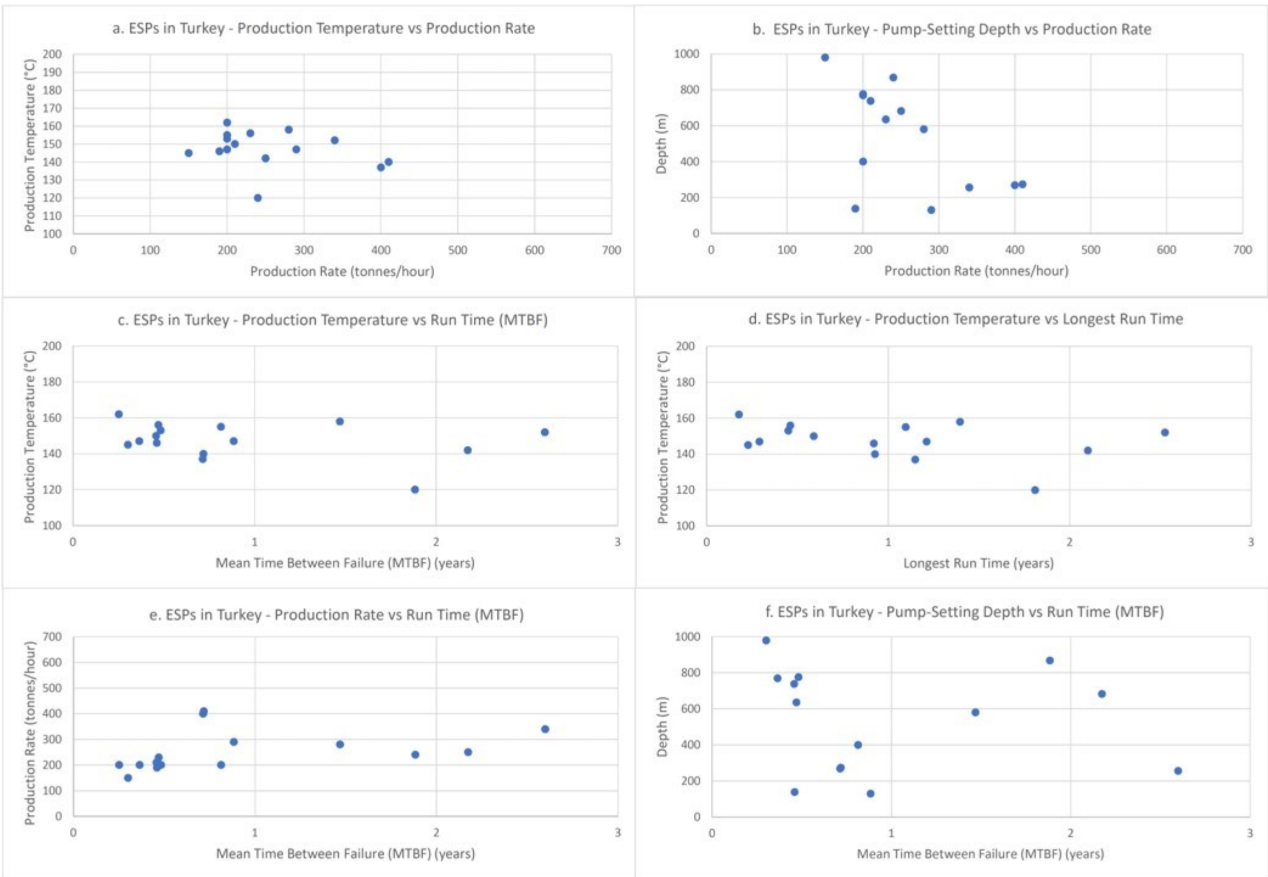

Figure 3. Characteristics of ESPs in Turkey

Appendix 1: ESP installations reviewed for present paper. Well designations have been altered to protect proprietary data.

Country	Well Designation	Production Temperature (°C)	Production Rate (tonnes per hour)	Setting Depth (meters below ground level)	Mean Time Between failures (MTBF)(days)
USA	G-2	168	136	303	748
USA	G-3	165	454	364	288
Turkey	U-2	162	200	NA	92
Turkey	Q-1	158	280	580	536
Turkey	T-1	156	230	615	172
USA	B-5	156	581	445	545
USA	B-3	155	381	520	650
USA	B-4	155	408	550	435
Turkey	P-6	155	200	400	297
Turkey	S-1	153	200	776	176
USA	B-1	152	408	551	1087
USA	B-2	152	435	529	436
Turkey	P-1	152	340	256	948
Turkey	S-2	150	210	738	167
Turkey	P-5	147	290	130	323
Turkey	U-1	147	200	769	133
Turkey	P-2	146	190	138	168
USA	G-1	146	590	201	444
Turkey	V-1	145	150	979	110
USA	A-1	143	340	533	1362
Turkey	P-3	142	250	682	793
Turkey	R-1	140	410	274	262
USA	G-4	139	590	293	572
Turkey	R-2	137	400	268	261
USA	E-4	137	590	121	1031
USA	D-1	135	227	362	797
USA	F-1	135	125	91	2,644
USA	C-1	132	590	427	280
USA	E-1	130	635	112	938
USA	E-3	130	590	171	774
USA	E-2	128	612	158	1136
Turkey	P-4	120	240	868	687