RESULTS OF FIELD TRIALS OF A NEW TYPE OF ELECTRICAL SUBMERSIBLE PUMP, THE HYDRAULIC DIAPHRAGM ESP, FROM, COAL BED, CONVENTIONAL GAS, AND CONVENTIONAL OIL WELLS APPLICATIONS IN THE UNITED STATES

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ABSTRACT
Pumping Solutions Incorporated in a new joint venture arrangement with Smith International, Inc. has developed and tested a new type of electrical submersible pump that uses a positive displacement, hydraulically activated diaphragm pumping mechanism in place of the traditional centrifugal pump. This paper presents the field trial results and lessons learned from over 80 real world field installations in coal bed, conventional gas, and conventional oil wells, with data documenting solids handling, gas characteristics, electrical efficiency, and pump performance. Test results show significant improvements over conventional rod, progressive cavity, centrifugal and other types of artificial lift in solids handling, gas lock characteristics, electrical efficiency, production economics and low volume/deep pump performance. The paper also discusses the issues associated with the use of this new technology, and the basics of the pumping system itself.

Armis Arutunoff's first invention related to the oil industry was the submersible electric motor which he perfected in the late 1920's. He was soon looking for applications for this invention, and found that coupling the motor to a centrifugal pump produced a revolutionary downhole pump that could be used for mining and oil production. With Frank Phillips, and the help of the citizens of Bartlesville Oklahoma, he formed the forefather of the entire submersible pump industry including both oil and gas, and modern submersible water pumps. One of the most vexing characteristics of the centrifugal pump is the inability to low volumes to high pressures, hence as reserves were depleted, and lower volumes were called for, only the rod pump was available. Then as today, less then ten percent of all pumped oil and gas wells in the United States use submersible centrifugal pumps for artificial lift. The rod pump is still used in the majority of all pumped well installations.

The natural question that was asked as early as the 1930's was why not combine Arutunoff's downhole motor with a different type of pump that would produce the majority of pumped wells. The dynamic (centrifugal) pump did not appear to be the answer, because the fixed loss per stage divided over a smaller volume pumped resulted in extremely low efficiency. In spite of many attempts, some dating into the 1980's, no practical solution was available to overcome basic physics.

So the search was on for a better pump. Several interesting pumps have been developed since Arutunoff's invention, including the progressive cavity pump (PCP) in the 1950's, and the hydraulic pump in the 1960's, but not until recently has there been much interest in developing a new type of pump for the submersible motor. The conventional thinking is to combine one of the well established pump types such as piston or progressive cavity with the downhole motor. This idea was and still is being pursued with some vigor by a number of submersible pump companies. The idea has enjoyed limited success to date because of complexity, and a mismatch of pump characteristics with motor characteristics. For example, most PCPs operate optimally at a fraction of the RPM produced by conventional submersible motors, requiring a reduction gearbox.

We took an entirely different approach. We looked within and outside the oil and gas industry for a type of pump that had characteristics that would produce good results in most types of wells. The type of pump that matched the best was the hydraulically-actuated diaphragm pump. This pump, when combined with a submersible motor, produces a Hydraulic Diaphragm Electrical Submersible Pump, or "HDESP" for short.

The HDESP is relatively simple. A source of electrical power, provided from the surface, is converted into mechanical rotational energy by the downhole electric motor. This power is then converted from mechanical power to hydraulic power by a hydraulic pump. The hydraulic energy is then directed into a two chamber, opposed hydraulically-actuated diaphragm pump, where the working fluid is separated from the pumped fluid by a flexible diaphragm. The working fluid in the diaphragm cycles between full and empty diaphragm states, which causes the well fluid to enter and exit the working chambers through conventional check valves, much like a conventional rod pump, with the diaphragm acting as a flexible piston, displacing the pumped fluid.

This HDESP is a positive displacement pump, much like a “triplex” piston pump, and has very desirable characteristics due to its positive displacement design. Positive displacement pumps, as compared to dynamic pumps, are typically single stage, with high efficiencies. In addition, they have advantages pumping high pressures with relatively low volumes, although they are not limited to this realm.

HDESPs also have other desirable characteristics. Diaphragm pumps are typically used in applications that have difficult fluid characteristics such as gas entrainment, high solids content, harsh chemicals and corrosive conditions. This type of pump, working downhole, offers a unique combination of qualities including high efficiencies, solids handling, three phase pumping, and resistance to common oilfield fluids. In addition, diaphragm pumps have nominal limits on input power, and are only limited on flow rates depending on the diameter of the pump.

Combining these two machines, the diaphragm pump and the downhole electric motor had several unexpected benefits. First, we eliminated the rotating seal between the motor and the pump by using the same fluid supply for each. Not only did eliminating the protector reduce costs, but it increased reliability substantially by eliminating leakage through a dynamic seal as a possible failure mode. We were also able to combine much of the machinery into a very compact unit with few moving parts, further increasing reliability and reducing costs. For example, in the current pump, there is only one shaft (the motor shaft) and one set of bearings. The pump has only two moving parts, the pump rotor, and the electric motor rotor. We were also able to cool the motor internally, circulating fluid from the diaphragm pump to the electric motor. As such, the HDESP may be “rat holed” or operated with little or no cooling flow around the motor.

When we introduced our pump to the field, we further confirmed the desirability of the this approach. We began to find that increases in production were being reported in wells previously produced with rod pumps. Upon further investigation, we discovered that a HDESP has the ability to pump fluids down much further than a comparable rod or centrifugal pump. The reason is simple, HDESPs can pump mixed liquid and gas flow, enabling the well to reach equilibrium by pumping off. This allowed the pressure at the inlet to drop well below the bubble point, resulting in decreased fluid levels in the well without any type of gas separator. Operators were also pleased with the lack of corrosion due to all stainless steel construction and the relatively small size (for a typical pump, 110 pounds, 10 feet long, 3 ¾ inch outside diameter).

This short paper will cover three topics. First, the field test results for the 3 ¾” HDESP pumps that have been deployed to date. Second, the results of lab tests that show the characteristics of these pumps with scientific measurements. And third, a limited discussion of the future directions of our development of the technology, limited by appropriate commercial considerations.

FIELD TEST RESULTS

Over 80 installations have been made in oil and gas wells using our proprietary HDESP technology. In every case, the pump was able to produce the well, and in most cases the pump’s performance in terms of efficiency, production rate and installation ease met or exceeded the customer’s expectations. The pumps were installed over a three-year period (2000-2003), primarily into wells between 1000 and 4000 feet in depth. While the hardware has evolved and the performance has improved, we continue to remain focused on enhancing the pumps overall reliability. Typically the pumps were installed on conventional tubing, with a plastic insulated electrical cable. Three-phase, 480-volt installations were the norm, but several single-phase, 220-volt installations were also successful.

Two generations of hardware have been tested in the field. The first used a patented electronic switching method that proved to be unreliable. Only 5 pumps were installed, and all failed in a relatively short time due to electrical problems. The next generation of hardware uses a patented all hydraulic switch which has proven to be reliable, and has been incorporated in all successive styles of hardware. There were 60 installations of this style of hardware, with most running anywhere from two to 18 months. The most sucessful installations were in shallow wells (less then 1000 feet) with a sharply increasing failure rate upon going deeper. It was discovered when out check valves failed to close properly, an unexpected pressure pulse developed on the low side of the pump. This caused low pressure areas of the pump develop high pressure, blowing out seals and bolted connections not designed for high pressure.

The second generation of hardware corrected this challenge and performed much better. This hardware also incorporated a vane pump as the main hydraulic pump and a 100% stainless steel housing. The changes improved performance significantly and resulted in improved run times in 20 installations. Some problems persisted however, mostly related to the use of a modified water well motor and pothead system. A more robust mechanical design was also needed to resist damage that occurred when installing on conventional tubing.

The third generation of HDESP is currently in testing. The main improvements over previous designs are the use of a fully custom, open stator motor design that has much improved temperature and cooling characteristics over the second generation. The mechanical design is simplified, resulting in a threefold reduction in the number of critical seals, and an improved electrical feed through that eliminates possible failure at the electrical junction. This generation of hardware has just entered testing, but the early results are encouraging. The field test program is continuing with a select group of companies, potentially leading to the availability of 3 ¾" OD products for both oil and gas production.

LAB TEST RESULTS

Over the past three years, our internal and several independent testing labs have developed a profile of the operating characteristics of the HDESP. Testing started with life testing of the diaphragm and hydraulic system components. The bearings, valves, pumps and associated components run in an hydraulic oil environment at content temperatures with few load excursions. This is an ideal environment for long life. The current hydraulic switch and hydraulic vane pump assembly are based on established deigns with long track records. Our testing has shown these components can be operated continuously for two years without experiencing a failure. The component supplier estimates based on test data, that mean times between failures of greater than three years can be expected in this application. As part of the same test series, the electric motors and associated bearing have also run continuously in an accelerated test environment, and when examined had no significant wear.

Diaphragms are a key critical wear component in the system, and one of the few components exposed to the oil well environment. As a result, this component has been the focus of most of the testing. Two types of testing were accomplished. First, a special pump was set up that switches ten times faster than normal. This high rate flexes a shorter then normal diaphragm through complete flex cycles to test the resistance of the diaphragm to flex fatigue. The second type of testing is exposure of the rubber material to the oil and gas environment both in the lab, and as a result of field testing. Several improvements were made as a result of both types of testing, with the final result being a diaphragm design capable of withstanding temperatures up to 200° F, sour and CO^2 environments and flex cycles up to two years simulated run life without failure. Testing continues with new materials and designs to expand the performance, enabling use in more demanding applications.

Flow performance is another area tested. We passed many fluids under varying conditions through the pump including heavy oil, gas/water, gas/oil, and sand. The pump is resistant to differing fluid types as one would expect with a diaphragm pump. All fluids tested are compatible with the pumping mechanism, and gas locking was not experienced during these test programs. Sand concentrations up to two percent by weight were tested, and all were pumped with ease. Furthermore, no wear was evidenced by the pump even after extended application at high sand concentrations. The only problem experienced was cavitation of the pump, which would occur if the inlet pressure and fluid conditions were lowered to the point where pressures below 1 atmosphere absolute occurred.

The last area tested in the lab was pump efficiency. This type of pump is inherently efficient due to the positive displacement design and the close coupling of the power source with the pump. Measurements were made over a variety of conditions and motor sizes, and the results are summarized as follows using room temperature water as the pumped fluid:

Overall efficiency= Pump efficiency X Motor efficiency

Pump efficiency
100 BFPD, 1000 PSI- 83%
200 BFPD, 1000 PSI- 85%

Motor efficiency
2 HP- 75%
3 HP- 77%

In our tests, typical overall efficiency was 63 percent from electrical power in at pump to fluid power delivered to the pumped fluid.

FUTURE DIRECTIONS

To a large extent, the future directions of the technology Smith Lift continues to advance will be driven by the specific challenges of customer applications. We have looked at some very interesting extensions of the technology into different sizes, flow rates and pressure capabilities. While the pump appears uniquely suited for coal bed methane applications, we will continue to broaden our technologies for oil and low rate fluid production from gas wells. Deviated wellbores and horizontal pump placement in horizontal wells are also a current area of interest to our customers due to the very short rigid motor section, the ability of the diaphragm pump to operate in most positions, and the potential to incorporate flexible pump chambers. Smith Lift will continue to design, engineer and construct pumps to allow operators to cost effectively produce their reservoirs. We are always interested in discussing challenging pump applications and would like to offer this technology as an additional pump type that should be considered when designing your artificial lift system.