RESULTS OF FIELD TRIALS OF A NEW TYPE OF OIL AND GAS WELL PUMP, THE HYDRAULIC DIAPHRAGM INSERTABLE (HDI)

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ABSTRACT
In response to customer needs Smith Lift has developed a 1 3/4 in hydraulically driven diaphragm pump that allows the operator to insert and pull the pump without pulling the production tubing. The Hydraulic Diaphragm Insertable (HDI) pump is driven by a surface hydraulic power unit which actuates a hydraulic cylinder down hole creating positive displacement pumping action, similar to a rod pump. The HDI pump can be installed with or without seating nipples in standard 2 3/8 in (or larger) production tubing. This paper will discuss the operation and deployment of the HDI pump along with initial results from preliminary testing including solid handling, electrical efficiency, pull and run economics, and low volume/deep pump performance.

INTRODUCTION

For decades pump designers have been searching for something better then the rod pump for the production of fluid from oil and gas wells. Even with millions of dollars spent on research and some very intelligent people working on the problem, today 85% of all pumped wells still use the old reliable rod pump. Last year, SmithLift LLC introduced the Hydraulic Diaphragm Electrical Submersible Pump (HDESP) which is now finding more widespread use in the industry. Generally, hydraulically driven diaphragm pumps use a flexible diaphragm to separate the driven fluid from the pumped fluid, allowing the pressure generating elements of the pump (primarily the seals) to be protected from the well environment. The pressure is generated by another pump (in the case of the HDESP, the pressure is generated by a vane pump) and then transmitted across the diaphragm to the well fluid.

To build any well pump, three elements are required. First, power must be generated and transmitted from the surface to the downhole pump. In a rod pump, this is accomplished with a reciprocating rod. The second required element is the pressure generating system, generally some type of pump. In a rod pump this is a piston-cylinder type pump. And lastly, a way of transporting the produced fluid to the surface, such as production tubing must be provided. The diaphragm is an extra element in the system that adds a barrier between the downhole pump and the pumped fluid. This “barrier” prevents wear on the downhole pump. In the HDESP, the diaphragm has allowed a vane pump to pump raw well fluid (something the vane pump could not do on its own) simply because the fluid running through the vane pump is clean hydraulic oil, which volumetrically displaces well fluid in the pump.

In 2004, we were challenged by Conoco-Phillips and others to develop a radically different pump using the diaphragm pump concept. What producers wanted was a small diameter submersible pump that could be inserted through existing production tubing, typically 2 3/8 tubing with a 2 inch inside diameter. This dream pump would be able to be lowered into the well on continuous cable or tubing, which would then provide power to the pump, and serve as a way of quickly installing and retrieving the pump out of the well. Producers requested two distinct types of pump, one for gas which is lower volume but capable of very deep placement and another for oil wells, which could move as much as 600 BFPD to depths of 7500 feet.

The design constraints provided by the customer for this system were already challenging. We added others including 2 year minimum run life downhole and low cost just to make it a little more challenging.

DESIGN OPTIONS

We started with what we know, namely, electrically operated diaphragm pumps. After several attempts, we had refined the design to one that would require a 1.5 in diameter electric motor that would produce up to 5 HP. Upon investigation with motor manufactures, developing such a motor would prove to be an expensive, if not impossible challenge. Other challenges included packaging the diaphragm assembly, valving, and producing a main pump in this very small diameter. We concluded that is was doable, but would not meet our other requirements, and would be as complicated as a Swiss watch. Being practical people, we looked more carefully at other options.

We started to look more carefully at the simple but effective rod pump. Our previous successful pump design was a cross between an ESP and a diaphragm pump. We thought maybe we could cross a diaphragm pump and a rod pump to obtain a similar hybrid. We know that the rod pump can be built in the diameters of interest, after all a large number of all oil and gas pumps used are some variant of the insertable rod pump. Looking at the rod pump, we had two major problems with adapting it to the requirements given to us by the customer. First, although small enough in diameter, the power transmission mechanism (the rods) would not allow us to adopt a diaphragm design directly, and would not meet the cheap and easy to install requirement. As a result, the pump needed to be some type of hydraulically actuated pump to work effectively as a diaphragm pump. Second, the pumping mechanism (plunger-barrel) was direct acting, and was not directly adaptable to a diaphragm pump. We needed a pump where we could separate the pumping mechanism from the pumped fluid by a diaphragm. After some debate, we determined the best way to solve this problem was to eliminate the rods as the power transmission mechanism in favor of a hydraulically operated downhole pump. The transmission of power from the surface to the downhole pump would be by application of hydraulic pressure and flow from the surface, roughly the same as how a Kobe type pump is operated.

The placement and operation of the diaphragm is absolutely critical. The diaphragm must be placed between the pressure generating mechanism (in this case a hydraulically operated rod pump) and the pumped fluid. The diaphragm must also 1) be free of any rotating or sliding seals and 2) allow the pumped fluid to interact with the seals within the pressure generating mechanism. If these two criteria are met, then seal wear is greatly reduced, due to the fact that hydraulic seal wear is caused mainly by the interaction of small particles with the seal, causing scratches and leaks. Common sense tells you that you must keep all dirt out of a high pressure hydraulic system if you want it to last any length of time. The elimination of moving seals prevents the barrier fluid (the fluid between the diaphragm and the pressure generating mechanism) from being lost to the well. An alternative is to allow for replacement of the fluid from the surface.

THE HDI PUMP

Putting it all together, we came up with the Hydraulic Diaphragm Insertable (HDI) Pump. (See fig 1) The pump has many variants but all the versions have three things in common. 1) Power is supplied from the surface by hydraulic power through small diameter flexible tubing. 2) The main pump, located downhole, is a reciprocating piston type, and provides power to the diaphragm pump. The main pump is a valveless design, that is the stroke of the diaphragm pump matches the stoke of the piston pump one for one, eliminating the need for intermediate valving. 3) The diaphragm is located between the piston and the pumped fluid (the space between the diaphragm and the rod being filled with an intermediate fluid). This prevents contact between the pump piston and pumped fluid, protecting the seals in the piston pump.

In this design, the piston pump ends up looking very familiar, it is in fact made from a rod pump barrel, with a specially modified plunger that drives a piston back and forth into and out of the diaphragm pump. Looking more carefully, this “pump” is in reality a hydraulic actuator similar to those found on construction equipment. The rod end of the actuator is not connected to anything, it simply moves into and out of the diaphragm, causing the diaphragm to change volume and transmit pressure to the pumped fluid. All that is added is a set of check valves, one below the pump and one above it, equivalent to the standing and traveling valves in a rod pump. A seal is required between the pump and the tubing string, the same as a rod pump, to complete the assembly.

The operation of this pump is deceptively simple. First, pressure is applied to the actuator, causing the piston to extend. This forces the diaphragm to expand, forcing the well fluid trapped between the ball and seat valves to be forced through the top ball and seat, and eventually to the surface. When the piston reaches the end of the stroke, the rod is retracted from the diaphragm by reversing the pressure in the actuator, causing the diaphragm to contract, forcing well fluid to enter the pumping chamber through the lower ball and seat valve.

Careful examination of the operation of this pump reveals that it is not direct acting like a rod pump because the “rod pump” portion is only supplying pressured fluid to operate the diaphragm pump; therefore it is an indirect pump. It is also not like a Kobe pump, where power fluid and pumped fluid are mixed within the pumping mechanism, and the pumping mechanism is in direct contact with the pumped fluid. It is in fact and entirely new class of indirect acting positive displacement diaphragm pump.

To operate the pump, a source of reciprocating hydraulic pressure is required from the surface to provide the power. The first approach taken was to provide two lines, one attached to the extend portion of the cylinder, and the other to the retract side. By applying pressure to the first line, and porting the other to a reservoir, the cylinder is extended. Reversing the lines cause the cylinder to retract.

To seal the pump to the tubing, the pump was designed at 1.75” OD, 5 feet long, with a short section at the top of the pump compatible with a standard seating nipple. Cup type seals were attached to the pump, and the pump was lowered into a bottom hole assembly consisting of a standing valve at the bottom, standard 2 3/8 tubing to a seating nipple located approximately 11 feet above the standing valve. The pump sealed at the seating nipple. A ball and seat check valve was located at the top of the pump, to allow flow into the tubing string.

We quickly discovered the limitations of transmitting hydraulic power over long distances, namely, at any flow rate, except very low flow, friction losses are very high, especially with high viscosity hydraulic oil. Another customer desire was to limit the cost of the working fluid, and to use environmentally benign fluids in the system in case of fluid leakage, especially in wells where water is discharged to the environment. These requirements lead to the decision to use water as the working fluid. With water, many problems are solved but finding hydraulic system components compatible with water was somewhat difficult and required some system compromises. The seals in the cylinder were ultimately designed to be compatible with clean water, or a mixture of water and glycol for freeze protection.

Although it was feasible to use water in the cylinder downhole and achieve long working life, the pressure pump on the surface needed to generate the high pressure water was more problematic. Few high pressure water pumps exist that are designed to run continuously. We ultimately chose the oilfield standard triplex pump, and designed the system around the requirement that only clean, filtered water could be run through the pump. With this, a low cost, simple surface power system, that runs on straight water was developed and tested. Other components, such as a valve and accumulator system were added at the surface to operate the pump in some configurations.

We considered two major configurations for the downhole cylinder, one with a downhole valve and the other without. The downhole valve has advantages if the return water from the cylinder can be vented to the output of the pump and then recovered at the surface, filtered, and reused in the system. Alternatively, a larger diameter second line to isolate the return fluid to the surface can be used without a filtration system. If that is not possible due to limitations of the fluids used, then another configuration with the valve at the surface is used. In this situation, the retract portion of the cylinder is hydraulically cycled at the surface, and the extend side is connected to high pressure nitrogen gas, which serves as a return spring. Both types of systems require only one high pressure hydraulic line from the surface, and the cost and efficiency reductions of the second line vs. a fluid recovery system determine which should be used.

SYSTEM MODELING

Once the basic configurations were set, extensive system modeling was accomplished to determine maximum flow rates, tubing sizes and system performance. System modeling determined that reasonable system performance can be obtained in a 2 3/8 system up to about 75 BFPD if a surface control valve is used, or up to 150 BFPD if a downhole control valve is used. The difference is due to the loss of energy and system response speed due to the compressibility of the water and the volumetric expansion of the tubing. If a downhole valve is used, it is believed that flow rates up to 600 BFPD can be obtained with a 2 7/8 system. Lab tests have confirmed the modeling of the 2 3/8 surface valve system, and other testing is ongoing to confirm the remaining models.

FIELD TEST RESULTS

We have performed three field tests, all with a surface valves. The first test used a dual line system, with conventional hydraulic hose to connect the downhole cylinder to the surface. A fluid separator was used to isolate the water portion of the system from the oil portion, and a surface oil hydraulic power supply was used to generate power. The pump was lowered into the well, which was a dead oil well, to 1895' and then operated. The flow rates generated were very low, about 20 % of what was predicted. Later it was determined that the hose used had a volumetric expansion of about 20% at the pressures used, and most of the power was being absorbed by the expansion of the tubing.

A new system was designed that used a single pressure line, and an accumulator downhole with a pressure generating valve in the tubing string to generate back pressure needed to operate the cylinder. The assembly was installed in the same well as before, and would not operate as predicted, again due to volumetric expansion.

Our third field test used a steel capillary tubing string as the main pressure line, and a conventional hydraulic hose with high pressure nitrogen as a return spring. This arrangement did not have the problems of operation as before, but in the process of installing the pump into a deeper well, it was discovered that the tubing string was crimped, preventing successful installation.

We are in the process of installing two additional pumps (see fig 2) into conventional gas wells in the San Juan basin. The first will be installed with steel capillary tubing as the main hydraulic line, and a gas line as the return. The second will be produced with a single line system and a downhole valve.

CONCLUSIONS

Based on the modeling and testing conducted so far, we expect efficiencies of between 25 and 60% for the pump, depending on depth and flow rate, with installed lifetimes averaging 2 years. The advantage of the system is the ability to retrieve the pump without pulling the production tubing, and the ability to power the pump hydraulically, which allows for a variety of power source options, high power transmission efficiency, and long life. If this development continues to be successful, producers will have another pumping system option that will allow for small diameter pumps to be installed inside conventional tubing. This will in turn, lower operation and maintenance costs.

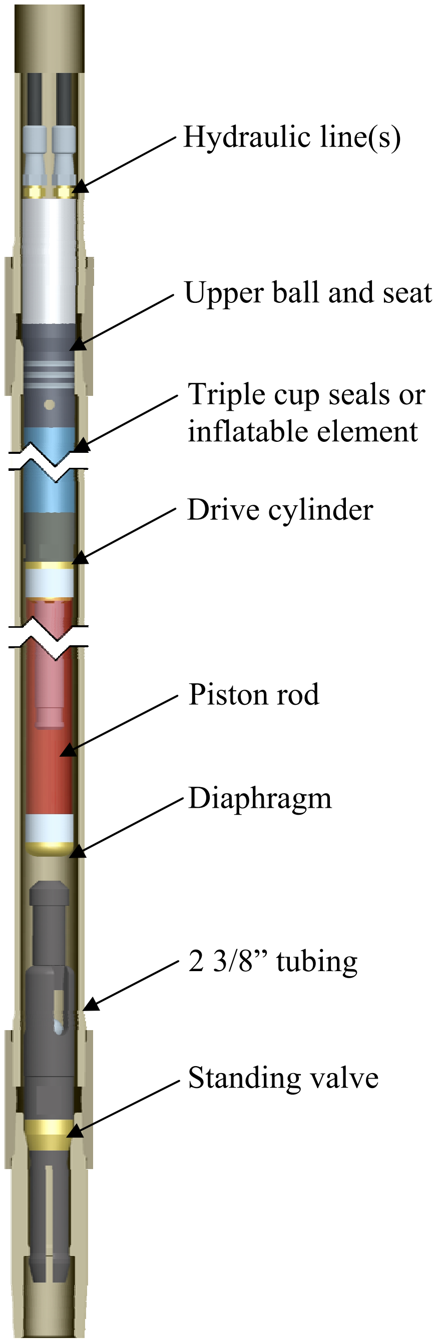

Figure 1 - HDI Model

Figure 2 – HDI Pumps