ESP Systems Operating Below the Perforations

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ABSTRACT

The ESP uses the flow of well fluid to cool the motor. This has been traditionally done by landing the ESP above the perforations, or by using a shroud to redirect the fluid around the motor. This paper presents some of the advantages and disadvantages for below perforation operation.

Several options on the equipment necessary for this type of operation are presented along with a field experience of an operator in a location where below perforation operation looked to be advantageous.

INTRODUCTION

Where should a ESP be set in the well? The conventional recommendation for the ESP was to set the pump as high as possible in the well, where the oil would be just under the bubble point (Ref 1). This was to save on initial cost of cable and tubing. It would also save on operating cost by reducing the voltage loss in the cable and the total friction loss in the tubing.

For operation where the fluid produced was below the bubble point, it was recommended to set the pump just above the perforations. The purpose of this is to maintain as high an intake pressure as possible and there by reducing the interference of the free gas in the fluid stream. Any time that the unit was to be set below or even in the perforated zone, it was recommended that the motor shroud be used to direct the fluid flow over the motor.

The oil world has changes significantly in the thirty plus years since these recommendations were published. The requirements of marginal operations to maintain profitability demand that many of the old paradigms be re–examined.

BELOW THE PERFORATION OPERATION

Figure 1 shows a modification of the inflow performance representation (IPR) for a well as proposed by Vogel[2]. The vertical axis has been changed to indicate the height of the column of fluid, rather than the pressure, at the perforations. With the pump setting at the perforations, the maximum production would occur when the height of the fluid column approaches zero. This figure also shows the total volume of liquid plus free gas. As the height of column of liquid is reduced the volume of free gas can be extremely large.

The ability of the centrifugal pump to handle the fluid is adversely affected by the presents of this free gas. Turpin(3) developed a correlation to predict the intake pressure necessary to prevent the free gas form interfering with the performance of the pump.

$$ø = 2000/6 * (Vg/Vl)/Pa$$

Where:
Vg = Volume of Free Gas
Vl = Volume of Liquid
Pa = Pump intake pressure (PSIA)
ø = Performance Indicator

His work concluded that if ø is less than 1, the pump will be able to handle the gas. This indicates that 25% free gas at the pump intake would require more than 220 PSI in order to operate. This translates into approximately 500 feet of fluid over the pump intake.

If this pump is setting above the perforations, the required intake pressure also acts on the formation and inhibits the flow. The paradox is that we want the well bore pressure low for the well production, but we also want it high to reduce the gas interference of the pump. Setting below the perforations can offer a solution.

By setting the pump intake below the perforations, you revise the traditional relation between the pump intake pressure and the pressure acting on the formation face, that is the intake pressure was always equal to or lower than the pressure at the perforations (Fig. 2). A little tweaking of the imagination produces scenarios where the pump intake could be located a thousand or so feet below the perforations. In such a case Turpin predicts that the pump could handle 56% free gas without any pressure on the formation face. The economics of drilling a thousand feet of extra rathole may be questionable.

Producing from below the perforations will also allow the system to make use of the natural annular separation of the gas. When the pump intake is above the perforations, the gas and liquid are flowing in the same direction through the narrow annular area between the ESP and the casing wall.

Many different arraignments of holes, cups, and chambers have been attempted to produce a passive gas separation system. This search for passive gas separation mimics much of what was done in the rod pump industry in which case, the most effective passive gas separation found was to set the pump intake below the perforations.(Ref 4). The combination of the natural annular gas separation, the lowering of the pressure on the formation face, and the possibility of increasing the pump intake pressure makes a very strong case for developing systems that can operate below the perforations.

A disadvantage in this system is that it requires that there is sufficient rathole below the perforation. There is also the problem of not knowing what is in the rathole. It can be filled with sand or miscellaneous debris.

ESPs BELOW THE PERFORATIONS

To set the ESP below the perforations, it is necessary to have a method to force the fluid to flow around the motor, or develop a motor that requires no fluid flow for the cooling.

Motor Shrouds

The oldest and most widely practiced method for setting an ESP below the perforations is to use a motor shroud (Fig. 3). The motor shroud is commonly constructed from a piece of casing of the design diameter for that series of motor. If a motor was designed for 5 1/2" casing, the 5 1/2" casing would be used for the shroud, and the unit would have to be installed in 7" or larger casing. For 5 1/2" casing it is necessary to use the slim line motors designed for 4 1/2" casing. One of the drawbacks to shrouded motors is that the equipment cost and the operational cost of the ESP motor increase with decreasing size.

No Circulation

If the unit is set below the perforation without the benefit of the flow of the well fluid, it will have to cool by what ever conduction is available. In cases where standard ESPs have been accidental set below the perforations, the life expectancy is measured in hours. With the development of the ultra high temperature motors, it is possible to operate without the benefit of forced convection cooling. These motors are designed to be able to tolerate internal temperatures as high as 600 degrees F. The theory of operation is to let the motor temperature increase to the point that the motor can function, being cooled only by the conduction of heat to the surrounding formation. This cooling may be assisted by some thermal siphon circulation of fluid between the cooler casing was and the hotter motor housing.

There has been success reported with this type of system. The system has the advantage of simplicity. The set up and operation of the system is basically no different from a standard ESP. The disadvantages are in the cost of the ultra high temperature motors and the possibility of increased scaling and corrosion due to the elevated surface temperature of these motors.

The standard design of the ESP assumes a motor internal temperature rise of 60 to 100 degrees depending on the philosophy of the design. Ratholed motors may have a temperature rise of two to four times this number. This requires a much larger oil reservoir than the standard designs.

Fluid Recirculation

Fluid recirculation certainly not new. It involves taking a portion of the pumped liquid and conducting it to an area below the motor. This liquid then flows across the motor back to the pump intake, providing the flow for the forced convection cooling.

The method is shown in figure 4 and is taken from the catalog of a water well motor manufacturer (Ref 5). This method is successful and can be economical when a relative small portion of the fluid is recirculated, that is, enough flow can be diverted from the pump exit with out significantly effecting the system efficiency.

If for example the system produced 50,000 BPD, taping off 500 BPD for cooling represents approximately a one percent change in the system efficiency. Obviously for 1,500 BPD production, recirculating 500 BPD knocks 25% off of the system efficiency.

In the oil production industry, the head is quite high. The high pressure is of little use in the recirculation scheme. It is dissipated in the recirculation tube and in the fluid turbulence below the motor. One method investigated for recirculation is to use the pressure energy to induce flow. A system was proposed that used a small jet pump in conjunction with an ESP. The jet pump was mounted on the head of the ESP and made use of the high pressure by converting it into a large flow rate which was to be used to circulate around the motor. Though innovative, this project has achieved long term back burner status. The very small port and nozzle sizes required are prone to plugging and high wear rates.

A third method was to tap off part of the fluid before there was a large increase in the pressure. If for example 500 BPD were recirculated in a system that was designed to lift 1500 BPD with 4000 feet TDH, if the recirculating fluid was taped off when its pressure had reached 40 PSI, the hit on the over all system efficiency would only be 1.34%. Because of the higher efficiency and the reduced number of unknowns, this was the system that was chosen for development.

RECIRCULATION SYSTEM DEVELOPMENT

In the concept stage of the project, it was decided to keep it simple and affordable. The use of as many existing parts and proven technology as possible is the best way to accomplish this.

The system chosen made use of two separate pumps. The lower one is referred to as the recirculation pump, and the upper is the production pump. There are two options in the design. One is to have the recirculation pump with its intake and exit separate from the production pump (Double Intake), figure 5. The other is for the recirculation pump and the production pump to share the intake (Single Intake) figure 6. Both options were equally simplistic in their design but had functional differences. Although easy to incorporate in the system design, the double intake tends to recirculate the same fluid. This might conceivable be of some advantage for cooling in a well with a high oil cut where the motor is sitting in water, but generally it would have a poorer cooling than the other design. The second design uses a single intake to be shared by both the production pump and the recirculation pump. In this design recirculated fluid is remixed with production fluid, reducing the bulk temperature before returning to cool the motor.

Configuration

The single intake system was selected for development. It makes use of a standard upper tandem pump, equalizer and motor. The recirculation pump is attached between a standard equalizer and a standard upper tandem pump. A recirculation tube for transporting the cooling fluid is tapped into the head of the recirculation pump. This tube runs down the unit to below the motor where it is clamped to an extension tube below the motor.

Recirculation Pump

The recirculation pump has a relatively small number of stages in it. The stages are selected so that their flow rate is larger than the production pump. With the production pump producing at its designed rate, the additional flow of the recirculation pump is tapped off at the recirculation pump head and directed down past the motor.

Recirculation Tubing

The tubing turned out to be the most difficult part of the entire recirculation system design. The size restriction of well casings caused the creation of a recirculation tubing formed to hug the outside diameter of the motor (Figure 7).

The working clearance between a 4.50" diameter motor and the inside diameter of 5 1/2"−17 lb casing (4.76) is only a gap of 0.26 inches. With 5 1/2 −14 lb casing, the clearance at the drift of 0.38". Although the tube can have many profiles inside these restraints, the one chosen uses reinforcement rods on both sides. These rods protect the tubing during installation, and with the welds on both sides tend to hold the outer shell from spreading during operation, reducing leakage of cooling fluid in its trip below the motor. Even with the special tubing, it is not practical to install the system in 5 1/2"−20 lb or heavier casing

Installation

With the close fit of the recirculation tube and the casing it is recommended to reduce the installation rate to no more than 10000' per hour to prevent possible damage to the custom formed tubing. Extra care must also be taken if the well is deviated well or upon entering liners.

Only minor changes in the installation process are necessary, The assembly is standard until after the recirculation pump is bolted to the Equalizer. The recirculation tube is lifted into the derrick, then lowered into the casing beside the motor. The tube is attached to the head of the recirculation

pump and the unit lifted in the derrick. The lower end of the recirculation tube is clamped to the extension tube on the bottom of the motor. Nuts are used to draw the recirculation tube up snug against the motor housing. In this manor the tube can be secured against the motor without using bands or clamps on the OD of the motor housing.

Problems

The only problems that have been encountered have been related to the tubing used to recirculate the fluid for motor cooling. The first versions had problems with the tubing kinking during installation. The result was to pinch off the flow and burn the motor. To correct this the tubing profile was redesigned to strengthen it. The tubing is now also to be shipped inside of its own specially designed shipping container to prevent damage in handling. The cap at the top of the tubing has also gone through some changes to strengthen its weld connection. One early installation suffered a crack in the cap weld and broke loose during installation.

FIELD EXPERIENCE

Amoco's Bumpass Unit, located in Carter County, Oklahoma, is one field where pumping below the perforations has proven to be a worthwhile benefit. This field was unitized in 1979 in the Springer–Deese formation. A typical Bumpass Unit will have five prominent sand lenses, spread over as much as 1000 feet. To add to the problems, the casing sizes and liners vary from will to well.

The well that really got attention on the is #52. It has 5 1/2" casing and had slim hole ESP equipment set below the perforations and shrouded. The problems with the setup were;

1. Slim Hole ESP equipment is very expensive, compared to conventional sizes.

2. The scaling tendency of the water is high and scale would precipitate out inside the shroud on the motor due to temperature and pressure, This made the runtime of equipment too short to be acceptable.

The last time the equipment failed due to this scaling problem it was decided to come up the hole 600 feet and set equipment designed for 5 1/2" casing above the perforations. The production dropped from 65 BOPD x 800 BWPD to 30 BOPD x 550 BWPD. It was seen then how much benefit there was from producing at the lower depth. Now the question was how to produce from below the perforations without the previous mentioned problems. That is when Fred Edens, Sr. Petroleum Engineer, and Danny Foster, Lift Coordinator in Ratliff City, met with a major ESP manufacture. The recirculation pump seemed to be the answer. It was $35,000 less than the slim hole equipment and did not require the tight fitting shroud that was part of the scaling problem.
When the unit was installed in June of 1995, the production returned to its previous volume. One operational change that was made was to start a continuous injection of a small amount of scale inhibitor down the backside, the casing annulus. This was done to insure that scale would not build up inside the recirculation tube.

Because of the success, two more installations have been made since well #52. Well number #114 had 5 1/2" casing, and the old ESP was set above the perforations. It was producing 18 BOPD x 720 BWPD. The fluid level in the well was starting to rise and a equipment resize was going to be necessary. With the knowledge of the success in #52, it was decided to run the unit below the perforations with a recirculation pump. The production is now 36 BOPD x 950 BWPD.

Another unit was installed in well #92. It replaced a beam unit that could not pump the well off. Production was 24 BOPD x 370 BWPD. The beam unit had been set below the perforations and it was decided that was where the ESP needed to be. The problem this time was getting into a 5 1/2" liner with the top located 1,900 feet form the surface, another good selection for the recirculation pump. The rig crews on all installs were cautioned to take it easy so not to damage the tube, but extra caution was used in this well until the unit was into the liner. The production of this well in now 34 BOPD x 650 BWPD. On both #114 and #92 continuous injection of scale inhibitor was started as a precaution.

CONCLUSIONS

Operation of the ESP below the perforations can increase the pump intake pressure without reducing the pressure at the formation face. It also makes use of the natural annular separation of gas so that it minimizes the gas interference at the pump with our using a gas separator. Below the perforation operation also allow the operator to apply the maximum draw down on the formation.

There are three methods for ESP operation below the perforation;

Shrouded Systems
No Circulation Systems
Recirculation Systems

The shrouded units have the most casing restrictions. The recirculation systems allow the units to operate in most of its designed casing sizes. The no circulation system puts no restriction on the casing size but requires that the motor operate an elevated internal temperature.

All three methods can work. The choice is a matter of field parameters, operation, and economics. The advantage in the recirculation system is that it can be constructed with a high percentage of standard equipment.

The recirculation and shrouded systems can be used in low production, large casing wells where the flow is not high enough to adequately cool the equipment.

In any well where the production rate is limited to keep the reservoir saturated, there is no advantage is setting below the perforations. The extra expense in tubing, cable and special equipment is not justifiable. Only in the cases where production can be increased should setting below the perforations be considered.

REFERENCES

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3. Turpin, J.L., Lea J.F., Bearden J.L.:"Gas–Liquid Flow Through Centrifugal Pumps – Correlation of Data" 33rd Southwest Petroleum Short Course, Texas Tech, Lubbock, Texas (1986)

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Table 1 - Production Change (BPS), Bumpass Unit

Well	Oil	Water	Comment	Oil	Water	Comment
#52	30	550	ESP Above Perfs	65	800	ESP Below Perfs
#114	18	720	ESP Above Perfs	36	950	ESP Below Perfs
#92	24	370	Rod Below Perfs	34	650	ESP Below Perfs

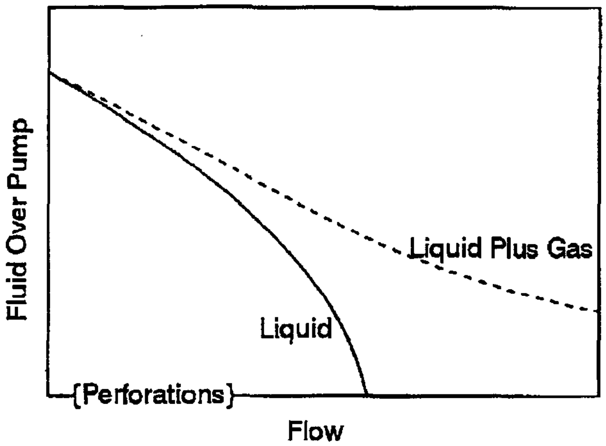


Figure 1 - IPR after Vogel

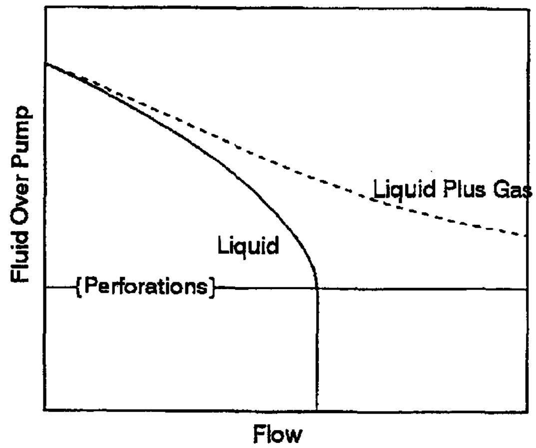


Figure 2 - IPR for Below Perforation Production

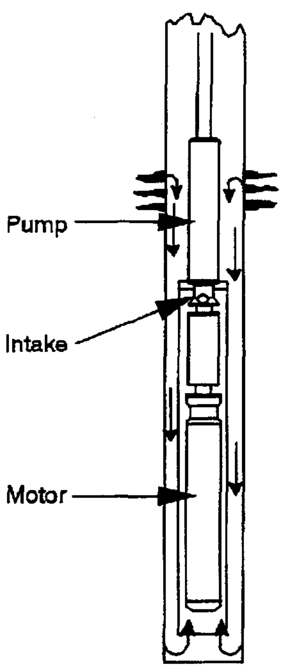


Figure 3 - Shrouded ESP

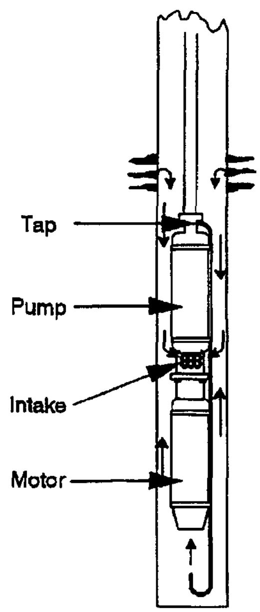


Figure 4 - Recirculation Tap

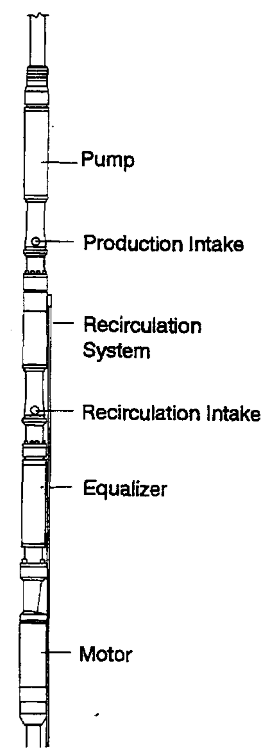


Figure 5 - Double Intake Method

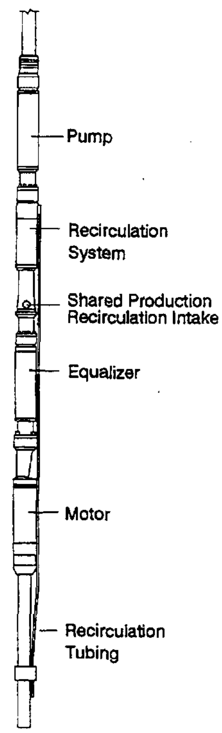
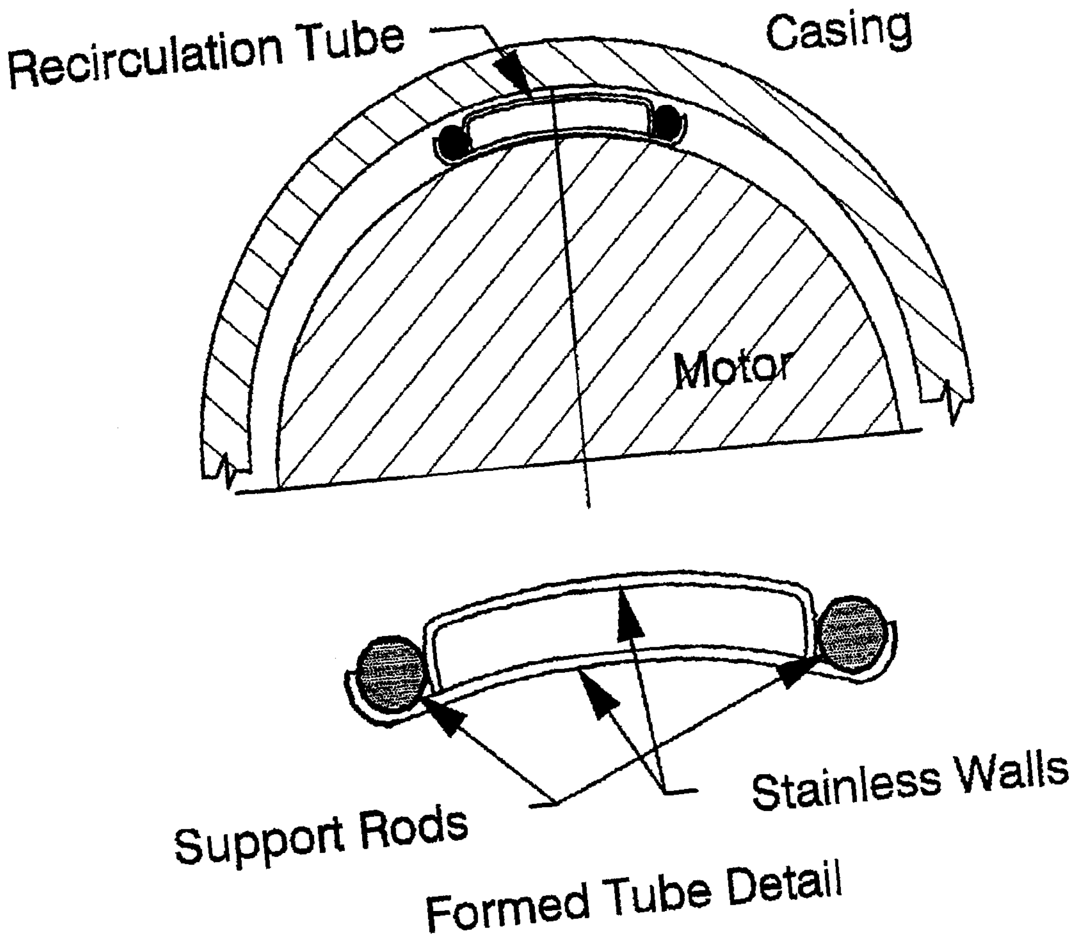


Figure 6 - Single Intake Method



Recirculation Tube

Figure 7 - Recirculation Tube