Downhole Oil Water Separation: The Triple Action Pumping System

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Introduction

Downhole Oil Water Separation (DOWS) is becoming one of the key technologies of the oil industry and to reap the benefits promised by this concept, a new system has been developed to separate oil and water in the wellbore. The first test of the system — the Triple Action Pumping System (TAPS) — will be described in this article. The new system has accomplished a number of industry firsts in oil/water separation. The potential of DOWS to improve revenues, reduce expenses and investments, and protect the environment when the right conditions exist has been described in previous articles.[1, 2, 3] By virtue of its capability to inject at high pressure, TAPS opens the door for DOWS to provide a whole new (less costly) method of waterflooding. The successes of this test are primarily attributable to two conscious efforts: 1) commitment at all levels – from the field to management and 2) true team effort involving an operator, vendors, and government agencies.

As the DOWS acronym suggests, the TAPS is capable of economically separating and injecting water downhole while producing only a fraction of the water to surface with the hydrocarbons. TAPS has extended the applicability of DOWS to "hard rock country" where high injection pressures are common. The TAPS is believed to have accomplished a number of industry firsts:

- It showed that oil and water segregation occurs even when the pump is placed below the well's producing perforations. This is significant when it is important to minimize backpressure on a well.
- It employed produced water recycling to achieve environmentally friendly "zero discharge". That is, any water produced to surface was dumped back down the annulus and injected so that no water hauling was necessary. This process is a closed system that reduces discharge opportunities and facilitates chemical treating.
- A pseudo-permeability log[4] (created using neural networks) was used to select the optimum injection interval for a DOWS application.
- A water-soluble, oil-dispersible chemical was used to protect both the producing and injection zones. This treating method appears to be far more successful than previous approaches.

The Triple Action Pumping System

The Triple Action Pumping System (TAPS) is an improved design of the Dual Action Pumping System (DAPS) which has been described in several articles.[1, 2, 3] The DAPS separates oil and water in the wellbore – 1) lifting oil and some water while 2) injecting the remaining water. The TAPS performs these same two functions and provides at least three additional benefits. First, it provides a third action of magnifying injection pressure as shown in the conceptual drawing of **Figure 1.** Similar to the concept of the pressure exerted by the heel of a spike-heeled shoe, TAPS transfers the force acting on a larger area to a smaller area to which it is directly connected. In this case the force of the column of fluid in the tubing acting on the large production plunger is transferred to the smaller injection plunger. A second improvement of TAPS is that it is capable of functioning in 4-½" casing. The upper intake valve, which was mounted on the exterior of the tubing was custom made for the DAPS. In the TAPS a simple ported collar allows fluid to enter the pump. TAPS is virtually constructed of off-the-shelf equipment, so a third benefit is that it has few specialty parts. The lower valve assembly, which is the intake for the injected water is one specialty part. The TAPS is a relatively simple and inexpensive DOWS system, employing gravity segregation in the wellbore to separate produced fluids.

Government Role

At the time that the TAPS was being designed for use in this well, Argonne National Laboratory sponsored a program to provide DOE cost sharing grants to test DOWS. Argonne has taken an active role trying to publicize and support DOWS development.[5, 6] Argonne proved to be very flexible and supportive before and during the testing. This supplemental funding not only allowed the development team to perform tests that would otherwise not have been conducted, but it also offset the cost of development related failures.

One of the biggest hurdles to testing DOWS can be obtaining permits – some projects die because of the proverbial pocket veto. The New Mexico Oil Conservation Division proved to be very flexible as they quickly grasped the potential benefits presented by this test. A conventional UIC permit with some special provisions (like access to the data) was granted on a temporary basis for the TAPS to be tested.

Candidate Selection

Another challenge of testing new technology is locating operators willing to risk a "good well." A well in southeast New Mexico proved to be an ideal candidate to test the TAPS. It was relatively new, so the casing could handle injection pressure (a frequent problem with the old wellbores too often used in previous DOWS tests). The well had been completed in deeper zones which were uneconomic to produce, so the rods and pumping unit were oversized for the application of TAPS in the zone in which it was tested, Figure 2. Additional benefits included dedicated tanks for this well, Figure 3, a pump-off controller, no partners, and a significant economic incentive. Figure 4 displays the configuration of the well with the producing zone at 4780' and the injection zone at 5 100'. The well was uneconomic at the time it was selected as a candidate, producing 17 bopd and 190 bwpd. All produced water had to be hauled off the location by trucks for commercial water disposal at significant cost. Most critical, however, was the existence of a field management team – from Operation Technician to Operating Unit Manager – committed and willing to invest time, effort, and money in this technology.

Once a candidate well had been selected a disposal zone could be identified. The original plan was to inject water into one of the deeper, uneconomic reservoirs that had already been stimulated. However, Texaco's geologists provided a unique solution that appears to be an industry first. Using a Texaco patented process that employs neural networks to learn from existing log and core data[4], they developed a pseudo-permeability log. This pseudo-log showed that a far more permeable and thicker salt-water aquifer was located just a few hundred feet beneath the producing zone. Completing this interval proved less expensive and provided a reservoir that is undoubtedly more capable of absorbing injection water than other zones in the well.

TAPS Design

The Triple Action Pumping System consists of a series of three sucker rod pumps that actuate an injection cycle and a production cycle. An injection packer between the production and disposal zones serves as a tubing anchor and as a boundary between the two cycles. A purge valve mounted below the packer prevents injection water flowback when the tubing string is unlatched from the packer's on-off tool, Figure 5. The lower valve assembly is a combination of valves that allow produced water to be loaded into the injection cycle from the casing/tubing annulus on the up stroke and displaced into the disposal zone on the down stroke. A polished rod, stroking through a three foot pump barrel, hydraulically opens and closes the lower valve assembly to load and displace the injection cycle using produced water as its working fluid. A sucker rod connects the injection cycle's polished rod to the production cycle. Two pumps, one tubing pump and one insert pump, of different sizes lift produced fluid to the surface. Since the TAPS cannot use a standing valve to load itself, two traveling assemblies were sized to create differential pressure in the cavity between them on the down stroke, opening the traveling valve in the larger, lower plunger, and loading the production cycle. On the up stroke, the volume of the cavity between the two traveling assemblies decreases, opening the traveling valve on the smaller, upper plunger, and producing fluid into the tubing string. The amount of fluid produced to surface is dependent on the change in volume of the cavity between the two traveling assemblies. A ported collar between the lower traveling assembly and the polished rod allows oil and some produced water to enter the production cycle. Balancing the size of the TAPS' three sucker rod pumps is critical to installation procedures, achieving the desired water injection volumes, overcoming required injection pressure and producing sufficient volumes of oil to surface.

The design process was simplified by the existence of oversized equipment. Although the design enabled the pumping unit to do more work by moving more tluid than before, the TAPS reduced the load range on the unit and rods. This load reduction occurs because the rod string and the injection interval continue to carry the fluid load on the downstoke. A conventional pump drops the fluid load onto the standing valve, which is supported by the tubing.

New Mexico permits surface injection pressures up to 0.2 psi/ft in disposal wells without well testing. Texaco was able to estimate and track the well's injection pressure by converting the well's minimum polished rod load to an equivalent surface injection pressure. The test well's disposal zone accepted water at 1600 psig at the perforations or an equivalent surface injection pressure of less than 0 psi. The theoretical injection pressure limit on this TAPS installation is *0.65* psi/ft due to the pressure magnification effect of transferring hydraulic force on a large plunger to a smaller plunger.

Water Recycling

Gravity segregation DOWS typically bring about one fourth or more of the total produced fluids to surface. One of the most aggressive goals of this test was to completely eliminate water hauling by recycling produced water down the well's annulus. The lease's high water handling costs made it attractive to add this feature to the test. **A** plan was established to pull the produced water off the bottom of the production tank and let it siphon down the annulus. Five primary concerns were 1) the breakdown of the fluid segregation process, 2) corrosion/scale effects, ***3)*** the additional withdrawal and injection capacity required, 4) the mechanics of controlling the recycled water, and 5) the accurate determination of injection data.

Dr. Howard McKinzie of Texaco's Technology Division quickly and correctly concluded that the water traveling down the casing/tubing annulus would immediately find the low side of the casing and stream down the side of the pipe. Whether it channels through the oil column or disperses is unresolved, but the end result is that produced water recycling worked.

Corrosion had been a particularly aggravating problem in DAPS installations; some were completely corroded below the production cycle when pulled. Unichem devised a corrosion solution that consisted of an oil-dispersible, water-soluble chemical that was added to the water recycling stream. This has provided totally satisfactory protection, whereas the previous weighted chemical approaches often failed within a few months. It now seems that weighted chemical simply did not have enough time to pass through the oil column even though the units were turned off for as much as half a day.

Additional withdrawal and injection capacity was required to handle recycled water. Siphoning water down the well's casingitubing annulus for injection was like taking four steps forward and one step back. The pump's production cycle might produce a given barrel of water more than once before that barrel was disposed of. TAPS was designed to inject more fluid than it produced enabling the injection cycle to outrun the production cycle and pumping the well off. Lengthening the stroke of the pumping unit was one way to increase the pump's ability to move fluid.

Control of the recycled water was established by a simple water return system, **Figures 6 & 7.** A heater treater dump valve installed on the produced water tank allowed water to enter the water return line. **A** Halliburton MC-II RTU water meter measured the amount of water recycled each day. From the meter, the water passed through a port in the wellhead and down the 90' **X** 3/8" siphon hose that was banded to the tubing, **Figure 8.** The siphon hose was designed to use the hydrostatic head of the recycled water to overcome the well's **30** psig casing pressure.

Accurate injection volume determination was dependent on accurate downhole stroke data. Industry accepted calculations were used to estimate the pump's downhole stroke and injected water volume from a surface dynamometer measuring forces acting on the polished rod. Future testing will provide a verification of these calculations as they apply to the TAPS. Injection pressure data was gathered in a similar manner.

TAPS Performance

Figure 9 provides a detailed rate-time curve. Management allowed installation of the TAPS with a plan of working up to maximum capacity over a period of time (rather than immediately testing the ultimate capacity of the system). This process was beneficial in resolving problems such an initial assembly configuration that had trapped gas within the injection pump assembly. Trapped gas below the injection polished rod was partially responsible for the loss of approximately 50% of the injection cycle and can be observed at the beginning of the down stroke in the downhole pump card displayed in **Figure 10. An** increase of 25% in the effective injection stroke was realized by modifying the injection polished rod to better handle gas interference, **Figure 11**. Note the small load range of the card that should help lengthen the life of the pumping unit and rods. No mechanical problem with either the pump assembly or the rods was expected because the rod loading was less than 50% of rated capacity.

It had previously been speculated that setting the pump below the well's producing perforations could create separation problems, but these concerns proved unfounded. The ability to set the pump below the producing formation becomes important when an operator wants to minimize backpressure on that formation.

Well Failures

Two preventable system failures occurred during the course of the testing. The first failure became apparent when oil production suddenly fell to zero. The pump was pulled and inspected. It appeared to be in good condition, but there were indications of rod wear and the lower valve assembly had split. **A** replacement lower valve assembly was installed and improvements were made to the injection cycle to reduce trapped gas interference. Several sinker bars were installed to reduce the likelihood of a rod wear related failure. The increased pump efficiency was expected to help lower the fluid level of the well further as we continued to push towards the maximum withdrawal rate. The pump efficiency increased, but within a few weeks the replacement lower valve assembly parted in precisely the same location as the previous failure. After the second failure of the lower valve assembly it was realized that the injection pressure generated by the TAPS was causing significant fatigue stresses in the lower valve assembly. Fatigue stress calculations showed the lower valve assembly was loaded to 160% of maximum capacity. A more robust lower valve assembly has been installed and is expected to resist fatigue stresses indefinitely, **Figure 12.**

Data Acquisition

Argonne's funding made it practical to acquire abundant data - adding to the scientific value of this test. Daily production and water recycling volumes as well as frequent dynamometer and fluid level measurements were recorded. Additionally, Nabla Corporation provided a base line dynamometer analysis as well as interpretation of unconventional TAPS data. These relationships proved to be helpful when it became evident just how difficult the data interpretation would be.

Summary

Texaco's testing and development of the Triple Action Pumping System was successful. Several breakthroughs were accomplished by this testing that will push gravity segregation technology towards ultimate widespread industry and government acceptance. Gravity segregation DOWS are on the low end of the spectrum for both production rate and cost, so these technologies may prove very valuable in the more mature oil producing basins. Almost without fail, tests of DOWS pumps have led to unforeseen benefits. This test was no exception.

(1) A solution developed for the problem of trapped gas below the injection plunger has been successfully transferred *to* typical sucker rod pumps to reduce gas interference conditions where high compression valve cages and gas anchors had not provided relief.

(2) A method for determining pumped off conditions in a DOWS environment has been successfully tested. Less than complete loading of the TAPS production cycle is noticed at the beginning **of** the upstroke, **Figure 13.**

(3) A "siphon" method for reintroduction of produced water and facilitation of continuous chemical treatment has been developed.

Vision

Continued testing of TAPS to demonstrate its economic viability and reliability is planned. Additional testing is being arranged through Argonne National Laboratory because calculating downhole rate and injection pressure appear to be more complicated than originally anticipated. Downhole rate and load sensors will be run to verify the calculated values so that the predictive model can be modified if necessary. Although developed for rod pump applications in mature, onshore settings, TAPS is a forerunner of Downhole Oil Water Separation systems that may soon be used in high cost applications to minimize hydrate or emulsion problems or to waterflood where it was previously unthinkable.

Acknowledgements

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References

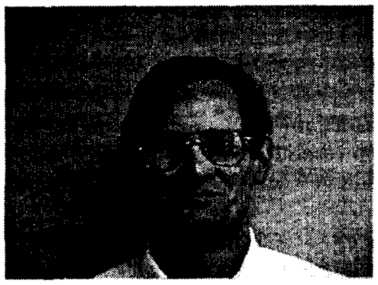
1. Stuebinger, L, K. Bowlin, J. Wright, M. Poythress, and B. Watson, "Dual Injection and Lifting Systems: Rod Pumps,'' SPE 38790, presented at the 1997 SPE Annual Technical Conference and Exposition, San Antonio, Texas, Oct 5-8.
2. Stuebinger, L. and G. Elphingstone, "Multipurpose Wells: Downhole Oil Water Separation in Your Future," SPE 49050, prepared for the 1998 SPE Annual Technical Conference and Exposition, San Antonio, Texas September 28-30.

3. Stuebinger, L., H. McKinzie, G. Elphingstone, and D. Gallaher, "Protecting Water Resources with DOWS," presented at the Annual Meeting of the Ground Water Protection Council, Sacramento, CO, Sept 19-23, 1998.
4. Wiener, J., J. Rogers, and B. Moll, 1995, "Predict permeability from wireline logs using neural networks," Petroleum Engineer International, v. 68, no. 5, p. 18-24.
5. Veil, J., B. Langhus, and S. Belieu, "Feasibility Evaluation of Downhole Oil/Water Separator (DOWS) Technology," January, 1999.
6. Veil, J., B. Langhus, and S. Belieu, "DOWS Reduce Produced Water Disposal Costs," Oil and Gas Journal. March 22, 1999, pp.76-84.

Biographical Information

Jason Wacker is a Production Engineer for Texaco's Carlsbad Field Management Team and 1997 graduate of Texas Tech University.

Lon Stuebinger, an engineer for Texaco in Denver, CO, is the primary inventor of DAPS, TAPS, and a number of other DOWS technologies.



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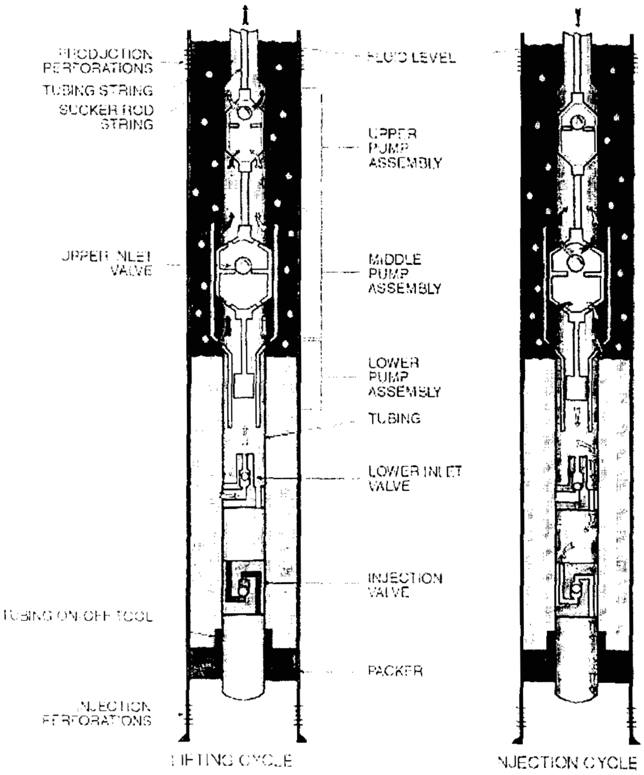

Figure 1 - Configuration of TAPS

Figure 2 - Bilbrey ***30*** Federal #5 Pumping Unit

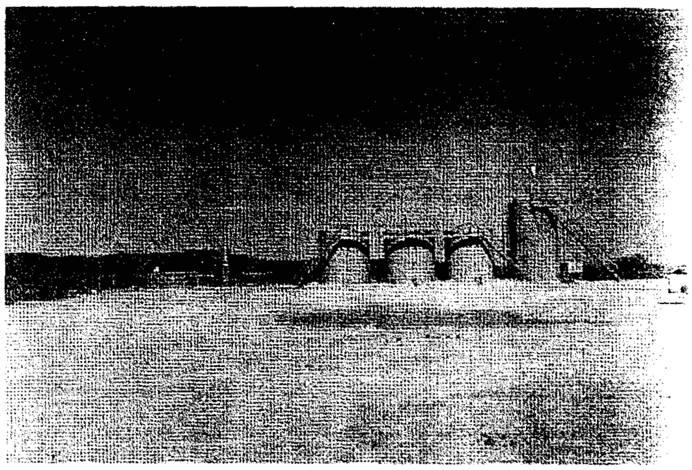

Figure 3 - Bilbrey 30 Federal #5 Tank Battery

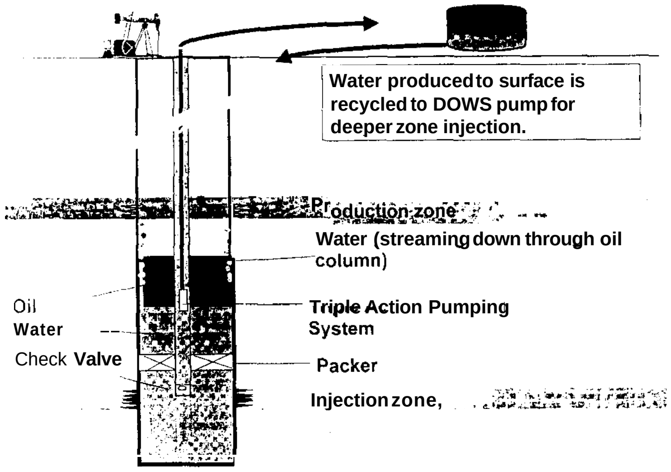

Figure 4 - Bilbrey 30-5 Well Schematic

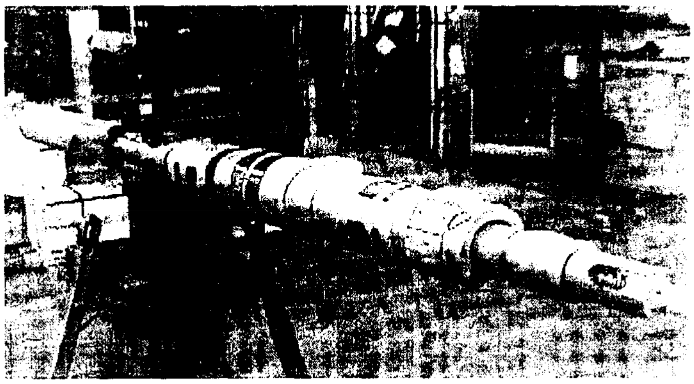

Figure 5 - Nickel Plated Injection Packer and Purge Valve (to Prevent Flowback)

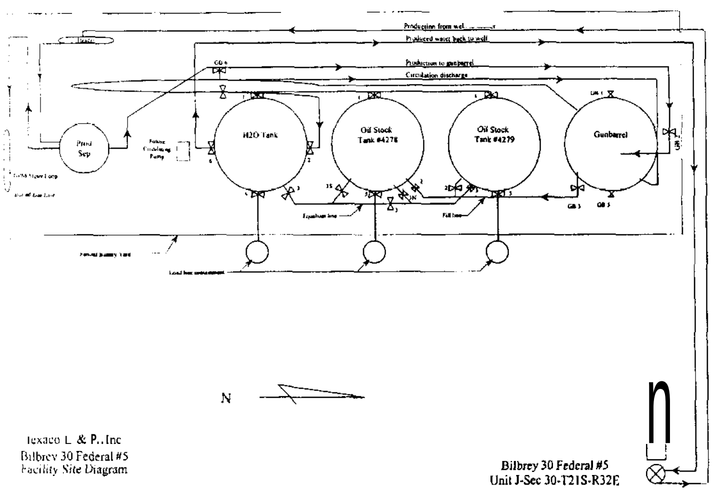

Figure 6 - Well Site Diagram

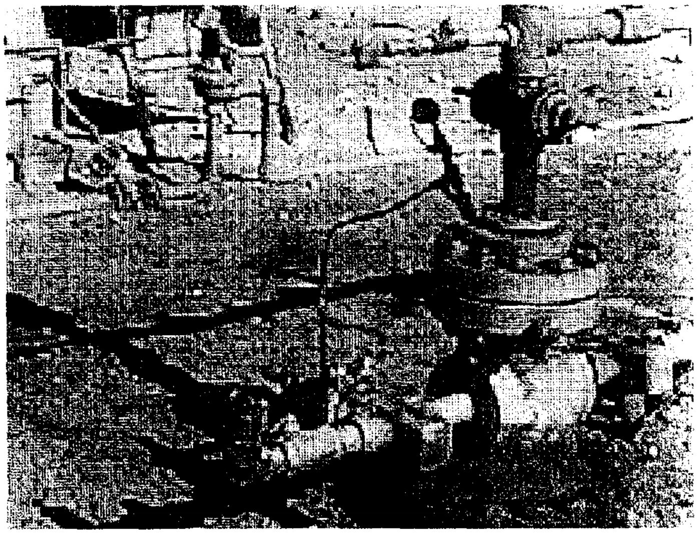

Figure 7 - Wellhead Ported for Water Recycling

Figure 8 - Banding Siphon Hose to Tubing

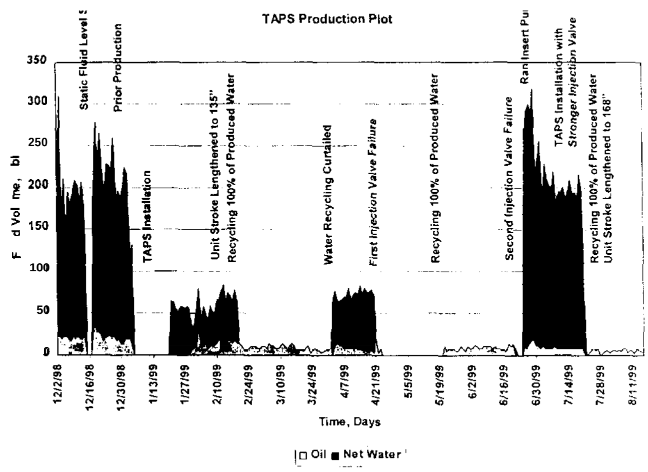

Figure 9 - Rate/Time Curve — Annotated

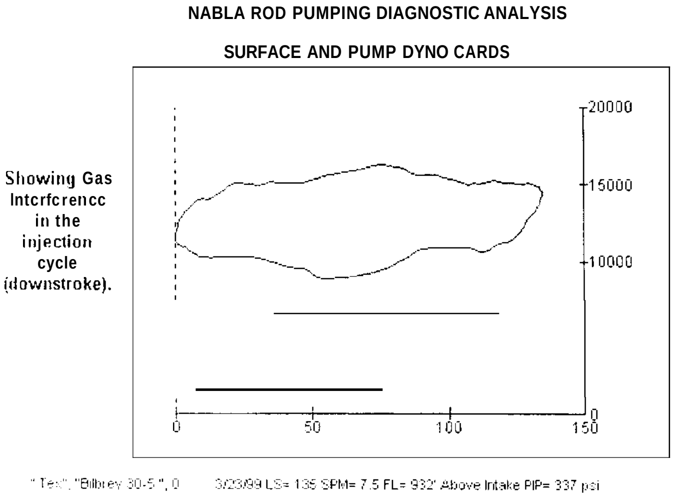

Figure 10 - TAPS Downhole Pump Card Prior to Injection Plunger Modification

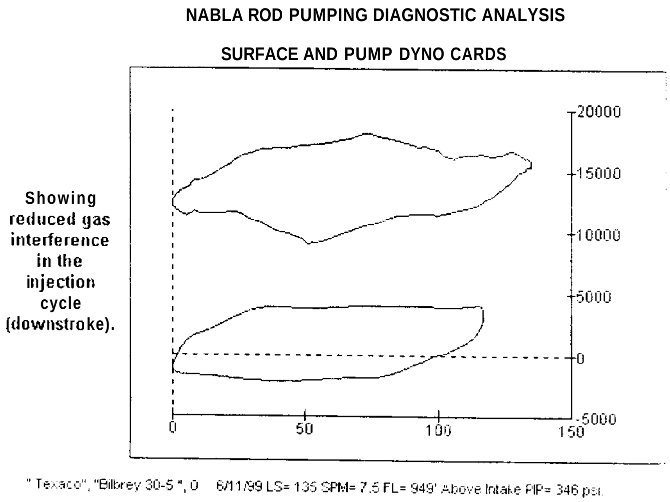

Figure 11 - TAPS Downhole Pump Card After Injection Plunger Modification

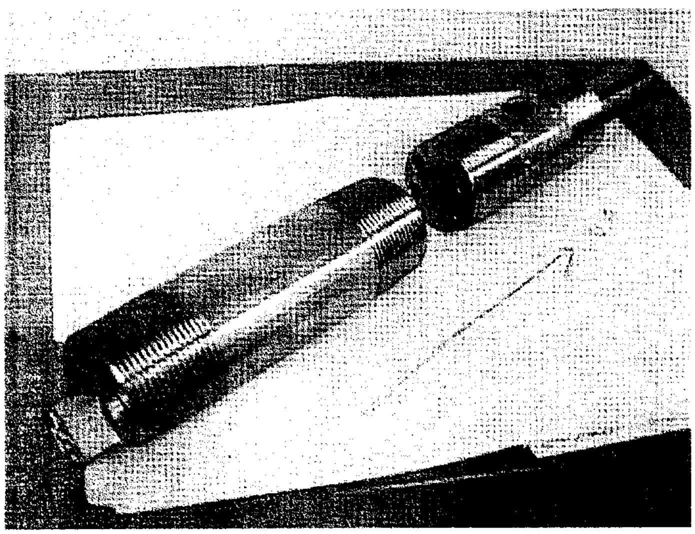

Figure 12 - Stronger Lower Valve Assembly

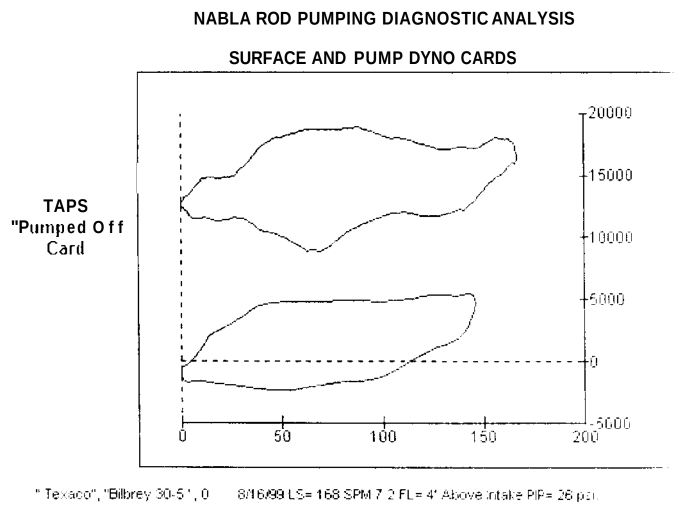

Figure 13 - Pumped Off TAPS Downhole Pump Card