LOCATING AND CONTROLLING WATER PRODUCTION IN HORIZONTAL WELLS (PERMIAN BASIN)

Andrew V. Padilla
Chevron U.S.A. Production Company
Midland, Texas

Jay Miller
TAM International, Inc.
Houston, Texas

ABSTRACT
Applying horizontal well technology to improve oil recovery in reservoirs undergoing active water flooding continues to evolve with improving success. Development of remaining unswept oil reserves with horizontal wells as a method to improve conformance is a significant challenge. Evaluating and optimizing well performance to achieve economic results in a waterflood setting is a critical step in maximizing the success of a horizontal well project. Horizontal laterals expose large amounts of productive reservoir rock, benefiting certain reservoir applications while adding a major risk component to well designs planned for heterogeneous, water flooded carbonate reservoirs. Long laterals increase potential of exposing undesirable geologic conditions such as water-filled fracture networks, zones of high water saturation and extreme permeability of thief zone intervals. A significant negative impact on well performance from high water production rates can result in lower oil rates and excessive lifting costs. This paper summarizes methods and experiences in mechanically evaluating and diagnosing fluid entry in newly drilled horizontal wells, efforts and results to control water entry and optimize well performance. Also discussed are field test results of a new tool design combining re-settable, inflatable packers and a hydraulic jet pump. Early field test results suggest this method will be a promising advance toward efficient diagnosis of fluid entry in both vertical and horizontal wells.

INTRODUCTION
Efforts to evaluate the potential benefits of horizontal wells to develop unswept oil reserves began in the McElroy field in 1995. Initial horizontal well results in this mature waterflood were encouraging but began to reveal a major problem with excessive water production. The horizontal producing wells designed to avoid water cycling conditions were encountering geologic and reservoir features that resulted in high water cut production performance. Basic horizontal well design in McElroy was a re-entry of an existing vertical wellbore and drilling medium radius lateral(s) with 4 ¾" open hole completions. Designs included 600 to 1000ft laterals drilled at 2 to 5 degrees from true horizontal to expose multiple layers of an overall 30 to 40 ft thick target zone. (Figure 1) A major challenge was to understand the true impact of horizontal producing wells in this waterflood setting which required some degree of evaluation to determine a fluid entry profile over the length of lateral and build sections. Neither practical nor effective logging procedures were available for wells requiring artificial lift methods, thus mechanical isolation and short term swab testing was utilized to understand fluid entry and to explain well performance. Inflatable packers are an integral component in the evaluation design due to the nature of the open hole conditions. Large 200 to 600 ft long sections of the laterals were isolated independently using a bottom inflatable bridge plug and an upper inflatable production packer. Swab testing or short term full drawdown production testing provided a basic indication of fluid entry rates and oil cut. After moving inflatable equipment and testing various portions of the open-hole wellbore, a completion design using inflatable isolation assemblies were used to exclude zones of excessive water entry and optimize oil production. Basic test objectives have remained the same over the past 4 years, however the equipment and methods have evolved to reduce costs and improve accuracy and efficiency.

Continued development of inflatable tools and production testing methods resulted in recent tests using a new approach to improve fluid entry testing process. Re-settable inflatable straddle packers combined with a hydraulic jet pump provide full drawdown testing on short intervals. This new method allows for testing multiple zones under full artificial lift drawdown with a single trip in the hole. Initial field trials demonstrated a major advance toward improved efficiency and reduced cost of evaluating well fluid entry.

EARLY EVALUATION METHODS

Initial production testing of newly drilled horizontal wells with the full length of the curve and lateral exposed frequently showed surprisingly poor results. Swab testing before the initial completion regularly showed 100% water production. Swabbing rates were not sufficient to draw the fluid levels down in the well due to high formation productivity. Initial tests using electric submersible pumps as the artificial lift method showed low oil cuts, high fluid levels and water rates 2- 5 times that of surrounding vertical producers. Wells that showed some or complete loss of circulation while drilling (fresh water drilling fluids with reservoir pressure of 600 – 800 psi) were typically the worst performing wells during initial testing. Drilling data and initial testing observations clearly indicated problems with undesirable water entry along the lateral portion of the well. A mechanical isolation and swab test procedure was designed to determine if the zone(s) of excessive water entry could be located. Inflatable packers were used to provide isolation, and swab testing was used to determine fluid entry rate and oil cut. A very coarse evaluation with three intervals, the curve and two segments of the lateral was the typical design that met testing objectives at acceptable levels of cost. The zones at which lost circulation occurred during drilling sometimes dictated how the lateral would be segmented for testing. Mud log data, drill rates, lithology, and oil fluorescence data was also regularly used to pick packer seats and assist in test zone determination.

Setting inflatable packers in this process proved to be relatively simple and reliable in the open hole. Inflatable packers used as bridge plug were configured with bull plugs and on/off tools to allow for disconnecting and retrieval. Retrieval has been 100% successful. Inflatable production packers were re-settable to allow for expanding or reducing the test interval if necessary. Once packers were installed, swab testing was expected to be ideal for obtaining simple and effective results. Although swabbing proved to be a low cost approach, it was found inaccurate and misleading. In wells with low reservoir pressure and/or high inflow condition, swabbing was not effective in creating sufficient drawdown to achieve inflow from tighter oil bearing zones. Oil cut results were often pessimistic with only traces or no oil shows present. At best, swabbing proved to be a good indicator of the water entry zones when the fluid level could not be pulled down. The potentially productive intervals were readily recognized because they could be swabbed down to various degrees and often showed 5 – 20% oil cut during swabbing. This method of evaluating fluid entry was slow, expensive, and was not successful in achieving accurate and definitive results. It did however, prove to be a highly valuable step in a successful well project. The qualitative findings were able to show oil production that was not present during initial well testing. It was able to provide important information resulting in improved decisions on the productive potential of a well, and the feasibility of further investment.

Typical testing by this method took up to 1-2 days per test interval and frequently required 10 to 12 days of rig time to complete a cursory evaluation the well.

A MODIFIED APPROACH TO FLUID ENTRY EVALUATION

Because of shortfalls in swab testing method, the testing procedures were modified in two basic ways. First, individual zones were tested for extended periods using ESP pumping equipment to achieve full drawdown. Secondly, test tool configurations were designed with straddle packers, seating nipples and sliding sleeves so that fewer packer sets were needed to accomplish the testing plan. The use of submersible pumps with variable speed drive units provided good flexibility to test zones with different inflow performance at full drawdown conditions. The duration of ESP tests were lengthened to ensure valid, stabilized oil cut results. Although test results improved significantly, frequent pulling and re-running ESP pumping equipment was time consuming and expensive. (Figure 2) summarizes a case history for this type evaluation.

Re-settable, inflatable, straddle packer systems were also introduced into the testing efforts and provided a process to test multiple zones without pulling out of the hole to redress tools and packers. (Figure 3) A packer spacing of 200 ft was used. Swab testing each isolated interval was again attempted as the necessary way to determine fluid entry and oil cut. Straddle packers worked quite well in improving the efficiency of isolating different zones and allowing for a more complete wellbore evaluation. Although the desired results of efficient multiple tests was achieved, swab testing again proved inaccurate and generally prolonged testing efforts. This evaluation method showed excellent potential in wells where swab testing would be effective. Depending on the length of the lateral and the desired test information required, spacing could be lengthened or shortened. A typical test could result in 10 to 25 zone tests with good wellbore conditions. These modifications in testing methods and tools began to solve many of the problems encountered, but there still had to be a better process to meet all the objectives.

The inflatable packers overall, performed well in achieving competent hydraulic seals in the open hole. The Grayburg reservoir is a dolomite formation with good compressive strength. Some difficult hole conditions were encountered (i.e. oval hole, key seats, and washouts), however most wellbores were found to be competent, gauge and suitable for trouble free testing. Packer setting was generally reliable with few function problems and element failures were rare. Use of different setting mechanisms as well as new element technology improved tool reliability. Because packer seats cannot be pressure tested on open hole situations, a practice of picking up and slacking off 10,000 lbs was adopted to help verify solid packer seats. Fluid movement through the near-wellbore area, around the 4-foot packer elements has not been recognized as a problem.

MECHANICAL WATER SHUT-OFF COMPLETION OPTIONS

Once water entry and oil productive intervals were delineated, three basic completion designs were used to control water entry. The type *of* mechanical control device depends on where the water is found in the lateral. Water found at the toe can be controlled by an inflatable bridge plug/cement retainer. (Figure **4)** Water production found in the lateral can be controlled by a scab liner. (Figure 5) Water production found in the toe and heel of the well can be controlled by an inflatable bridge plug/cement retainer at the toe and a scab liner in the heel. (Figure 6)

TESTING OF THE JET PUMP STRADDLE PACKER METHOD

A reliable, re-settable test tool including an artificial lift method was required to determine a producing profile and make water shutoff decisions. The simplicity and reliability of a hydraulic jet pump were coupled with inflatable re-settable straddle packers. The ultimate intended use of this tool was to test open hole horizontal wells, but the initial well selected was a vertical cased hole well with multiple perforations.

The tool string was configured with three packers and a jet pump. (Figure 7) The bottom two packers isolated the test interval and the top packer isolated perforations from the produced and power fluid returns producing up the casing annulus. The jet pump is placed in the string just above the top packer. **A** remote setting head above the jet pump and inflatable packers is connected by a ¼" stainless steel inflation line, insuring that all three packers function simultaneously.

Once the tool string is made up, it is lowered to the desired set depth. The jet pump is pumped from the surface to the carrier and is seated. Continued pumping results in increased tubing pressure and is held at approximately 800 psi to inflate the packers. Simply slacking off on the work string traps inflation pressure in the elements. Continued tubing weight is applied during this test.

Power fluid rate and pressure to the jet pump are adjusted to establish drawdown and production. Power fluid along with produced fluid return to surface via the tubing-casing annulus. Both power fluid and produced fluid rates are measured with the difference equaling production rate. If no extra fluid is produced, then that zone is deemed nonproductive and the tools are moved. If the hole is full, casing volume is calculated to determine when actual bottoms up fluid can be expected at the surface. For the McElroy tests, produced fluid was calculated to reach the surface in 1.5 hours. Bottoms up fluid is not necessary on all tests to determine fluid entry and production rates, but is necessary if oil cuts are to be determined. If the produced rates are low, the perforations can be grouped in later tests to obtain good oil cut data. If the hole is empty, bottoms up fluid will be the first produced.

After testing each zone, moving tools to the next test interval required less than 30 minutes. The only difficulty encountered while restarting a test, was a loss of blanket gas in the test separator. Care should be taken to assure that all valves on the surface equipment are closed when moving tools.

The initial intent was to test the tool configuration and workability in a vertical well before running in a horizontal well. After experiencing the effective and reliable tool function, seeing the quality of the test results and the ease of obtaining them, this method *of* testing was deemed very applicable to testing vertical cased hole wells.

Acidizing during the test procedure can be done without pulling the tools. The jet pump is removed and replaced with a blanking sleeve, test zone stimulated, sleeve pulled and jet pump replaced. Spent acid is then produced and the zone re-tested.

JET PUMP DETAILS

Jet pump offers several advantages as the artificial lift means. A wide range of test rates can be achieved with one pump size. The pump size can be easily changed to match the well production and a broad range of jet pump sizes is available. The pump can be easily removed from well by reversing it out of the hole or pulling it with the sand line. Inefficiency in power fluid use is not a problem during short duration tests versus running the pump for a permanent artificial lift application. Power fluid can be oil, field water, produced water or any readily available, compatible fluid.

SURFACE EQUIPMENT

- Portable test separator for fluid handling.
- A propane tank to supply blanket gas pressure for instruments and fluid dumping on wells producing low gas volumes.
- A pump and filter with output of 1.5 bpm at 3000 psi. In this example, the available workover rig pump was used.
- Storage tanks for power fluid, produced water and produced oil.

Testing was initiated with 100 bbs of field salt water in a 500 bbl tank. Separate oil and water test tanks made measurement of produced fluid easy and accurate. Flow meters could be used, however the tanks provided simple, inexpensive and accurate results.

JET PUMP TESTING IN HORIZONTAL WELLS (Planned for February 1999)

To test in horizontal wells no modifications to the tool string are needed. (Figure 8) The lower inflatable straddle packers are spaced out with tubing and perforated pups to cover the desired test interval. Spacer pipe is attached and spaced out so the upper packer can be set at the bottom *of* the cased section of the well. **As** before, the jet pump is attached in the string just above the top packer and the remote head just above it. The remote head and all three packers are connected by ¼ stainless steel tubing again assuring that all or none of the packers is set. The stainless steel control line is placed inside the tubing in the horizontal application to guard against damage from rubbing when running into the lateral.

One potential problem with this simple tool configuration is that each time tools are moved, the jet pump is moved higher in the vertical well reducing drawdown capacity. This results in a higher chance of pumping off that test interval. If the pump were on top of the two packers comprising the straddle interval, this would not happen. With the simple system, the tool string must be pulled and the spacing between the lower straddle and upper packer reconfigured to optimize drawdown capacity.

A modified horizontal well test tool is in development utilizing an inner string hung off in a crossover head just above the upper packer and containing the jet pump positioned immediately above the test interval. Power fluid is pumped down the inner string, produced fluid and power fluid are returned up the annulus between the tubing and

!

the inner string until it reaches the crossover above the upper packer. Total fluid flows through the crossover hanger into the tubing -casing annulus and to the surface.

This system, positioning the jet pump on top of the straddle packers in the lateral (Figure 9) provides maximum draw down capability for all tests of the lateral. This method will be the primary test method in the future and both provide major cost and time savings over previous methods used.

Pending completion *of* proposed well work, results *of* the horizontal tests will be presented in April at the *SWPSC.*

CONCLUSIONS

An accurate and cost effective method to diagnose water entry in horizontal wells is necessary to verify and optimize successful well projects.

Mechanical water shut-off methods can be very effective in controlling unwanted water production in horizontal wells. Successful results can be achieved at a reasonable cost.

Inflatable packers used for selective open hole testing applications have proven reliable and effective. Improvements in inflatable element design have greatly increased their reliability in multiple set, open hole testing operations.

Jet pumps provide an artificial lift method that is flexible and effective in varying inflow rates at full drawdown conditions.

Multiple set inflatable straddle packers and jet pump tool combinations can drastically reduce testing cost and provide for a more detailed and thorough testing information in both horizontal and vertical wells.

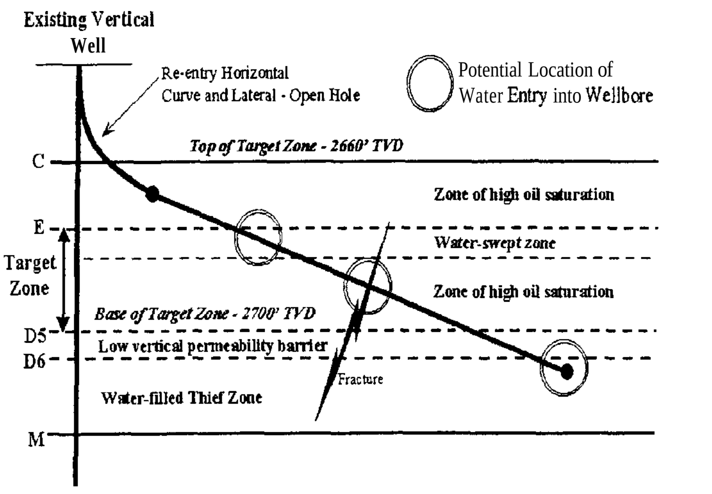


Figure 1 - McElroy Field, Typical Horizontal Well Application

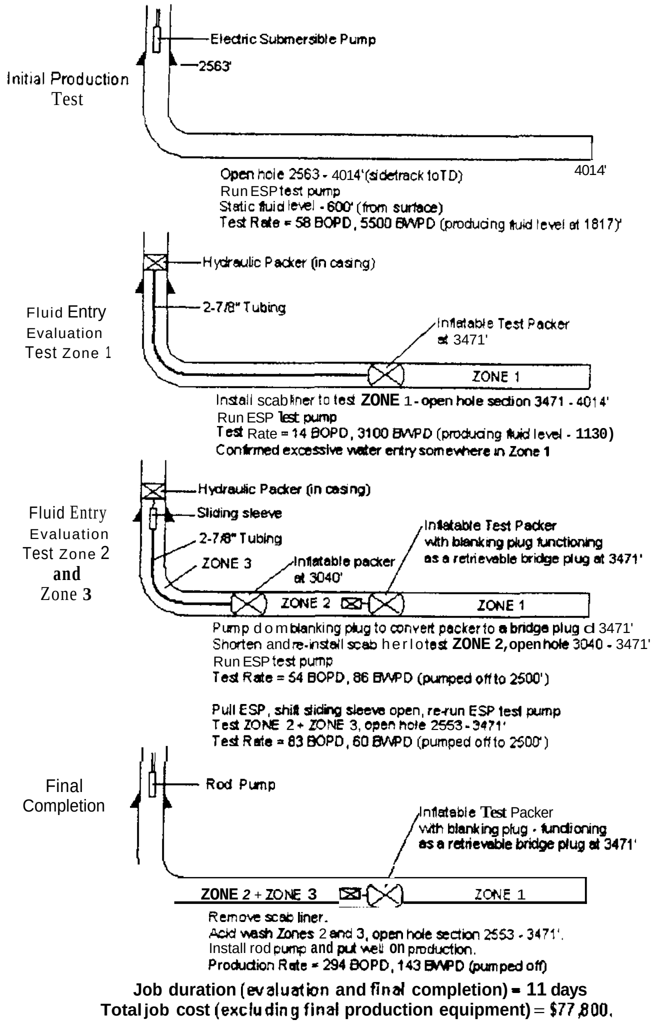


Figure 2 - McElroy Field Horizontal Well Case History No. 1, Crier Mcelroy 147, Fluid Entry Evaluation and Water Shutoff

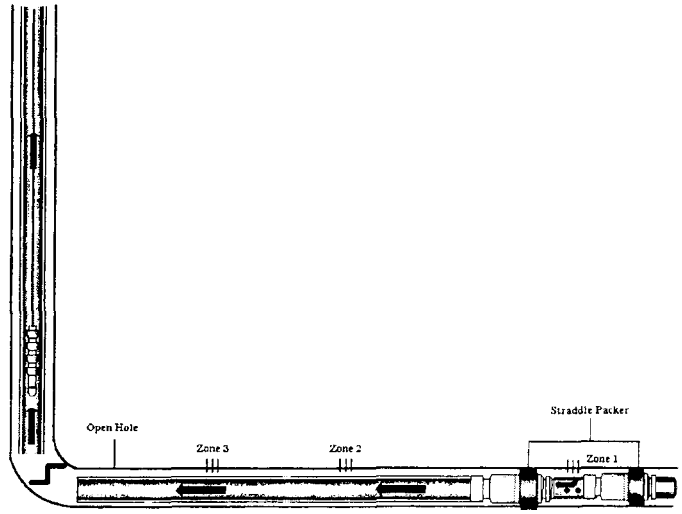


Figure 3 - Swab Testing

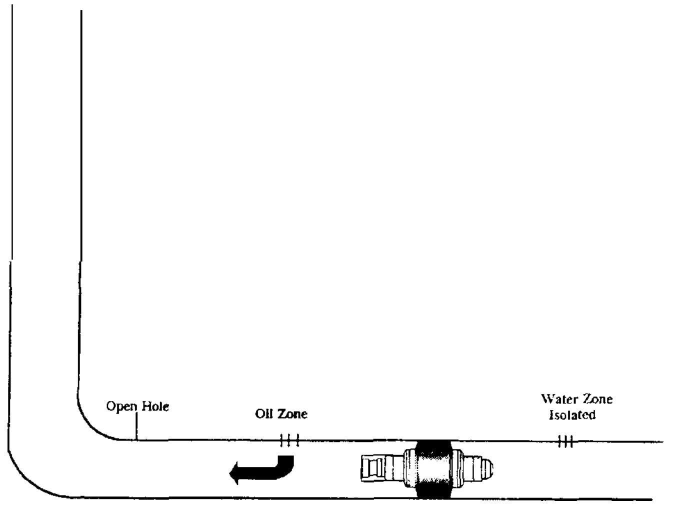


Figure 4 - Bridge Plug Isolating Water Zone in Horizontal

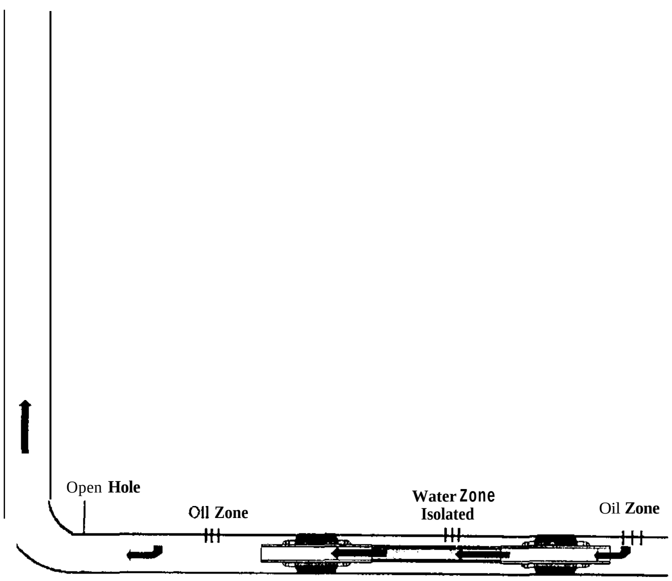


Figure 5 - Scab Liner in Horizontal Section

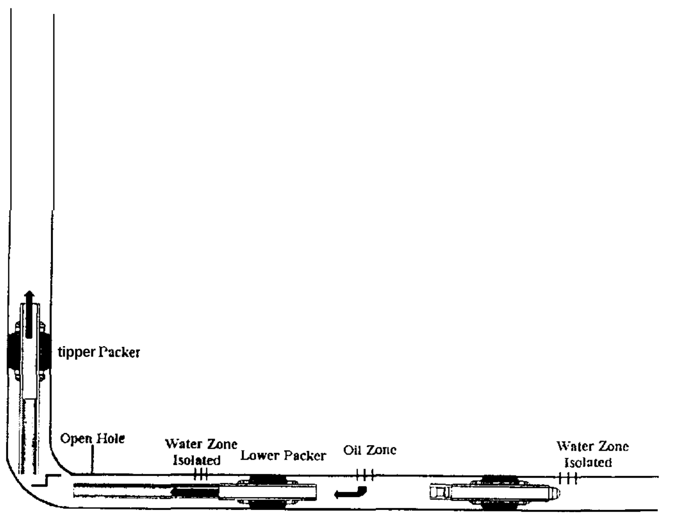
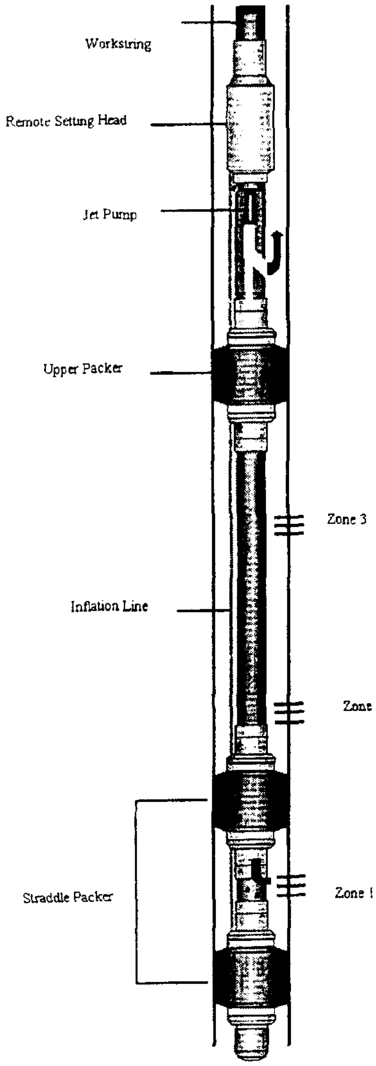


Figure 6 - Scab Liner and Bridge Plug



Seven sets of perforations were tested The top two perforations contributed 100% of the water entry with no oil cut Test results confirmed no communication between perforated intervals Full drawdown was achieved in all intervals tested Total test effort included eight separate tool sets in **2 ½** days at cost of $ 38,700.00 Early production test showed a drop from *1400 to 200* BWPD and an **increase** *from* ***6*** *to* **49** BOPD

Figure 7 - Jet Pump Testing, Vertical Well

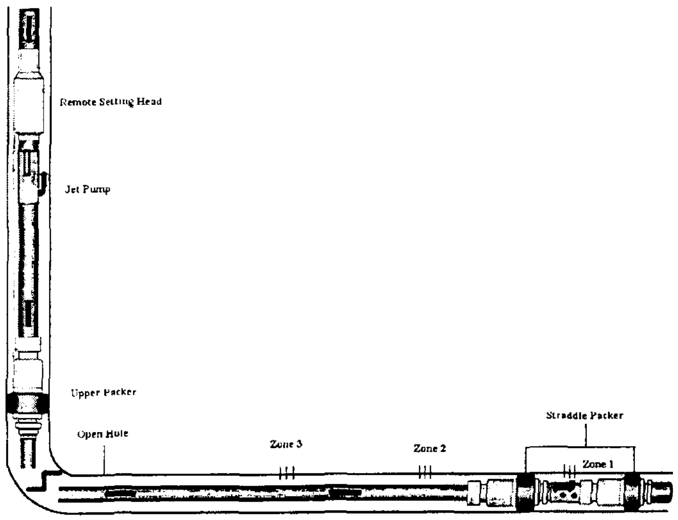


Figure 8 - Horizontal Jet Pump Testing

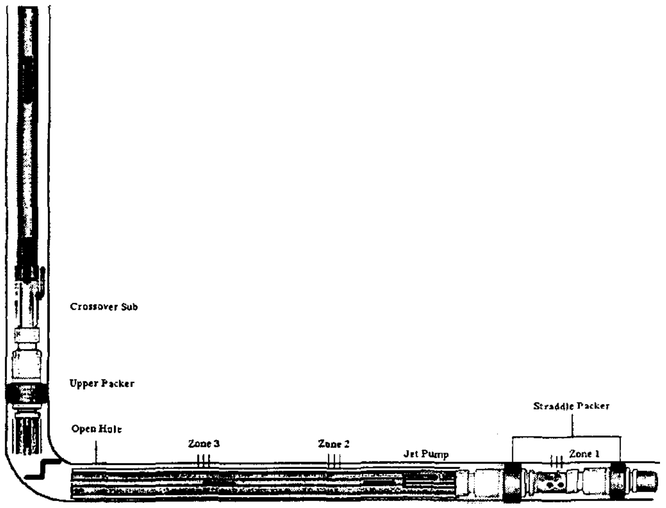


Figure 9 - Horizontal Jet Pump Testing
With Jet Pump in Lateral