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Alternate Path Gravel Packing

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ABSTRACT

A new and superior gravel packing method called ALLPAK™, for alternate path gravel packing, is reported here. It has been found that gravel packing problems associated with formation of sand bridges in the annulus outside the screen can be eliminated by adding alternate flow paths for slurry flow. The alternate paths are provided by perforated shunts or secondary piping placed in the annulus, usually by attaching the tubes to the screen. Laboratory gravel pack simulator tests indicate that essentially complete annulus packs can always be obtained, even in cases where current methods provide very poor pack efficiencies. This paper describes the laboratory experiments and field tests which verify the advantages from this new concept.

SUMMARY

A new completion method is described which solves the classical problem of sand bridging in conventional gravel packing. Provision of properly designed alternate slurry flow paths, through shunts or secondary piping placed in the annulus, eliminates almost all of the voids seen with common gravel packing procedures. The results from laboratory testing done on a 30-ft full-scale gravel pack simulator indicate 95-100% gravel pack efficiencies as compared to 65-80% obtained with conventional procedures, where both efficiencies are estimated by visual observations. In addition to providing superior gravel packs, the new method, called ALLPAK™, for alternate path gravel packing, also permits wider ranges in slurry rheology and pumping rates. Field test results from U.S. Gulf Coast offshore wells validate and extend the laboratory observations.

References and illustrations at end of paper.

INTRODUCTION

The classical problem in gravel packing occurs when premature sand bridges form in the annulus between the sand retainer screen and the casing wall, for an in-casing gravel pack, or the formation, for an open-hole gravel pack. The bridges usually form either at the top of the screen or adjacent to zones of higher permeability. Once a bridge forms, slurry flow past that point ceases, leaving an incomplete pack below the bridge.

Many mechanical variations for gravel packing apparatus have been developed or proposed for avoiding sand bridging[1-14], and a large body of literature exists reporting studies of the effects of gravel packing variables such as fluid rheology, pumping rates, sand density and concentration, etc. However, major problems still exist, especially where long intervals and/or highly deviated wells are involved.

This work describes apparatus and methodology for alternate path gravel packing which can eliminate bridging problems.[15] The key to the new approach is the addition of alternate paths for slurry flow adjacent to the screen. These could either be inside or outside the screen, although the mechanical assembly is much simpler if the alternate paths are placed in the annulus. The alternate paths consist of small separate tubes or pipes attached to the screen and perforated with small holes every few feet. Slurry can either be injected directly into the tubes, or the tubes can be left open at the top of the annulus to act only as shunts.

Currently, our preferred arrangement is the shunt configuration because this permits running screens and placing gravel packs with little change from conventional equipment and procedures. Figures 1 and 2 illustrate the concept. Ultimately, injecting the slurry directly into the tubes may prove to be the preferred arrangement because this would provide a more orderly, controllable, and predictable process.

LABORATORY TESTS

A series of tests were run on Baker Sand Control's 6.2 in. ID gravel pack simulator shown in Figures 3 and 4, using a 2 7/8" wire wrapped screen. The 18-ft perforated length simulates 12 shots/ft, with each 0.7 in. I.D perforation backed by a 2.5 in. long 0.7 in. I.D. tube packed with 20/40 mesh sand to simulate the formation.

The simulator can vary in inclination between 0 and 90°, but most of the runs were made in a horizontal position to provide the most difficult packing conditions. Pertinent results are summarized in Table 1.

The first set of experiments listed in Table 1 were the initial experiments made in an attempt to verify the alternate path concept. The base case was previously known to provide incomplete packing and was repeated here for comparison purposes. Although the shunt runs were relatively successful, the packing mechanics were haphazard with slurry running in and out of shunt holes almost at random. From this it was surmised that the shunt holes were too large and that there were too many holes.

In the second set of experiments, the goal was to investigate the use of 36# XC/1000 gal. clarified gel rather than 40# HEC/1000 gal. and to improve shunt hole designs. The two base cases were run to provide comparisons for both squeeze and circulation positions. As an afterthought, one run was made using water as a carrier fluid with approximately the same results. The use of 0.75" I.D. tubes rather than 0.824" I.D. occurred because the 0.824" tubes were not immediately available. The small size variation did not alter results in any noticeable way.

The final set of experiments were made after a field apparatus design was tentatively identified. Rectangular shunts were chosen in order to maximize the clearance in the annulus while still retaining substantial shunt tube cross sectional area for slurry delivery. The squeeze-circulation experiment was chosen as a standard in order to simulate use of a differential valve. Four shunts set at right angles were chosen to assure that two shunts would always be at the top of the apparatus. The runs with 40/60 sand were made to study the effects of settling on the packing mechanism. The smaller holes were investigated to find how small the holes can be with minimal possibility of plugging.

A separate set of tests were run where up to 300 ft long shunt tubes were laid out on pavement and slurry was injected directly into the tubes. From these tests, it was found that the XC gel and 40/60 sand can be delivered several hundred feet at shunt flow rates of less than 0.2 bbls/min.

DISCUSSION OF LABORATORY RESULTS

For every sand size, hole angle, and slurry density relative to completion fluid density, gel rheology, and shunt design, there is a minimum shunt fluid slurry velocity, and hence pumping rate, required to pack a given length of interval. For the sake of practicality, experimentation has been concentrated on finding combinations that work, rather than investigating all options.

From the first set of experiments, it was found that numerous relatively large shunt holes produce a disorderly packing mechanism. We believe that such a mechanism would fail when packing long intervals.

The second set of experiments proved the value of the shunts. With uniform leak-off from the perforations, a squeeze pack produces better results. However, in later experiments, not reported here, poor packing resulted with squeeze packs when long intervals had no perforations leak-off.

The final set of reported experiments was performed to provide data for designing field tests. The rectangular tubes were chosen strictly for mechanical design advantages. Smaller shunt holes, 36# XC/1000 gal. clarified gel, and 40/60 sand were chosen primarily as a result of the long shunt tube tests. The last laboratory tests were intended to verify the general shunt design and to investigate the effects of longer shunt hole spacing. Visually, the tests with 4 ft spacings initially appeared to have the same complete annulus packs as found with smaller spacings. However, upon back-flushing with water, some slight sand movement and voidage occurred estimated at 5%.

It is probable that all packs would be improved with higher pressure differentials. The 100 psi limit in the experimental apparatus is quite low for dehydrating a gel pack, especially with 4 ft spacing between the pressure application points provided by the shunt holes. Although the field designs have been based on the outdoor long tube experiments, an interesting and helpful phenomenon occurs inside the simulator which makes these designs quite conservative. Too many holes obviously will provide too much leak-off from the shunts and reduce shunt fluid velocities. However, as the upstream holes are covered with sand, a major amount of the flow is diverted to downstream holes, with the result that the shunts are active over a longer distance inside the casing than they are when no casing is present. The length which can be treated is unknown at present since the simulator studies are so limited in length, but should be well in excess of the 300 ft test length in the outdoor tests.

One difficulty in developing detailed design information is that determining the mix between annular flow and shunt flow is beyond current engineering theoretical prediction capabilities, especially since the mix is dependent on geology. However, this dilemma is neatly avoided by using slurries where the sand settles slowly. In that case, those periods of time when the shunt flow velocity is low do not result in shunt plugging because the sand is once again transported as soon as the shunt flow velocity recovers.

FIELD TESTS

Two U.S. Gulf Coast offshore wells were chosen for the first field tests. Each well provided a specific challenge for the new method. Well #1 was only inclined at 45° from vertical but had two productive zones separated by more than 50 feet of shale. The upper 18-ft perforated zone was much more permeable than the lower 9 ft zone, and the lower zone's estimated reserves were too small to justify a separate completion. Well #2 was inclined at 64° and had 190 feet of perforations in a 220-ft zone of highly variable quality.

The ALLPAK™ design for Well #1 included three joints of 2 3/8 inch screen with four half inch by one inch rectangular shunts attached and perforated every three feet with 3/32 inch holes. One joint of blank pipe with blank shunts was placed above the top of the screen. The connectors between individual screen joints are key elements in obtaining shunt fluid transmission continuity. Figure 5 provides an external view of the connectors. An internal O-ring assembly at each end of each connector assures a good pressure seal. Failure of a seal ends a shunt's effectiveness below that location. A connector is attached to the end of each shunt tube and the short length of shunt tube between the two end connectors allows for adjustment to slightly variable shunt and screen combinations. Additional installation time required to run an ALLPAK™ assembly has been about 15 minutes per joint. Most of the extra time is associated with making the connections.

Well #1 was initially packed at 3.5 bbls/min with 8 lbs/gal 40/60 sand, and a 40 cp, nearly Newtonian fluid. A lower tattletale and 300 psi differential valve were used. Since the packing pressure was at approximately the fracture gradient, fracturing apparently occurred and a second batch of slurry was required. The second batch was pumped at approximately 1.5 bbls/min and a 2500 psi sand-off was soon achieved. The total amount of sand placed behind the pipe was approximately 0.65 cu ft/ft of perforated interval, much above the 0.2 to 0.25 normally expected for a superior gravel pack. It is currently speculated that the shunts facilitate fracturing along the entire perforated length when the fracture gradient is exceeded. Work is underway to exploit this advantage.

Figure 6 shows a silicon activation gravel pack log for Well #1. Although a standard analysis indicates some possible small voids, this is misleading, since no known mechanism exists to provide voids at and slightly above the very top of the upper screen. The most likely situation is that the added steel of the shunt tubes and normal statistical variations in silicon activation logs account for the occasional log interpretations of deviations from 100% packing efficiency. In addition, the shunt tube stand-off from the screen is not uniform and occasionally a shunt will lie directly against the screen. This also will tend to cause variation in the silicon activation log. The vertical line on the log indicates the position of the almost certainly packed zone at the top of the screen. In all probability, the annulus was completely packed.

The apparatus design for Well #2 varied primarily in that two of the shunts had 3/32 inch holes at 5-ft intervals over the entire length and the other two had holes every 5 feet only over the bottom 100 feet of the perforated interval. Holes were offset so that at least one hole occurred every 2.5 feet across the pay zone. This design followed long tube experiments which showed that unperforated shunts provide excellent slurry transport along the unperforated length.

Well #2 was packed with the same methodology used for Well #1, except that 36 #XC/ 1000 gal. clarified gel was used as the carrier fluid. It was felt that the high inclination angle and excessive length required a longer sand settling time than was needed for Well #1. No problems were encountered either in running the screen or pumping the slurry for Well #2. One noteworthy occurrence was that approximately 10 minutes after the slurry reached the crossover, a rapid 300 psi pressure rise was observed. At that point, the pump rate was dropped to 2.25 bbls/min and the pumping pressure stabilized at approximately the initial value. Pumping continued at this rate and pressure for another 8 minutes, at which time pumping pressure began to rise again, with a high pressure (2600 psi) sand-off occurring 3 minutes later. It is speculated that the first pressure rise indicated formation of a complete annulus bridge near the top of the completion interval, and the later somewhat steady rise indicated dehydration of the pack for this relatively viscous carrier fluid.

Figure 7 shows a silicon activation gravel pack log covering the top 145 feet of the 220-ft screen. The previous comments regarding packing efficiency once again apply. The logging tool wouldn't slide below this level and was not forced lower for fear of retrieval problems. Once again, within our evaluation capability, the pack appears to be complete over the logged interval. Approximately 0.24 cu ft of sand was placed per foot of perforated interval.

Both test wells were put on production and flowed efficiently with little drawdown. As a result of these successful completions, reserves not otherwise available were added for Well #1 and the cost of breaking the zone into two completions was saved for Well #2. Following these excellent test results, the new procedure was adopted as a standard operation. Six more zones have since been completed with packing results similar to the test wells.

CONCLUSIONS

1. The ALLPAK™ gravel packing method eliminates bridges and voids which occur with current practices.

2. The prototype system has successfully packed over 200 feet of interval and is adequate for packing intervals up to 300 feet or more at any deviation angle.

3. The apparatus is compatible with current technology and can provide insurance whenever potential problems are anticipated.

4. The apparatus apparently enhances fracturing along the wellbore, raising the possibility of low rate fracturing over extended vertical intervals. This would provide superior productivity over longer completion lifetimes.

ACKNOWLEDGMENTS

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REFERENCES

1. Cornett, H. M., and Weingarten, J. M.: "Gravel Pack Well Completions," U.S. Patent No. 4,995,456, c. 2/26/91, f. 5/4/90.

2. Dickinson, W., Anderson, R. R., and Dykstra, H.: "Gravel Packing of Horizontal Wells," SPE 16931, 1987.

3. Donovan, J. F., et al: "Method and Apparatus for Completing a Non-Vertical Portion of a Subterranean Well Bore," U.S. Patent No. 4,856,591, c. 8/15/89, f. 3/23/88.

4. Forrest, J. K.: "Horizontal Gravel Packing Studies in a Full-Scale Model Wellbore," Paper SPE 20681, presented at the 1990 SPE Annual Technical Conference and Exhibition, New Orleans, September 23-26.

5. Gruesbeck, C., Salathiel, W. M., and Echols. E. E.: "Design of Gravel Packs in Deviated Wellbores," JPT, January 1979, pp. 109-115.

6. Huang, Wann-Sheng, and Brown, A.: "Method for Forming a Gravel Packed Horizontal Well," U.S. Patent No. 4,553,595, c. 11/19/85, f. 6/1/84.

7. Huang, Wann-Sheng, and Brown, A.: "Method and Apparatus for Gravel Packing Horizontal Wells," U.S. Patent No. 4,558,742, c. 12/17/85, f. 7/13/84.

8. Hudson, T. E., and Martin, J. W.: "Use of Low-Density, Gravel-Pack Material Improves Placement Efficiency (Part 2)," SPE 18227, 1988.

9. Ilfrey, W. T., et al.: "Gravel Packing Apparatus and Method," U.S. Patent No. 4,858,691, c.8/22/89, f. 6/13/88.

10. Maly, G. P., and Laurie, A. M.: "Gravel-Packing Tool Assembly," U.S. Patent No. 4,192,375, c. 3/11/80, f. 12/11/78.

11. Maly, G. P., Robinson, J. P., and Laurie, A. M.: "New Gravel Pack Tool for Improving Pack Placement," JPT, January 1974, pp. 19-24.

12. Nini, C. J., and Owen, G. W.: "Successful High-Angle Gravel Packing Techniques," SPE 12105, 1983.

13. Solum, J. R.: "A New Technique in Sand Control Using Liner Vibration With Gravel Packing," SPE 12479, 1984.

14. Zaleski, Jr., T. E.: "Innovations in Completion Technology for Horizontal Wells," Offshore, February 1989, pp. 34-37.

15. Jones, L. G., "Method for Gravel Packing Wells," U.S. Patent No. 4,945,991, c. 8/7/90, f. 8/23/89.

TABLE 1

Summary of ALLPAK™ Testing on Gravel Pack Simulator

Test	No. of Shunts (-)	Comments	Pack Type (-)	Shunt Size (in)	Hole Size (in)	Hole Density	Pack Efficiency (-)
1	0	w	circulation				75
2	2	w	circulation	0.824	3/16	2 per 1'	90
3	2	w	squeeze	0.824	3/16	2 per 1'	100
4	0	x	circulation				80
5	0		squeeze				70
6	2		circulation	0.75	1/8	1 per 1'	90
7	2		squeeze	0.75	1/8	1 per 1'	100
8	2	w	circulation	0.824	1/8	1 per 2'	95
9	2	x	circulation	0.824	1/8	1 per 2'	95
10	2	y	circulation	0.824	1/8	1 per 2'	95
11	0	z	sque-circ				65
12	4		circulation	1X0.5	3/32	1 per 2'	95
13	4		circulation	1X0.5	3/32	1 per 2'	98
14	4		sque-circ	1X0.5	3/32	1 per 2'	98
15	4	x,z	sque-circ	1X0.5	3/32	1 per 2'	99
16	4	z	circulation	1X0.5	1/16	1 per 4'	95
17	4	z	sque-circ	1X0.5	1/16	1 per 4'	95

Comments:
w - Run with 40#/1000 gal HEC gel
x - Run repeated with same result
y - Run with water and 4#/gal sand concentration
z - Run with 40/60 sand

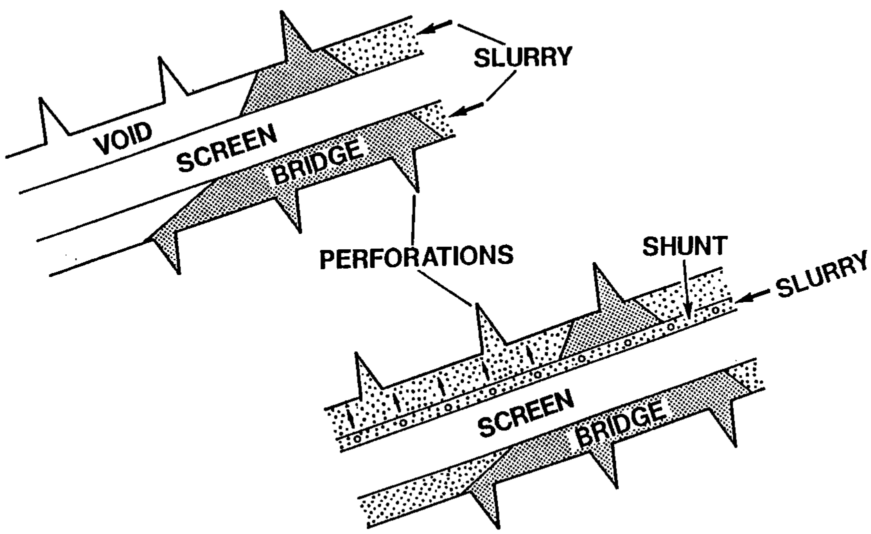

Figure 1 ALLPAK™ (Alternate Path Gravel Pack) Mechanism

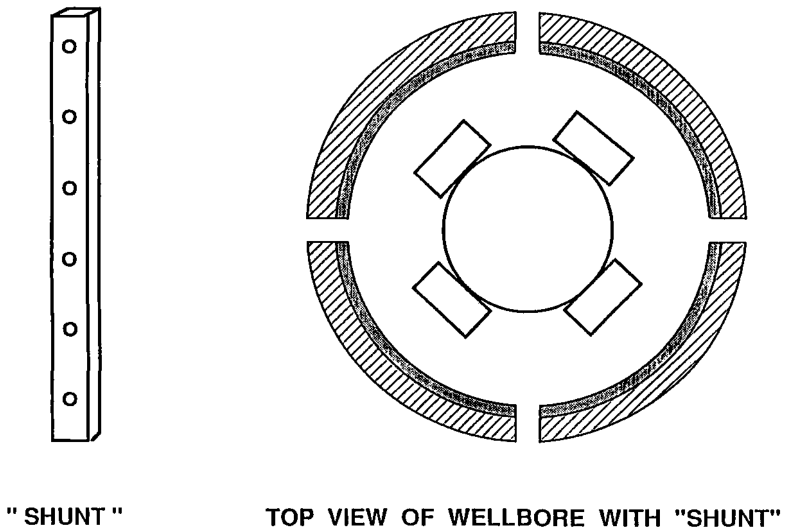

Figure 2 Schematic of ALLPAK™ Assembly

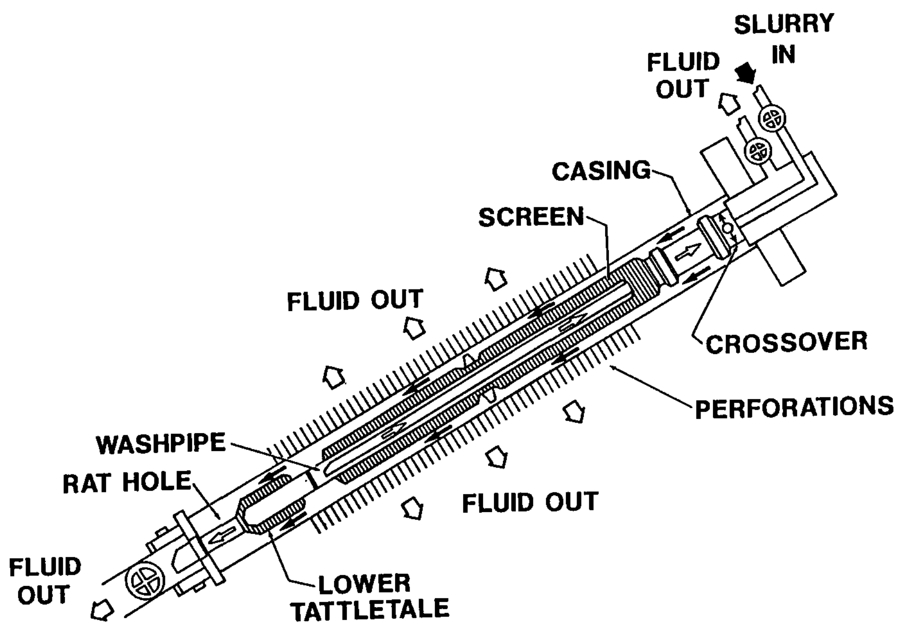

Figure 3 Schematic of Gravel Pack Simulator

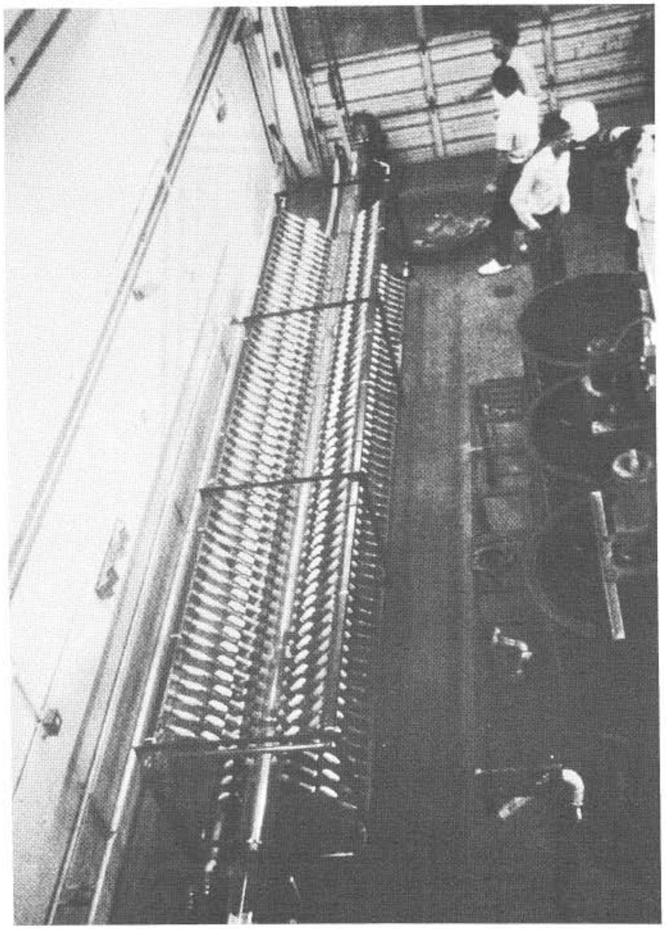

Figure 4 Gravel Pack Simulator

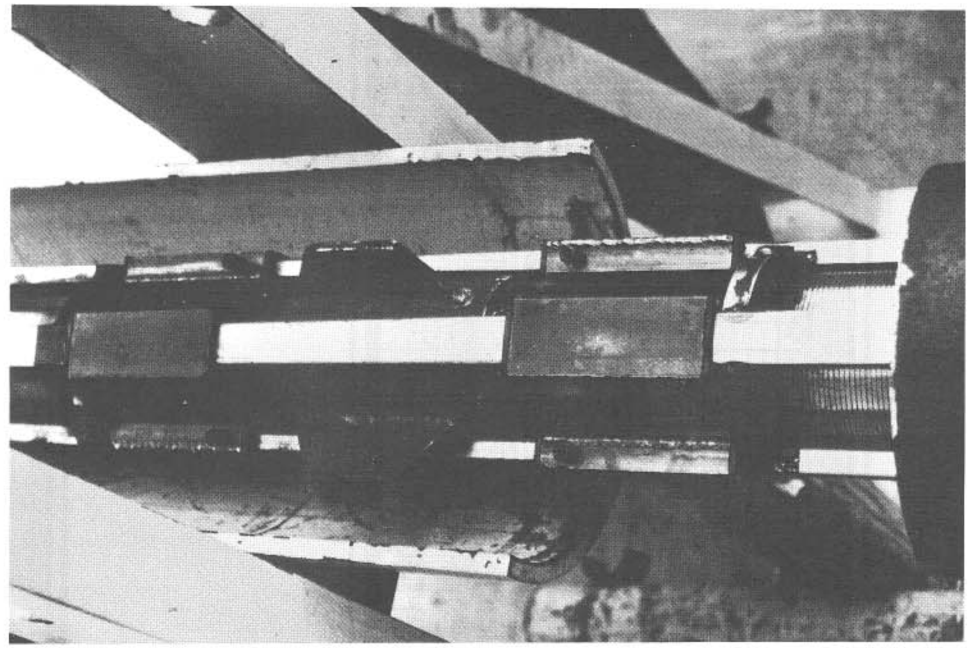

Figure 5 Field Type Shunt Connectors

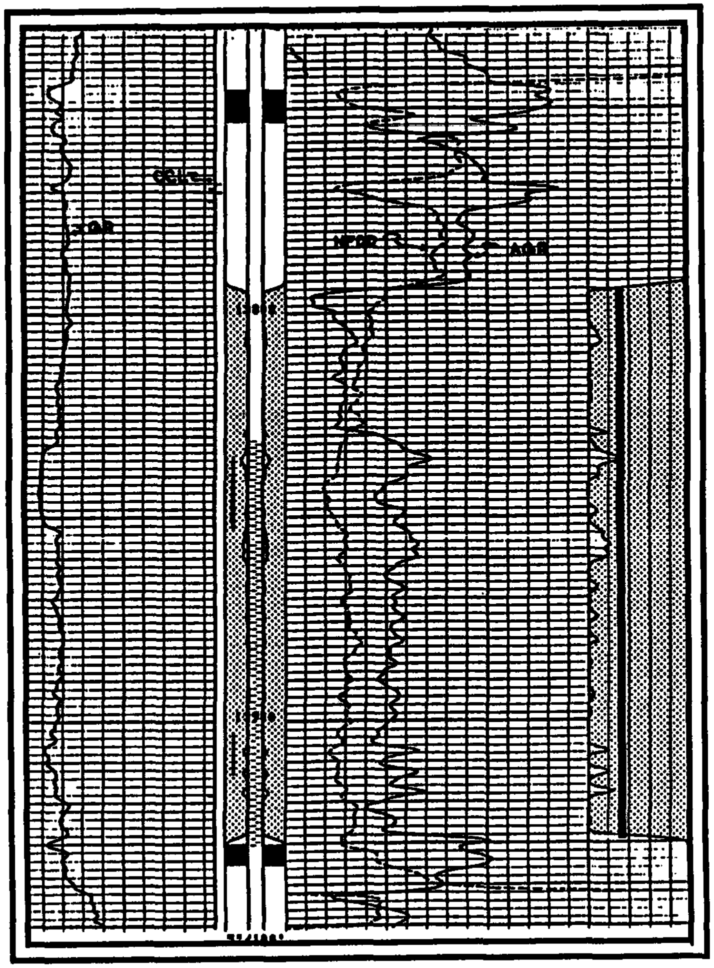

Figure 6 Well #1 with ALLPAK™

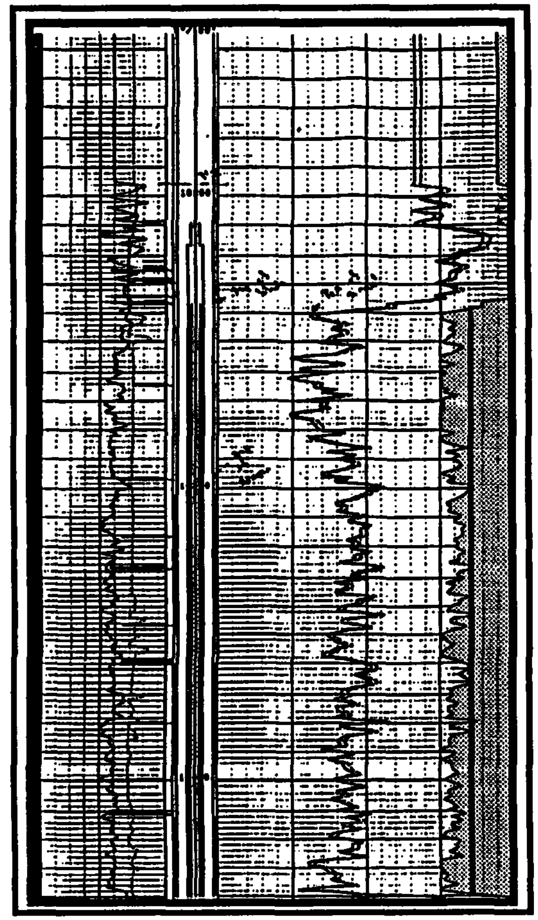

Figure 7 Well #2 with ALLPAK™