

# Completion and Production Results From Alternate-Path Gravel-Packed Wells

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## Summary

A successful gravel pack requires two things: perforations packed with gravel-pack sand and a completely packed annulus. Failure to obtain either one can result in low productivity and/or a sand-producing gravel pack. Alternate-path gravel packing ensures that the annulus will be completely packed and that all perforations taking fluid will be packed with gravel-pack sand. Alternate-path gravel packing has provided long and highly productive completions without any sand production.

This paper presents completion data and production results from 39 wells completed with the alternate-path gravel-pack technique. The completion data include completion length, net perforations, carrier fluid, sand placement outside casing, workover fluid, and return rate during packing. Production results include qualitative discussion of all completions with quantitative results, including permeability-thickness product and skin on select completions.

## Introduction

By the end of 1992, ALLPAK<sup>SM</sup> (alternate-path gravel packing) completion technology<sup>1,2</sup> had been used in 43 completions. Included are an oil well reportedly tested at more than 40,000 BOPD by Statoil in offshore Norway, and a gas well tested at more than 70 MMcf/D by Mobil in the Gulf of Mexico. Experience with the new technology is related along with a description of insights and modifications growing out of these applications.

Alternate-path gravel packing uses bypass tubes, or shunts, attached to the screen. The shunts are perforated with small holes at various locations along the screen (Fig. 1). Although slurry can be injected directly into the bypass tubes, the preferred approach has been to leave the tubes open at the top of the annulus to act only as shunts. In a normal gravel-packing operation, the shunts have little impact until a sand bridge forms in the annulus. Then the shunts activate, carrying the slurry through that bridge and any others that subsequently form, ultimately completing the pack (Fig. 1). High well productivity and longevity result from the efficient placement of pack sand in the perforation tunnels accompanied by complete annulus packs.

In laboratory gravel-pack simulator experiments, the shunts have been shown to improve packs with all currently used carrier fluids, including water. Logic suggests that the best results should be obtained with high-quality gels. Because no special pumping requirements have been delineated, many different pumping procedures and carrier fluids have been used in field applications, which are described later.

The ability to pack extremely long pay intervals, highly deviated wellbores, and/or separate pay zones of highly variable permeability provides new engineering opportunities and challenges. Production at higher rates from fewer wells can be considered. Simultaneous production from multiple zones is feasible, with possible wireline water shutoff in selected zones. Separate prepacking operations are probably no longer required, and the need for perforations washing can be re-examined.

The packing operation itself can be changed to use the advantages offered by the shunts better. Squeeze packing or severely restricting returns no longer risks incomplete packs resulting from bridging and appears to be a preferred procedure. High-pressure pumping

with the shunts in place appears to enhance the probabilities for frac-packing as long as the screen/washpipe annulus is small enough to limit flow through that path.

## Gravel-Packing Mechanisms

Optimum uses of alternate-path gravel packing ultimately require a thorough knowledge of the various flow mechanisms provided by the shunts. Sand transport is dominated by one of the following mechanisms<sup>3-12</sup>: (1) viscous fluid flow, as in packing with a carrier fluid like xanthan (XC) gel, where the sand does not settle and is carried to and deposited at locations where fluid exits from the casing/screen annulus; (2) velocity and gravity, as in packing with water, where sand is transported downward by gravity and laterally by turbulent fluid flow; or (3) some combination of these two mechanisms.

**Packing With Viscous Fluids.** In packing with viscous carrier fluids, the pack forms outward from the screen as the carrier fluid exits through the screen into the screen/washpipe annulus and inward from nodes that form in and around each perforation that takes fluid. At a high-leakoff location without the shunts, these accumulations will eventually join to form a complete bridge in the casing/screen annulus, preventing further slurry flow to any point below the bridge. The incomplete pack below the bridge remains until a repair process or gravity causes the gravel in the annulus to move down and fill the void. Regardless of how the annular void is eliminated, the perforations in that area are not packed with gravel-pack sand. In a circulation mode, the pack above the bridge is completed as gel leaks off through the screen and flows through the screen/washpipe annulus and the open casing/screen annulus below the bridge to the washpipe entrance or into the perforations taking fluid in or below the bridge. In a squeeze mode, the pack above the bridge is completed as gel leaks off through the screen and flows through the screen/washpipe annulus to any perforations taking fluid. In either case, when the pack reaches the top of the screen, the fluid-leak-off path through the screen is no longer available and a high-pressure sandout occurs.

Obviously, the leakoff paths provided by perforations can have a high flow resistance, and the perforations may be poorly packed unless low-flow-resistance leakoff paths, such as the washpipe, are closed. Consequently, without shunts, the circulation mode normally produces better annulus packs, and the squeeze mode packs the perforations better. Prepacking offers the chance to gain the advantages of both packing modes but at the expense and inconvenience of adding another operational step without guaranteed elimination of voids.

When a shunt or shunts are present, the higher packing pressure that occurs above a newly formed bridge activates one or more shunts. Slurry then preferentially flows through the shunts. When the slurry reaches the open-shunt portholes, it exits back into the casing/screen annulus and packing below the bridge continues much as before (Fig. 1). Most shunts are designed with very small holes so that slurry will exit from 10 to 40 holes simultaneously. Whenever a pack forms in the annulus over one or more shunt holes, the small size of the holes restricts leakoff to such a negligible amount that the slurry is diverted to uncovered shunt holes farther downstream. Fig. 1 illustrates the various flow paths available to the slurry and carrier fluids when shunts are used.

Premature internal plugging of the shunts has not been a problem with gels in field applications to date. The shunts normally pack off at high pressures from the bottom up after the annulus is completely packed. The packoff usually occurs below 0.25 bbl/min. However, laboratory studies have shown that premature plugging can occur

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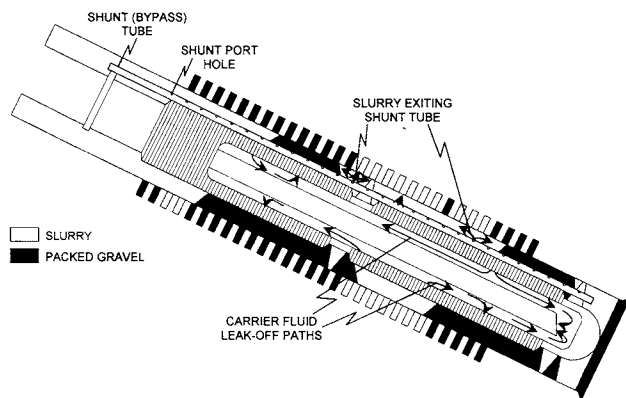


Fig. 1—Gravel-pack mechanisms with shunt bypass tubes.

inside the shunts if the exit ports are too large and allow too much leakoff or if too much packing takes place through a short section of a shunt. Excessive packing through a short shunt section can occur if there is no pack buildup adjacent to that section because of limited leakoff from the annulus. The shunt ports can be eroded to a much larger size, destroying the effectiveness of the shunt and eventually allowing internal bridge formation. Internal bridges can also form because of a natural separation process that occurs inside a shunt, where a certain fraction of the sand particles bypasses the small shunt holes while the gel exits. Eventually the slurry becomes too concentrated to pump through the shunt. Both premature shunt-plugging mechanisms can be eliminated with modest mechanical improvements, but they have not been considered necessary yet.

Because prematurely formed bridges in the casing/screen annulus are bypassed by slurry flow through the shunts, holding back pressure in a squeeze mode or limiting returns during packing is no longer counterproductive to annular pack quality. In fact, limiting returns is the preferred procedure because it eliminates the need for a separate prepacking operation. However, to take full advantage of this potential, it is necessary to recognize that complete annulus packing with shunts requires only modest leakoff capacity. Gel leaked off by packing associated with any shunt port can flow through the screen/washpipe annulus either down or up to any location where leakoff at a lower pressure occurs. To obtain high localized pressures for packing low-permeability perforations or for frac-packing, it is necessary either to use a small screen/washpipe annulus or to limit leakoff through the packed perforations. Because the latter can be counterproductive, the use of a small screen/washpipe annulus seems to be preferred. If frac-packing is desired, more viscous carrier fluids provide obvious advantages.

**Packing With Low-Viscosity Fluids.** When compared with gel slurry packing, packing with water or other low-viscosity carrier fluids provides both advantages and disadvantages. In a nearly vertical hole, the sand is carried downward both by fluid movement and by gravity, and the pack builds upward from the bottom of the hole. Regardless of the completion length, the annulus will usually be packed completely provided there is no high-permeability stringer at the top of the perforations. There may be enough leakoff into each perforation to provide sufficient velocity for packing perforations if only a few perforations are present. As the number of perforations increases, the amount of fluid available for leakoff into each perforation is reduced, and perforation packing efficiency declines. Field studies that graphically illustrate this situation have been presented.<sup>12,13</sup>

As hole deviation increases, there are marked tendencies for gravity to enhance packing of low-side perforations and for high-side perforations to remain open and capable of taking excessive quantities of fluid. Nonetheless, annulus packing will usually be complete until the hole angle reaches about 60°. At hole angles above 60°, a settled bed forms along the bottom of the casing and sand is carried toward the bottom of the hole by turbulent flow in a channel along the top of the sand bed. The thickness of the sand bed at any location depends on the amount of carrier fluid flowing through the annulus

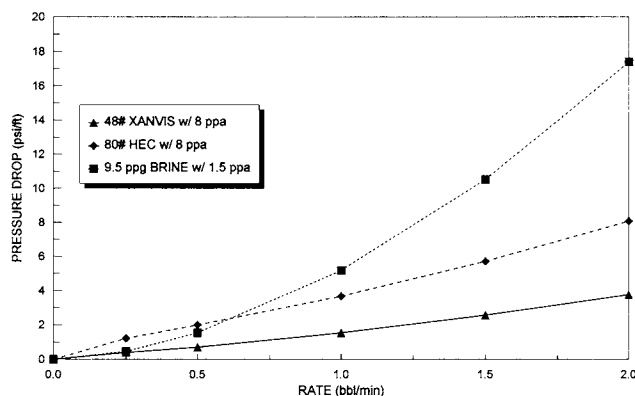


Fig. 2—Pressure drop as a function of slurry rate through a single shunt tube with three different slurries.

at that point. As carrier fluid is lost to the formation and to the screen/washpipe annulus, the sand bed becomes thicker. The pack will continue to build toward the bottom of the hole as long as enough fluid is available to maintain the critical carrying velocity along a narrow channel at the top of the bed. At the location along the completion where leakoff has taken too much carrier fluid, the sand bed reaches the upper casing wall and a bridge forms. The pack above this location is completed as sand is deposited along the upper channel and the associated carrier fluid exits through the pack into the screen/washpipe annulus.

The length of a more or less horizontal completion that can be packed with a low-viscosity carrier fluid therefore primarily depends on leakoff. If no leakoff is present, the distance appears essentially infinite. If leakoff is high, the distance can be very short, on the order of a few tens of feet. The screen/washpipe annulus can be kept small enough to limit flow and leakoff into the screen/washpipe annulus. But, a large number of perforations into a highly permeable formation will take enough fluid to limit pack length severely unless perforation leakoff is controlled. The pack length can be extended by using low sand concentrations, which has become common practice. The low sand concentration provides extra fluid for leakoff, preventing the critical velocity from being reached in the upper channel.

Shunts can be used to extend pack length and efficiency for low-viscosity carriers as well as for gels. Packing improvements will always be obtained with the shunts. However, there are some noteworthy differences. Any shunt with its entrance buried in a sand bed becomes inoperative, and this fact must be considered when designing the shunt arrangements. In a truly horizontal hole, the amount of sand entering a high-side shunt is negligible, but shunts located on the low side may take enough sand to form a bridge near their entrances. A simple rupture disk arrangement would eliminate this possibility but has not been used as yet. Leakoff from shunt port-holes to a packed annulus is considerably greater with low-viscosity fluids and limits the number of possibly effective shunt holes. It is much more difficult for the sand to exit upward from a shunt with low-viscosity carriers, which increases the likelihood of internal bridging in the top-side shunts if the shunt holes are in the top shunt wall. Therefore, shunt holes are better placed in the sides of the shunts for horizontal wellbores, raising the possibility that a carelessly drilled shunt hole might direct the slurry against the screen, which could erode the screen. The result of these differences is that optimum shunt designs are different for low-viscosity carriers. The total interval length that can be packed with a low-viscosity carrier fluid with shunts is greater than that without shunts but less than that with shunts and gel carriers.

In addition to the different mechanisms, the rheology plays a large part in the performance of the shunt tube. As Fig. 2 shows, the pressure drop through a single tube at 0.75 bbl/min for low-viscosity carrier fluid is greater than that of hydroxyethylcellulose (HEC) or clarified xanthan gum (XANVIS™). The greater the rate through the tube, the greater the pressure-loss differences between low-viscosity and gelled carrier fluids. Based on the previous discussion, all

TABLE 1—ALLPAK COMPLETIONS

| Completion       | Screen Length (ft) | Net Perforations (ft) | Average Angle (degree) | Gravel Outside Casing (ft <sup>3</sup> /ft) | Workover Fluid Density (lbm/gal) | Gravel Size | Carrier Fluid | Returns (%) | Number of Tubes | Allpak Design | Hole Spacing (ft) |
|------------------|--------------------|-----------------------|------------------------|---------------------------------------------|----------------------------------|-------------|---------------|-------------|-----------------|---------------|-------------------|
| 1                | 236                | 194                   | 60                     | 0.24                                        | 14.3                             | 40/60       | Xanvis        | 10          | 4               | Dual          | 4                 |
| 2                | 100                | 27                    | 46                     | 0.65                                        | 16.2                             | 40/60       | 14.5 HP       | 36          | 4               | Single        | 3                 |
| 3                | 257                | 62                    | 28                     | 0.10                                        | 15.9                             | 40/60       | Xanvis        | 54          | 4               | Dual          | 4                 |
| 4                | 109                | 83                    | 62                     | 0.17                                        | 10.0                             | 40/60       | Permpac       | ?           | 4               | Single        | 4                 |
| 5                | 109                | 83                    | 62                     | 0.17                                        | 10.0                             | 40/60       | Permpac       | 0           | 4               | Single        | 4                 |
| 6                | 182                | 172                   | 45                     | 0.08                                        | 9.3                              | 40/60       | Xanvis        | 87          | 4               | Dual          | 5                 |
| 7                | 32                 | 22                    | 43                     | 0.22                                        | 9.3                              | 40/60       | Xanvis        | 85          | 4               | Single        | 3                 |
| 8                | 101                | 44                    | 6                      | 1.52                                        | 16.2                             | 40/60       | 14.7 HEC      | ?           | 4               | Single        | 4                 |
| 9                | 53                 | 30                    | 8                      | 1.27                                        | 16.2                             | 40/60       | Permpac       | ?           | 4               | Single        | 3                 |
| 10               | 77                 | 62                    | 16                     | 0.25                                        | 9.4                              | 40/60       | Xanvis        | 55          | 4               | Single        | 4                 |
| 11               | 188                | 115                   | 3                      | 0.14                                        | 9.4                              | 40/60       | Xanvis        | 50          | 4               | Dual          | 4                 |
| 12               | 42                 | 20                    | 0                      | 0.38                                        | 8.7                              | 40/60       | Xanvis        | 44          | 4               | Single        | 3                 |
| 13               | 57                 | 32                    | 46                     | 0.18                                        | 9.5                              | 40/60       | Permpac       | 0           | 2               | Single        | 3                 |
| 14               | 55                 | 25                    | 46                     | 0.16                                        | 9.5                              | 40/60       | Permpac       | 0           | 2               | Single        | 3                 |
| 15               | 55                 | 30                    | 46                     | 0.22                                        | 9.5                              | 40/60       | Permpac       | 0           | 2               | Single        | 3                 |
| 16               | 87                 | 49                    | 46                     | 0.24                                        | 9.5                              | 40/60       | Permpac       | 40          | 2               | Single        | 3                 |
| I 17             | 58                 | 50                    | 28                     | 0.40                                        | 11.6                             | 50/70       | Permpac       | 5           | 4               | Single        | 3                 |
| N 18             | 58                 | 48                    | 28                     | 1.21                                        | 11.0                             | 50/70       | Permpac       | 35          | 4               | Single        | 3                 |
| N 19             | 81                 | 64                    | 30                     | 0.56                                        | 13.3                             | 50/70       | Permpac       | 25          | 3               | Single        | 3                 |
| N 20             | 63                 | 33                    | 20                     | 0.34                                        | 8.8                              | 40/60       | Xanvis        | 35          | 4               | Single        | 3                 |
| N 21             | 57                 | 36                    | 38                     | 0.25                                        | 8.6                              | 50/70       | Permpac       | 20          | 4               | Single        | 3                 |
| 22               | 27                 | 14                    | 38                     | 0.37                                        | 9.5                              | 50/70       | Permpac       | 40          | 4               | Single        | 3                 |
| 23               | 61                 | 50                    | 21                     | 0.20                                        | 12.9                             | 40/60       | Xanvis        | 25          | 2               | Single        | 3                 |
| 24               | 58                 | 40                    | 20                     | 0.38                                        | 16.0                             | 40/60       | Xanvis        | 25          | 2               | Single        | 3                 |
| 25               | 107                | 90                    | 2                      | 0.21                                        | 14.7                             | 40/60       | 11.0 HEC      | 0           | 1               | Single        | 4                 |
| N 26             | 106                | 86                    | 3                      | 0.02                                        | 8.5                              | 40/60       | 8.4 HEC       | 0           | 3               | Single        | 4                 |
| 27               | 30                 | 19                    | 41                     | 0.61                                        | 9.3                              | 40/60       | Permpac       | 0           | 3               | Single        | 3                 |
| 28               | 53                 | 31                    | 41                     | 0.81                                        | 9.8                              | 40/60       | Permpac       | 0           | 3               | Single        | 3                 |
| 29               | 68                 | 52                    | 21                     | 0.07                                        | 13.3                             | 40/60       | 8.4 HEC       | 0           | 1               | Single        | 3                 |
| 30               | 68                 | 52                    | 21                     | 0.44                                        | 13.3                             | 40/60       | 8.4 HEC       | 0           | 1               | Single        | 3                 |
| 31               | 36                 | 20                    | 20                     | 0.78                                        | 9.5                              | 40/60       | 8.4 HEC       | 0           | 1               | Single        | 2                 |
| 32               | 115                | 99                    | 26                     | 0.23                                        | 12.9                             | 40/60       | 8.4 HEC       | 0           | 1               | Single        | 4                 |
| 33               | 42                 | 27                    | 30                     | 0.41                                        | 9.6                              | 40/60       | 8.4 HEC       | 0           | 1               | Single        | 3                 |
| NI 34            | 109                | 94                    | 19                     | 0.71                                        | 14.5                             | 40/60       | 8.4 HEC       | 0           | 4               | Single        | 4                 |
| 35               | 38                 | 20                    | 44                     | 0.97                                        | 10.9                             | 40/60       | Xanvis        | 0           | 2               | Single        | 2                 |
| 36               | 246                | 210                   | 54                     | 0.20                                        | 10.9                             | 40/60       | Xanvis        | 25          | 3               | Single        | 4                 |
| 37               | 259                | 252                   | 36                     | 0.01                                        | 11.4                             | 40/60       | Xanvis        | 25          | 1               | Single        | 4                 |
| N 38             | 90                 | 72                    | 46                     | 0.37                                        | 16.5                             | 50/70       | 8.4 HEC       | 0           | 2               | Single        | 3                 |
| N 39             | 176                | 160                   | 2                      | 0.74                                        | 14.0                             | 50/70       | 11.0 HEC      | 5           | 3               | Single        | 4                 |
| Average          |                    |                       |                        | 0.42                                        |                                  |             |               |             |                 |               |                   |
| Weighted Average |                    |                       |                        | 0.32                                        |                                  |             |               |             |                 |               |                   |

N—Perforations were not washed.

I—Injected directly into the shunt tubes.

Mobil's ALLPAK completions have been done with gelled carrier fluid.

### Completion Data

**Table 1** gives available completion data as of early 1993. In addition to these, Statoil has reportedly used alternate-path technology for gravel-pack lengths of up to 480 ft and at deviation angles up to 75°. Gravel-pack logs were run on seven of the completions reported here. All indicated complete annulus packs. Considering the exceptional ability of the shunts to pack the annulus, this result was expected. Today, gravel-pack logs are run only if the volumetric calculations indicate insufficient sand to fill the annulus. All the ALLPAK completions are producing sand-free.

The average of 0.42 ft<sup>3</sup>/ft and a weighted average of 0.32 ft<sup>3</sup>/ft of gravel placed outside the casing are comparatively good (**Fig. 3**). Historically, Mobil has placed an average of about 0.10 to 0.15 ft<sup>3</sup> of gravel/ft of perforated interval using similar packing techniques without shunts. Placement volumes of greater than 0.5 ft<sup>3</sup>/ft are believed to have resulted from the development of small fractures.

Reasons for low placement are not fully understood. They could be the result of very poor formation leakoff, as in Completion 6; extremely high formation leakoff over a small portion of the perforated interval, as in Completion 26; or a small volume outside the casing that is filled with gravel, as in Completion 37. As with all the completions in Table 1, these completions performed equal to or greater than the rate calculated by system analysis. Also, there are no reports of productivity decline with age for the ALLPAK completions. Because of the excellent productivity results obtained with ALLPAK, there is a reluctance to accept the expense and trouble associated with taking the downhole measurements required to determine permeability thickness and skin in a substantial number of wells.

Early completions were done with a tell-tale screen with a differential valve to move into the upper circulating position to finish the annulus pack. When it was recognized that any bridges that formed prematurely were easily bypassed with the shunts, backpressure was applied to restrict returns in an attempt to obtain more sand outside the casing. **Fig. 4** shows the pump pressure, rate in, and rate out

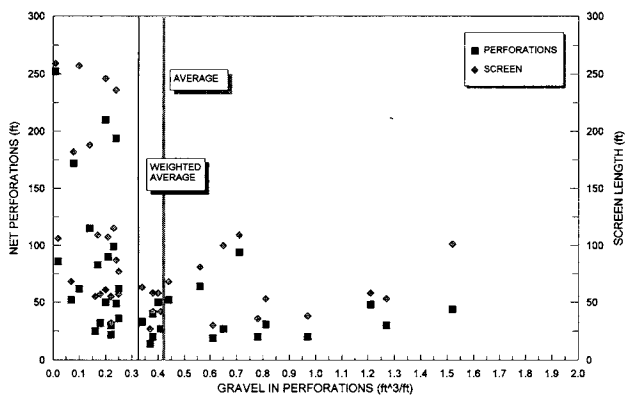


**Fig. 3—Gravel in perforations as a function of the net perforations and screen length.**

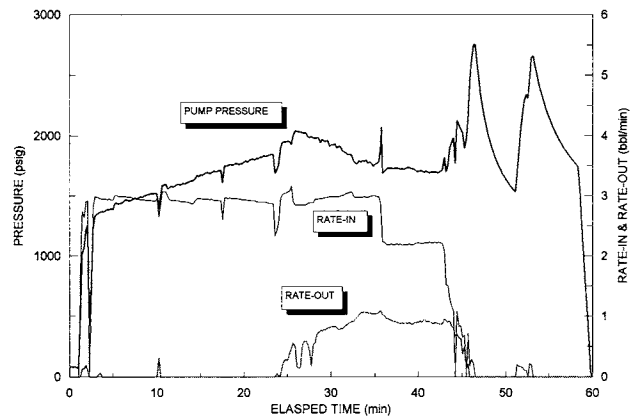


**Fig. 4—Pump pressure, rate in, and rate out as functions of time for Completion 1.**

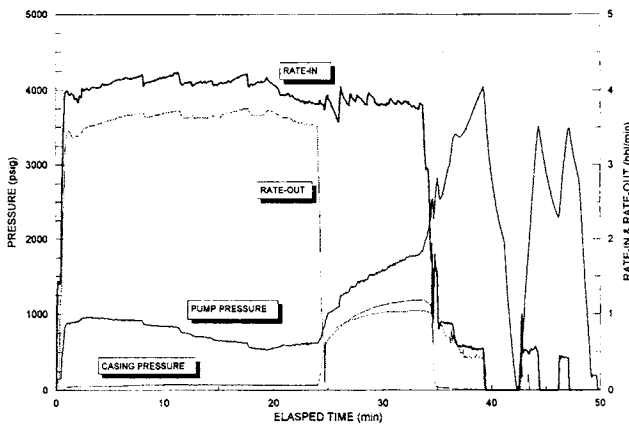


**Fig. 5—Casing pressure, pump pressure, rate in, and rate out as functions of time for Completion 36.**

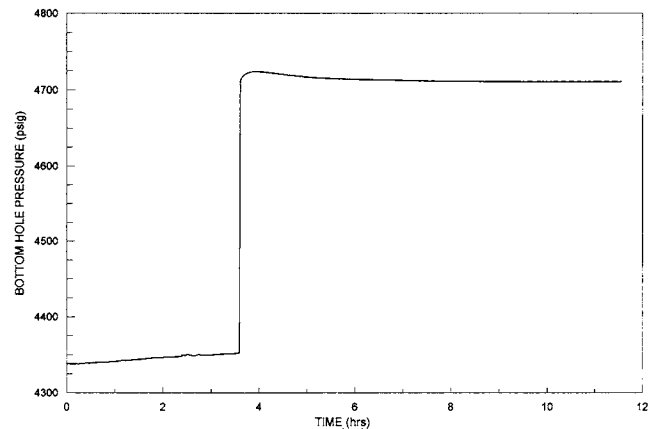


**Fig. 6—BHP data for commingled Completions 35 and 36.**

as a function of time for Completion 1. The sharp pressure increases at 35 minutes indicate the formation of a bridge in the screen/casing annulus. The rate was decreased from 3 to 2.25 bbl/min, and the job continued for another 10 minutes. Similar behavior, although not as pronounced, has been seen on other ALLPAK completions. Placement results appeared to become more consistent with the restricted-returns' approach, and the tell-tale screen was dropped.

An attempt was made to frac-pack Completion 29. However, because of a poor fracture design, high leakoff beyond the damaged zone, and high pump pressures, the fracture sanded off early and the blank pipe collapsed. Completion 29 was successfully washed over and fished. Completion 30 was a repeat of Completion 29, but stronger blank pipe and a better fracture design were used. When enough leakoff was developed by the fracture to handle a leakoff rate of 8 bbl/min, the annulus packed off instead of continuing fracturing. Use of a very large washpipe to restrict flow severely in the screen/washpipe annulus might have produced better fracturing results.

The fifth completion was a repeat of the fourth. A packer failure required pulling Completion 4 from the hole. The well was then recompleted with the same procedure, and the sand placement was almost identical. We learned two things from this experience. The first was that the apparatus was strong enough to be washed over and pulled without difficulty. The second was that all the shunt holes located in "dead" spaces in the screen assembly (collars and centralizer breaks) showed a slight key-slot erosion pattern associated with slurry flow through the shunt holes, indicating that considerable packing took place at these locations after formation of a bridge in the casing/screen annulus.

Well-test data on four recent completions can be used to illustrate the high well productivity being achieved with alternate-path gravel packing. These were chosen because the data were available.

**Fig. 5** shows the rate out to be approximately 90% of the rate in until the return valve was pinched off at 24 minutes on Completion 36. The rate out was held to about 25% of the rate in for the remainder of the job. A distinct pressure increase is seen at 26 minutes. It is believed a bridge formed, and the remainder of the job was pumped through the shunt tubes until a sandout was obtained at 39 minutes, indicated by the increased separation of the pump and casing pressures. The average gravel placement over the perforated interval was 0.20 ft<sup>3</sup>/ft.

Bottomhole pressure (BHP) data for commingled Completions 35 and 36 are shown in **Fig. 6**. The well was initially opened on a 1/2-in. choke, and then choke size was increased to 7/64 in. for the stabilized flow period, with a final measured flow rate of 73.4 MMcf/D. The well continuously cleaned up over the final flow period, with an initial flowing BHP of 4,337 psi and a final flowing pressure of 4,353 psi. The well was still producing several hundred barrels per day of completion fluid at the end of the flow period. Reinjection of produced completion fluid and condensate obscured the entire buildup, and no quantitative analysis could be made. Permeability estimates from sidewall core data, log data, and injectivity tests before gravel packing indicate a value of about 60 md. This value agrees qualitatively with the BHP data. Using 60 md for the permeability and accounting for the partial completion effects, we estimate that approximately 50% of the 1,840, 0.818-in.-entrance-hole-diameter (EHD) perforations were contributing to flow.

Completion 39 is in a typical low-resistivity oil zone in a flexure trend reservoir. The total perforated interval was 160 ft, with an estimated net pay of approximately 50 ft. The zone was perforated with 12 shots/ft having a 0.6-in. EHD. To facilitate sand placement in the perforations, only 5% returns were taken at a pump rate of 6 bbl/min. Fracturing was initiated and then was halted by stepping the rate down until a high-pressure sandout occurred (**Fig. 7**). The well was

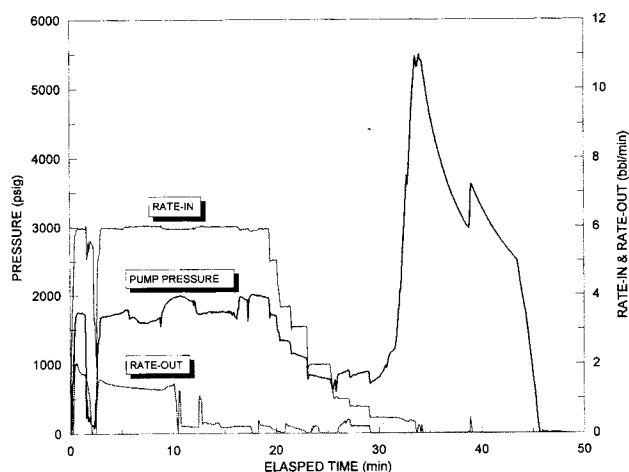


**Fig. 7—Pump pressure, rate in, and rate out as functions of time for Completion 39.**

tested at a rate of 1,600 BOPD for 202 hours. **Fig. 8** shows both the semilog and derivative plots for the associated buildup. Calculated permeability-thickness product and skin effect were 3,014 md-ft and 1.1, respectively. The low skin effect reflects a relatively high number of packed perforations.

Completion 38 is a low-resistivity gas zone with multiple sealing boundaries. The zone was tested at 7.1 MMcf/D with associated condensate. **Fig. 9** shows both the semilog and the derivative plots for the associated drawdown. Calculated permeability-thickness product and skin effect were 149 md-ft and 0.5, respectively. The zone was completed at 12 shots/ft with 0.6-in. EHD over a 72-ft interval with an estimated net pay of 32 ft. The low skin effect reflects a relatively high number of packed perforations.

Completion 37 is a replacement completion where a casing leak forced the abandonment of the initial completion. The initial completion was a non-ALLPAK completion perforated at 10 shots/ft with a 0.67-in. EHD and a 3 1/2-in. gravel-pack assembly. The replacement completion was an ALLPAK completion perforated at 6 shots/ft with a 0.53-in. EHD and a 2 1/16-in. ALLPAK gravel-pack assembly. Both completions covered the same net pay interval at the same measured depth with the same size production tubing. As

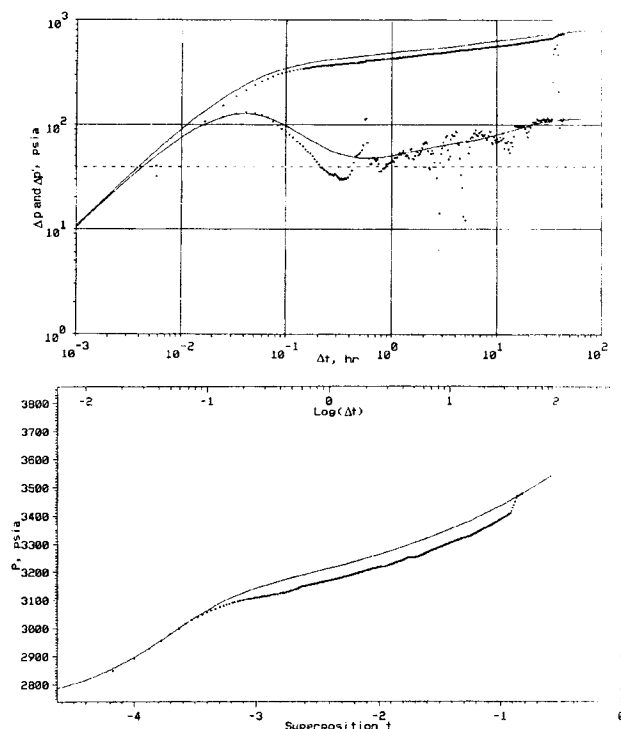


**Fig. 8—Derivative and semilog plots of Completion 39 well test.**

shown in **Table 2**, the ALLPAK completion indicates a 244% PI increase over the non-ALLPAK completion.

## Conclusions

Alternate-path gravel packing provides a solution for most of the problems that have long plagued offshore operators. Well completion strategies and gravel-packing techniques previously considered infeasible can now be used to obtain greater reserves and higher well productivities. We observed the following:

1. Packing with ALLPAK and gel slurries appears to provide complete annulus packs and packing in all perforations that will take fluid at any hole deviation angle for completion lengths up to 480 ft or more, regardless of variations in permeability.
2. The average amount of gravel placed outside the casing increased from 0.10 to 0.15 ft<sup>3</sup>/ft to 0.42 ft<sup>3</sup>/ft.
3. Two or more pay zones of widely variable permeability separated by short or long shale zones can be completely packed without difficulty.
4. Higher well productivity and longevity than obtained from previous gravel-packing techniques are usually observed.
5. Failures to control sand production have been eliminated in more than 40 completions to date.
6. Alternate-path packing is adaptable to a wide variety of gravel-packing procedures, and packing operations can be simplified considerably.
7. The shunt screen assembly is fishable.
8. The need for gravel-pack logs and prepacked screens has been greatly reduced.

## Nomenclature

- $m(p)$  = pseudopressure, m/Lt<sup>2</sup>, psia<sup>2</sup>/cp  
 $\Delta m(p)$  = pseudopressure change, m/Lt<sup>2</sup>, psia<sup>2</sup>/cp  
 $\Delta p$  = pressure change, m/Lt<sup>2</sup>, psia<sup>2</sup>/cp  
 $\Delta p'$  = derivative of pressure change, m/Lt<sup>2</sup>, psia<sup>2</sup>/cp  
 $t$  = time, t, hour  
 $\Delta t$  = elapsed time, t, hour

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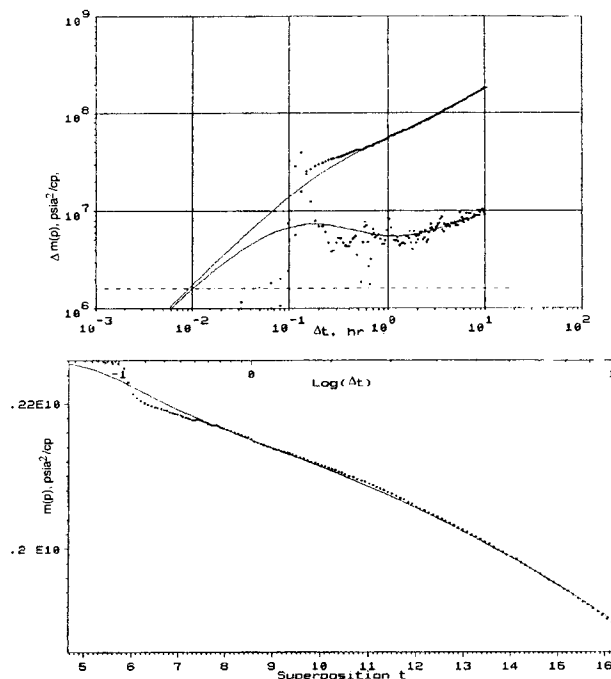


**Fig. 9—Derivative and semilog plots of Completion 38 well test.**

TABLE 2—COMPLETION COMPARISON

| Completion Type | Shut-in tubing pressure (psi) | Production Data                    |            |             |                         | Completion Area (ft <sup>2</sup> ) | Specific PI (BOPD/psi-ft <sup>2</sup> ) |
|-----------------|-------------------------------|------------------------------------|------------|-------------|-------------------------|------------------------------------|-----------------------------------------|
|                 |                               | Flowing tubing head pressure (psi) | Oil (BOPD) | Gas (Mcf/D) | Gas/Oil Ratio (scf/bbl) |                                    |                                         |
| Non-ALLPAK      | 4,200                         | 3,100                              | 3,700      | 2,491       | 673                     | 5.4354                             | 0.6188                                  |
| ALLPAK          | 3,646                         | 2,802                              | 3,330      | 2,236       | 672                     | 2.3252                             | 1.6968                                  |

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## SI Metric Conversion Factors

|                             |                          |
|-----------------------------|--------------------------|
| bbl × 1.589 873             | E - 01 = m <sup>3</sup>  |
| ft × 3.048*                 | E - 01 = m               |
| ft <sup>3</sup> × 2.831 685 | E - 02 = m <sup>3</sup>  |
| in. × 2.54*                 | E + 00 = cm              |
| md × 9.869 233              | E - 04 = μm <sup>2</sup> |
| psi × 6.894 757             | E + 00 = kPa             |

\*Conversion factor is exact.

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