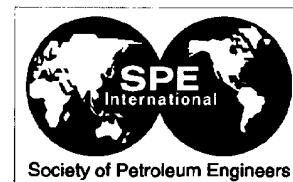




SPE 38640



Gravel Packing Horizontal Wellbores with Leak-Off Using Shunts

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Abstract

Because of the abnormal length of most horizontal wellbores, they present an exceptional challenge for gravel packing. Previously, the only way to gravel pack a long horizontal wellbore in a permeable formation was to seal off the wellbore from the formation to such an extent that substantial circulation could be maintained during the entire packing operation. While this approach has shown limited success, it necessitates the removal of the filter cake after the job is completed, which can be both difficult and expensive.

In this paper, equipment and procedures are described which allow gravel packing of long cased or open hole horizontal wellbores using alternate path shunts, without requiring circulation. The design methodology, procedures and evaluation have been developed with information obtained from studies using a series of physical wellbore simulators ranging from 150 to 500 feet in length. The simulators are described and results from the simulator studies are presented. Two case histories are included. The advantages of the new methodology are that it permits removal of the filter cake before or during the gravel packing operation and allows modest fracturing while packing, if desired.

SUMMARY

The pumping techniques and apparatus used in alternate path gravel packing have been extended here to allow gravel packing of long, open hole horizontal wellbores with or without substantial leak-off. Modest fracturing is possible, if

desired. The major pumping change is the use of gels that suspend the proppant during the entire job. The major apparatus changes are the use of larger exit ports from the shunts and use of a shroud over the screen and shunts to act as both a protector and centralizer.

The pumping and apparatus design changes are based on results of experiments performed with wellbore simulators ranging from 150 to 500 feet in length. Description of the experiments and results are provided below.

Two case history of the first field applications are presented. Total solids placement was 150% of the calculated annular volume of the 500-foot horizontal wellbore, suggesting that some modest fracturing took place. Productivity index for the well was 21, resulting in a production rate of 12,000 bbl/day from a formation with modest permeability thickness.

INTRODUCTION

Gravel packing of horizontal wellbores in unconsolidated formations is appealing because a tight gravel pack stabilizes the formation face. This will prevent movement of formation sand to the sand screen and permit use of a normal screen, which won't be plugged by the few fines that move through the gravel pack.

While gravel packing in cased horizontal wellbores has been used in places like the North Sea since 1991, Open hole horizontal well gravel packing has been difficult to accomplish because fluid leak-off along the horizontal interval dehydrates the slurry, leading to early annulus bridging and sand-out with long unpacked intervals. Numerous studies (1-14) have explained and documented the weaknesses and strengths of using either gels with good carrying capabilities or low viscosity fluids, such as water, for high angle and horizontal well gravel packing.

Horizontal water packing requires enough fluid velocity to maintain turbulent flow along the top of the wellbore to move the sand downstream. With leak-off, as soon

as enough fluid is lost so that turbulence can no longer be maintained the forward packing process (alpha wave) is halted. At this point the pack builds backward into the gap at the top of the hole until a completed pack reaches above the top of the screen. With substantial leakoff, such as at a fracture or high permeability location, the completed pack may be extremely short. Beyond that there is no pack at all (Figure 1 and Figure 2).



Figure 1: Water Packing Alpha Wave



Figure 2: Water Packing Beta Wave

Viscous gels will deliver solids over a much longer interval than water if leak-off is present. But the inevitable occurrence of a bridge in the annulus near top of the completion still severely limits the length of the pack. A bridge also prevents squeezing the slurry to remove excess gel from the portion of the completion below the bridge where slurry has penetrated (see Figure 3). The result is a poorly consolidated pack beyond the bridge. Therefore, until now the only method for producing acceptable long horizontal gravel packs has been to seal off the wellbore from the formation so tightly that the carrier fluid (usually water) is kept available for solids transport (14) and circulation is maintained. Fracturing must be avoided at all cost in such an operation. Even if successful, sealing off the wellbore necessitates removal of the seal after gravel packing, which can be difficult and expensive. The equipment and methodology described

below eliminate the need to maintain a seal while gravel packing a horizontal wellbore, and simultaneously permit fracturing if desired.

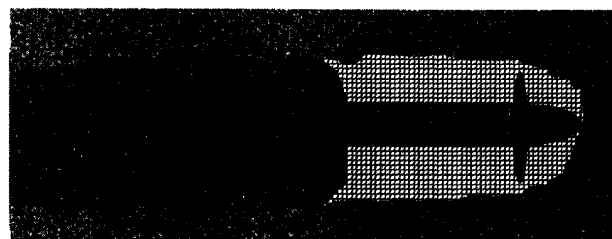


Figure 3: Conventional Gel Pack

Use of shunts attached to the screen to provide alternate paths for slurry flow in ordinary gravel packing or frac-packing has been previously described. (15-17). The primary attribute of the shunts is the capability to deliver gel slurry and associated hydraulic pressure past any bridges that form in the annulus outside the screen. This allows full application of squeeze pressure all along the completion length, resulting in complete packing, more fracturing, and very tight packs. The technology is adapted here to long horizontal open hole intervals by adjusting shunt exit port design to eliminate internal slurry concentration, by using low damaging fluids with good carrying capacity at low shear rates, and by protecting and centralizing the shunt screen with a perforated shroud. The required design and operating parameters for field use were established using experimental results from wellbore simulators ranging from 150 to 500 feet in length.

SIMULATION

It has been previously established that shunt packing of void spaces in the annulus is mostly independent of whether leak-off occurs through the screen or through the perforations, and that the squeeze position can always be used if desired (16). It is also known that each shunt operates independently of the others, in the sense that each can be used to pack an individual segment of the annulus by beginning the shunt ports, in an individual shunt, at the top of the segment it is to service. Accordingly, the simulators were constructed for rapid turnaround and minimum expense by using a single one half by one inch shunt inside a three inch O.D. plastic casing

Test Number	Fluid	Nozzle Opening	Shunts	Sand Size	Proppant	Density lb/gal	Length Packed	Model Length
1	40 lb Xanthan	N/A	0	20/40	Ottawa	5	25	150
2	60 lb Guar	1/8"	1	20/40	Ottawa	5	40	150
3	40 lb Xanthan	1/8"	1	20/40	Ottawa	5	90	150
4	2.5% VES*	1/8"	1	40/60	Low Dens	10*	250	250
5	1.5% VES	1/8"	1	40/60	Ottawa	8	120	250
6	1.5% VES	1/4"	1	40/60	Ottawa	8	500	500
7	0.5% VES	1/4"	1	40/60	Ottawa	8	160	500
8	1.5% VES	1/4"	1	20/40	Ottawa	8	250	250

Table 1 : Simulation Results

* A different VES formulation than the other tests presented 740

* Equivalent sand concentration

with 120 ten thousandth slots (10 gauge) per foot to provide leak-off. All tests were horizontal and in a squeeze mode with a cap at the end of the slotted liner.

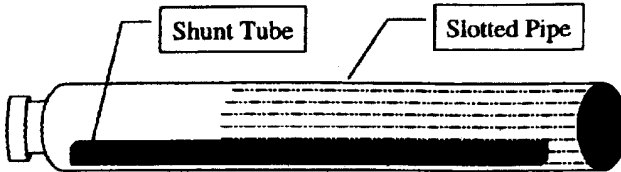
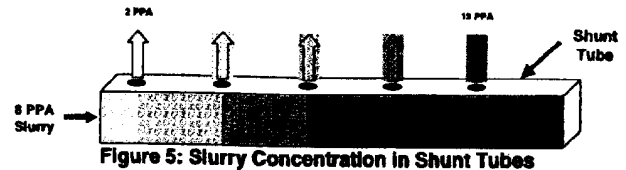


Figure 4: Test Fixture Setup

The shunts contained exit ports at 5-foot intervals lined with tungsten carbide inserts to prevent erosion problems. The ports were either an eighth inch diameter and a quarter inch long or a quarter inch diameter and five eighths inch long. Figure 4 shows the general arrangement and a short length of shunt. The slurry would enter through a connection on the left once in the blank section it can flow either down the casing or through the shunt tube. Run number 1 was performed without a shunt tube in the simulator. Enough blank with shunt and blank pipe was installed above the slotted liner to assure that the top bridge would not build above the shunt entry. Slurries of 4 to 8 lbs/gal of 40/60 sand, 20/40 sand, and 40/60 low density gravel substitute were pumped in a variety of carrier fluids into the annulus at 20 gallons per minute. The rate was normally reduced at the very end of the run in order to keep the pressure below the maximum for as long as possible. The various experiments and results are listed in Table 1. Significant findings were:

1. The carrier fluid must suspend the particles during the pumping period.
2. Sand grains do not turn the corner easily into small shunt ports, resulting in slurry concentration inside the shunt to an extent which limits the packing distance.
3. The large shunt ports are highly effective in preventing internal slurry concentration.
4. High viscosity and low solids concentrations extend the packing length.
5. Low-density particles follow the fluid better, thus extending packing length.

The great length of the simulators allowed study of effects that are not easily recognized in a shorter apparatus. Figure 5 graphically illustrates the problem of internal slurry concentration in the shunts when particle density is much higher than fluid density. Although this problem was known to exist prior to these studies, the magnitude of the problem was not fully understood. Likewise, the absolute necessity to avoid particle settling during the pumping phase was not appreciated until rapid shunt plugging was observed with linear carrier fluids in simulator runs 1 and 2. Neither effect is nearly as significant in wells with a deviation less than 50 degrees.



From simulator run 4 it was established that each shunt with 1/8 inch ports could pack at least 250 ft when using low density gravel substitute. The use of 1/8-inch ports was a necessity for the first well because those were the only shunt screens readily available at the location. Since the maximum length of the horizontal segment in the first well was to be less than 1000 ft and four shunts were attached to the screen, this result indicated the job could proceed.

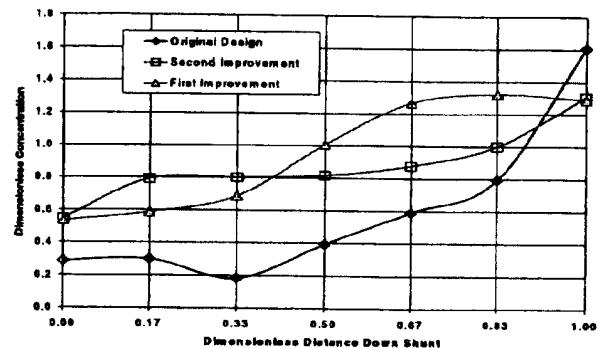


Figure 6: Plot of Concentration in Shunts

From simulator run 6 it has been established that the use of large ports extends the maximum packing length to least 2000-ft with sand. Figure 6 illustrates how modifying the size and shape of the exit ports affects the concentration of the slurry leaving the ports. Pumping 8 PPA slurry down a shunt tube and measuring the concentration of the slurry leaving through various ports generated this data. If the shunt is passing through a gravel packed region, these slurry concentration phenomena will be greatly reduced. Angled ports extending into the shunt flow stream, as shown in Figure 8 reduce the tendency of the slurry to concentrate inside the shunt and thus extend the packing length. A design of this type may be required to extend the packing distance to the very long intervals of 3000 ft or more. Figure 7 shows the pressure record while packing. Annulus sand-off is clearly indicated at point A. Packing through the shunt then commences and proceeds until point B, when the pack reaches the end of the simulator. Pressure rises linearly during this period as the pack is extended farther and farther along the simulator. A short period of squeezing the pack follows until point C, at which time a sand-out occurs where no more space is available for packing in the annulus. This result is an important commercial milestone because of the availability and low price of sand. Results from run 8 indicate that 20/40 sand is a viable option in some cases. However, it must be

recognized that fluid requirements are more stringent for this option.

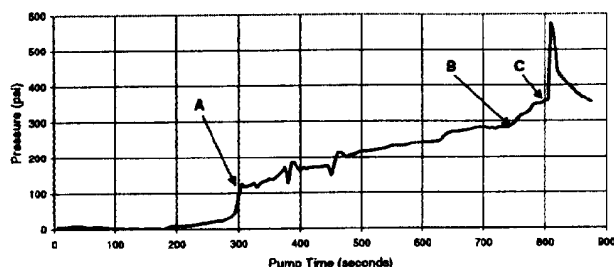


Figure 7: Simulator Pressure History

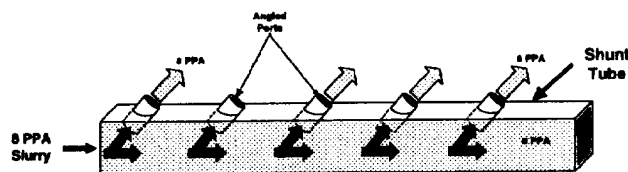


Figure 8: Shunt with Angled Ports

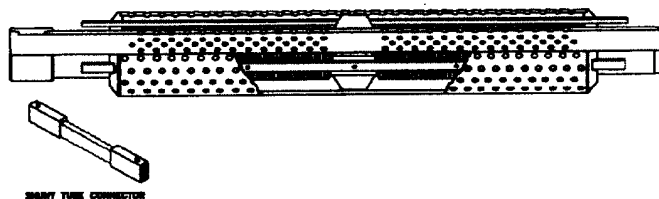


Figure 9: Shunt Tube Screen Design

Open Hole Screen Design

It was felt that the shunts needed thorough protection for running into open holes. Adding a perforated casing shroud over each screen joint to act as both a protector and centralizer provided this. An adapter at each end of every screen joint supports both the screen and the shunts, as shown in Figure 9. Connections are then made in the valleys between each screen joint. Gravel packing takes place through the multitude of holes in the shroud.

Case Histories

Early results in this field without the shunt tubes produced wells with PI's from 8 to 19 with post gravel pack skins from 9 to 23 and very high draw down pressures. The shunt tube technology was introduced simultaneously with a change in the gravel pack fluid, switch to open hole, and increased pay. The result of all these changes was an increase in the PI's, with a reduction in skin and draw down pressures. Case histories from three separate horizontal wells are presented in this section. Some of the data common for both wells are:

- The horizontal sections were drilled with a water based drill-in fluid.
- Low density gravel substitute (SG 1.7) was used.
- A visco-elastic surfactant was used as the carrier fluid.
- A gravel concentration of 5 PPA (lbs per gallon added) was used. This gravel concentration is equivalent to about 8 PPA of sand.
- CaCO_3 Fluid Loss control agent was used before running in with the screen.
- Both wells were packed in the squeeze position with the choke $\frac{1}{4}$ open.

Case 1: 508 ft

This 508 foot $8\frac{1}{2}$ inch open hole was drilled with from 75 to 82° deviation. The formation net height was measured from logs to be about 30 feet. This was the first open hole completion that used the new open hole shunt tube system. A drawing of the completion can be found in Figure 11. The well was drilled in January of 1997. The initial pumping sequence used 20% excess in gravel. A screen-out was not obtained. At this point, additional slurry was mixed and pumped until a screen-out was obtained. A total of 50% excess was placed. The total amount of low density gravel substitute placed was 15,600 lbs (equivalent to about 25,000 lbs of sand) No returns were observed until well into the job and only $\frac{1}{4}$ returns were then observed. This large excess of gravel with little or no returns and a relatively high surface pressure could be an indication that some fracturing occurred. The initial production from this well was measured at 12,000 bopd with a PI of 21 and a horizontal skin of 1. So far the PI has remained constant even with a decline in the reservoir pressure.

Case 2: 617 ft of Open Hole

This second well was drilled with a 1000-foot open hole section with between 85 and 90° of deviation. The formation net height in this well was 18 feet. Because of hole problems, only 617 feet of horizontal shunt screen made it into the open hole section. The other 383 feet of screen remained in the cased section of the well. During the pumping operation, 17% excess low density gravel substitute was placed. The initial PI from the well was measured at 23 with a horizontal skin of slightly less than 4. Figure 12 contains a drawing of the completion.

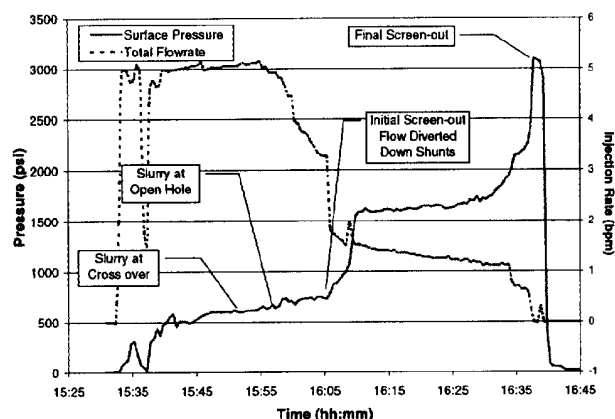


Figure 10: Well 2 Pumping Data

Figure 10 contains the surface pressure chart from this well. Note the similarity between this chart and the pressure chart obtained from the surface simulator in Figure 6. From Figure 10 it is clear that the shunt tubes became operational about 32 minutes into the gravel pack. After accounting for the material reversed out, 21,000 lbs of low density gravel substitute was placed (equivalent to 33,600 lbs of sand). Approximately 40 % of the total gravel pack was pumped through the shunt tubes. About 57% of the gravel placed in the open hole section was pumped through the shunt tubes. Since this gravel pack was performed with 8 ppa equivalent slurry, the actual slurry pumping time and fluid used in the slurry was reduced to 1/8 of that required for a water pack. While CaCO_3 was used to control losses during the running of the screen, it was not necessary to obtain 80 to 90% returns (or complete formation shut-off) in order to get a good gravel pack.

Case 3: 1000 ft of Open Hole

The third well was also drilled with a 1000 foot open hole section with a 90° deviation. During the first run, only 350 feet of screen could be pushed into the open hole. The string was pulled and rerun to bottom with 5 1/2 inch drill pipe. This example showed that the screen could be pulled if required. After the completion was landed, the gravel pack was pumped as per Figure 13. The batch of gravel did not result in a screen out. A second batch of 65 bbls of slurry was pumped approximately 2 hours later. The 37,000 lbs of light weight gravel placed was 35% excess. A screen out was obtained at the end of this second injection. The PI from this third well was measured at 60. This was the highest PI to date.

Conclusions

The following conclusions can be drawn from the work performed so far:

- The shunt tubes enable slurry pack techniques to be

used in long horizontal open hole intervals. This has been shown in both surface tests and field case histories.

- The protective shroud around the shunt tubes centralizes the screen, which insures that gravel is placed around the entire screen. Conventional water packing would normally leave the bottom of the screen exposed to the formation.
- The use of the shunt tubes reduces both fluid requirements and pumping times. This should translate into significant rig time savings.
- Production rates from these gravel packed wells are much better than the equivalent vertical wells.
- While the current well tests were only performed in open hole sections up to 1000 feet, intervals as long as 2000 feet can be performed with the current technology.
- Modifications in the shunt tube design should increase the maximum gravel pack length to the 5000-foot range.

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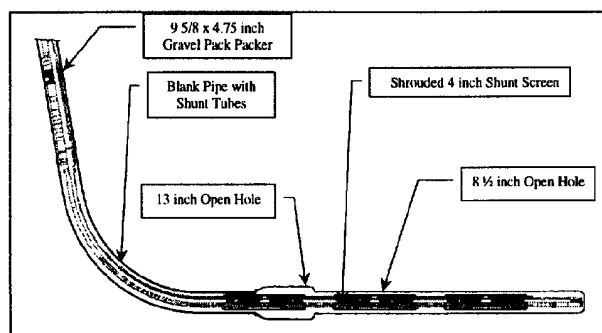


Figure 11: Case History 1 Completion Diagram

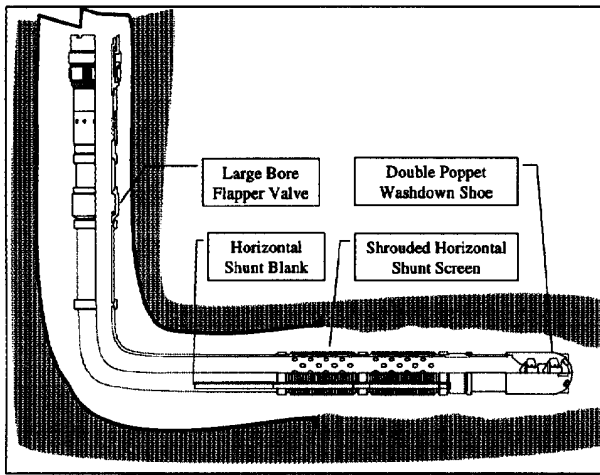


Figure 12: Case History 2 Completion Diagram

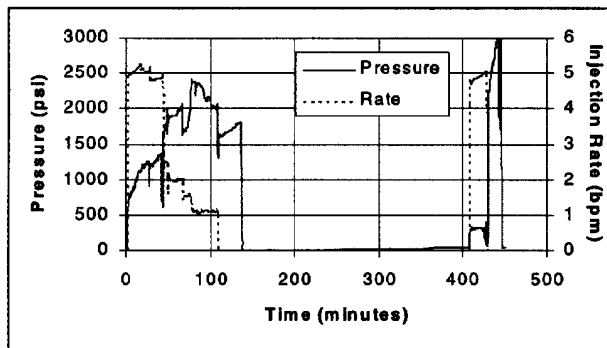


Figure 13: Case History 3 Surface Data

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