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Gravel Packing for Completing Long Horizontal Wells in Unconsolidated Formations

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Abstract

This paper briefly describes in the introductory section general issues regarding gravel pack in horizontal wells. "Theoretical considerations" section underlines the key parameters to be achieved and monitored for a successful gravel pack operation. A typical horizontal gravel pack sequence of events is depicted in "Installation method" chapter. Finally is presented the case history of completing well # QWSB-53 Obigbo-North field, Niger Delta.

Key words: *viscous gel carrier fluid, alpha wave, beta wave.*

Introduction

In order to complete a high deviated or horizontal well that opens an unconsolidated formation it is necessary to use a different sand control technology compared with that used for a vertical well.

A horizontal well is defined as a drilled hole achieving a deviation angle of 90^o from vertical, but in application, a highly deviated well (deviation angles exceeding 70^o) is referred to as horizontal well too, if the length of wellbore exceeds many times the producing layer thickness.

Despite the fact there are many other options for downhole completion of unconsolidated formations, like slotted liners or standalone screens (wire wrapped, premium or prepacked screens), these technologies are applicable only for certain applications compared with gravel-packing which is a more general-purpose completion technology.

In addition, this technology is suitable for high volume producers (2400 cm/day in oil wells and 2 mil St cm/day in gas wells) and long horizontal sections (more than 750 m)[1].

Theoretical Considerations

The main problem is to place gravel over an interval of several hundred meters. It was tried to use viscous gel carrier fluids, but after several studies and research in physical models it became obviously that performing a successfully gravel-packing operation in a horizontal well using viscous carrier fluids is very difficult [2],[3]. At the same time, it was proved that using brine as carrier fluid, appropriate completion equipment design and pumping schedule, the success is ensured. The fundamental requirement for a circulating pack is a hydraulically isolated formation. The filter cake must remain intact during the gravel packing. The angle of repose of the gravel is about 60^o, so up to well deviation of 60^o gravity tends to assist in transporting the gravel to the bottom of the screen. For wells with deviation that exceed 60^o the gravel placement is initiated at the top of the completion. The subsequent gravel placement extends downward until the gravel dune, referred to as alpha wave, reaches the bottom of the well. At this point, secondary placement of gravel, referred to as beta wave, packs the volume above the alpha wave. A typical sequence for a horizontal well is shown in the next figure.

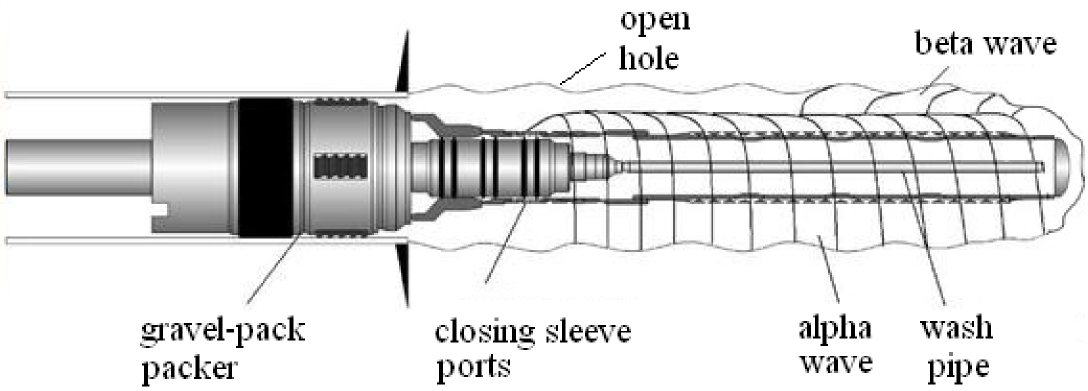

Fig. 1. Circulating pack sequence

If the sand ratio is too high, the flow rate is too low, or the annulus cross sectional area between outer diameter of washpipe and inner diameter of the screens is too large, the alpha wave could cease before reaching the bottom of the well.

The main requirements for a successful horizontal gravel-pack are:

- washpipe OD-screen ID ratio of at least 0,75
- mantaining a superficial velocity of at least 0,3 m/s (cecked on the return flow)
- using a slurry with a typically sand ratio of 119,8 kg/m^3
- ensure a hydraulically isolated borehole during gravel-pack operation
- ensure the washpipe end is placed at the bottom of the screen[3].

An illustration of alpha - beta wave principle is shown in Fig.2 and Fig.3 [4].

Installation Method

1. After the horizontal section is drilled, the drilling fluid is displaced to a solid- free, water-based completion fluid.
2. The downhole assembly (setting tool, crossover tool, washpipe and gravel-pack packer with screen) is run in, after which the gravel-pack packer is set.
3. A low-ratio gravel slurry (60-240kg/m^3) is circulated into the annular space between the screen and formation. The circulating fluid (usually KCl brine) has little capability to keep

the gravel in suspension (slurry velocity around 0,3 m/s) and the gravel settles out and forms a dune.

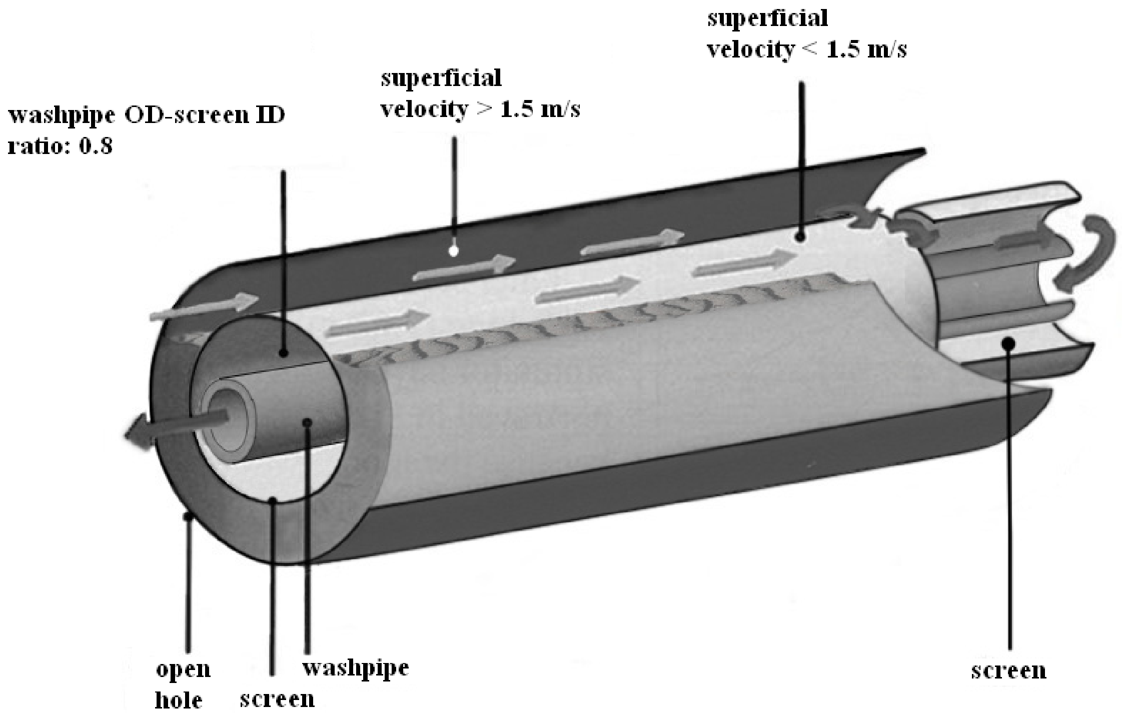

Fig. 2. Alpha wave

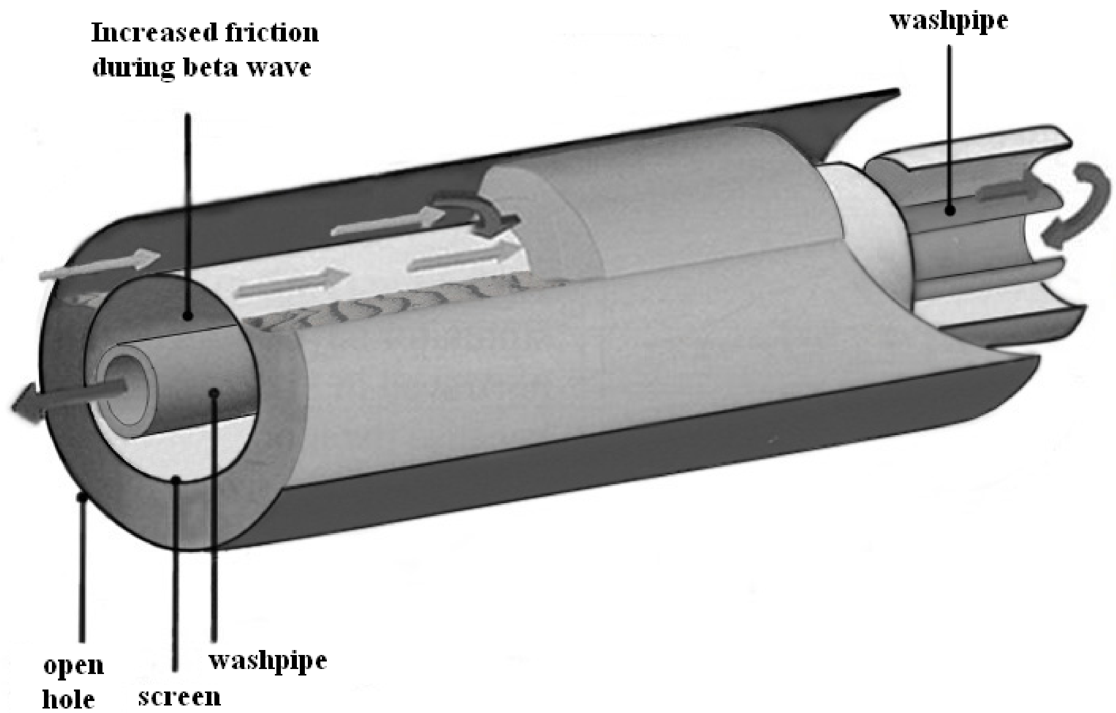

Fig. 3. Beta wave

4. After the dune is formed, the slurry flow section (cross section area of annular space between the screen and formation), becomes 70–90% of openhole area. This corresponds to the critical dune height. Lower rates lead to higher, slower dunes or could create multiple waves. The slurry velocity above the dune is fast enough (around1,5–2 m/s) to turbulently transport the gravel.
5. The dune extends along the open hole section by dune action (referred to as alpha wave) until it reaches the toe of the well. After slurry dehydration, the carrier fluid is returning via the screen – formation annulus until the toe of the well, and through the screen to the end of washpipe.
6. The annular space between open hole and screen, beyond the end of the washpipe will receive very little gravel. It will be created a rathole, not effectively packed. The alpha wave will stop at the end of the washpipe.
7. The injection pressure increases because the carrier fluid, after slurry dehydration, has to circulate through the pack and the screen to reach the end of washpipe. The gravel is then progressively packed back towards the heel (referred to as beta wave). The slurry has to be pumped at lower rates to avoid high pressures that could fracture the formation.
8. The injection pressure increase until further pumping is impossible. It is the moment when beta wave reaches the heel of the well. Excess gravel is reverse circulated up the running string[5].

Fig. 4 shows pressure variation versus time during installation process.

Well QWSB-53 Case Study

In mid-2002, on the horizontal well QWSB-53, located in the Niger Delta, Obigbo-North field, it was performed a water-packing operation with the objective of achieving 477 m^3/d of sand-free oil production. (see the schematic below).

After the 7 in casing was cased and cemented, it was drilled out cement in the bottom joint of casing and the float shoe and another 9 m of pay to perform a pressure limit test. To ensure an adequate pressure margin for packing, engineers used for job design the fracture gradient of14,5 kPa/m determined from this test as the upper limit for placing gravel.

Then, it was drilled a 305 m horizontal section to total depth using a 11 kPa/m water-base drilling fluid. After reaching total depth, drillers circulated the borehole clean with no significant fluid loss, which indicated that filtercake on the sandface provided a good seal. To minimize screen plugging, the open hole was displaced with a solids-free fluid of the same composition as the reservoir drilling fluid without calcium carbonate, but with additional salt to maintain a 11 kPa/m pressure gradient. The casing was displaced with filtered brine before running the sandface completion assembly.

A volumetric calculation determined that 4190 kg of gravel would be required to pack the 6 in openhole annulus. Gravel was pumped using a filtered 12% potassium chloride brine carrier fluid.

Injection pressure, rate, and sand concentration were monitored at surface to track the alpha and beta waves (see the plot in Fig. 6).

Gravel was placed in four stages at different, concentrations while reducing the injection rate to adjust for injection pressure increases. In formations with low fracture gradients, it is necessary to reduce the slurry injection rate once a beta wave initiates, to avoid prematurely breaking down formations prior to developing enough dune height to completely cover the screens. This technique lays down additional alpha waves on top of previous dune beds resulting in complete screen coverage.

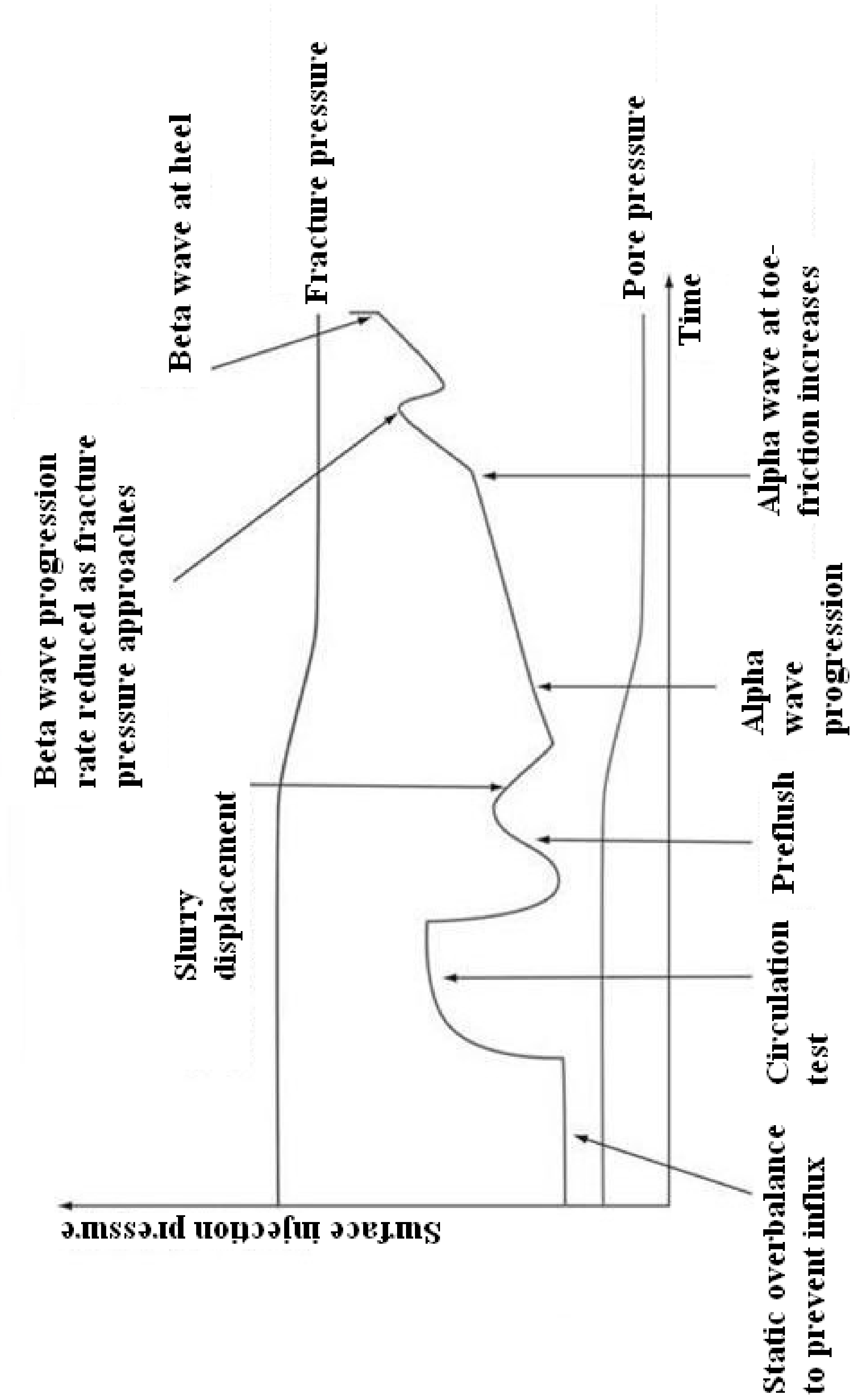

Fig. 4. Brine pack circulation pressure variation

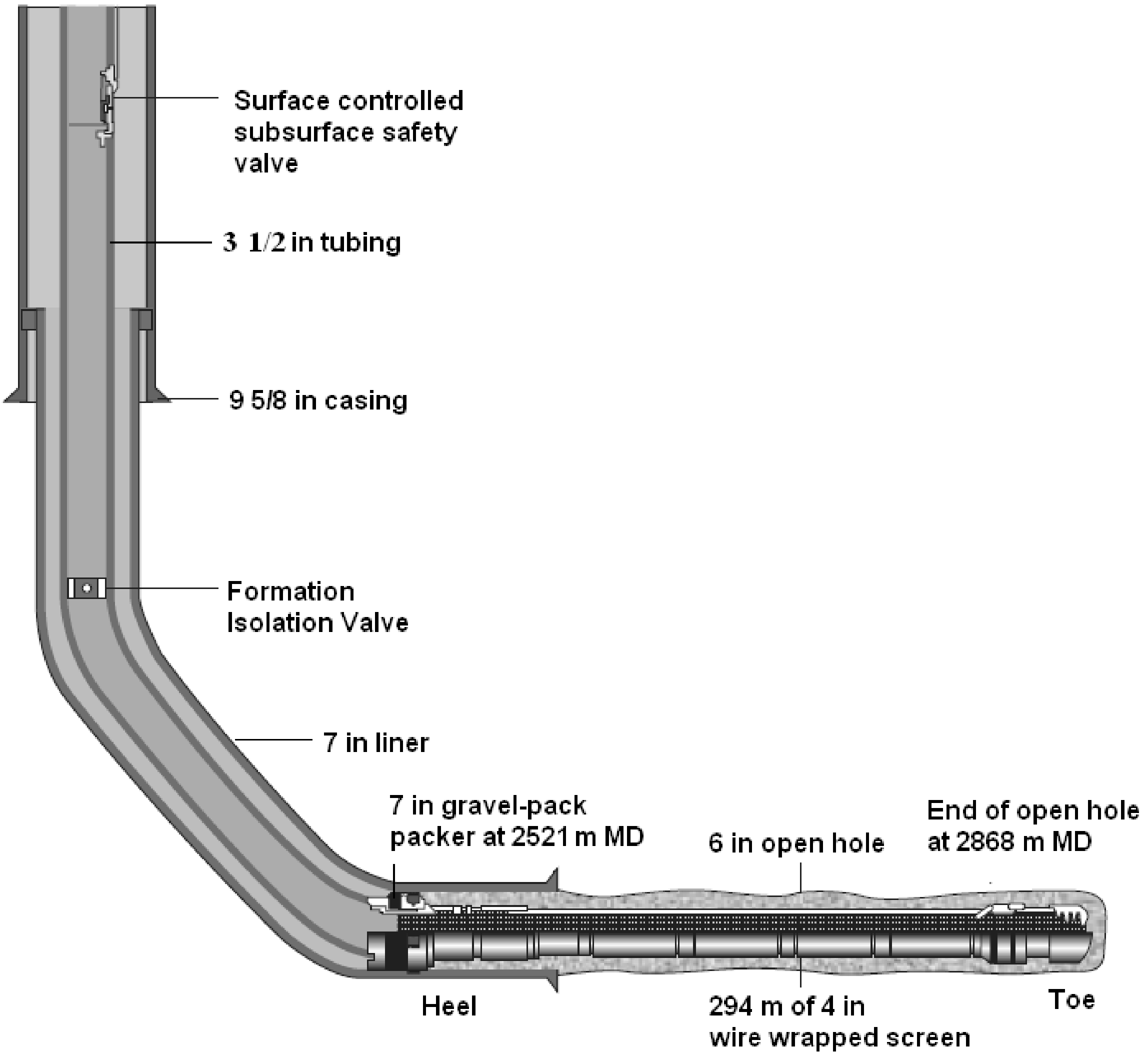

Fig. 5. QWSB-53 wellbore and completion schematic

The operator pumped a total of 6123 kg of gravel, but reversed out 1211 kg of excess gravel, leaving about 4912 kg of gravel around the screens, which corresponds to an actual borehole size of 6,25 in.

After gravel packing, the running tool and wash pipe were retrieved. A 3 ½ in tubing string with a tubing retrievable subsurface safety valve and gas-lift mandrels for future artificial lift was installed. A 10% hydrogen chloride acid treatment energized with nitrogen was displaced in the horizontal section using 1 ½ in coiled tubing and a downhole tool with 360° rotating jet nozzles to generate hydraulic turbulence and make closer contact with filtercake on the borehole wall.

Post-treatment cleanup improved well performance by diverting acid across the horizontal section. The well initially produced oil at517 m^3/d. A spinner inflow profile, pressure drawdown and total production rate from a memory production log indicated 100% pack efficiency, with the entire horizontal section producing into the screen assembly.

This completion demonstrated better initial inflow capability and longer sustained productivity at a higher drawdown pressures than other wells with stand-alone screen

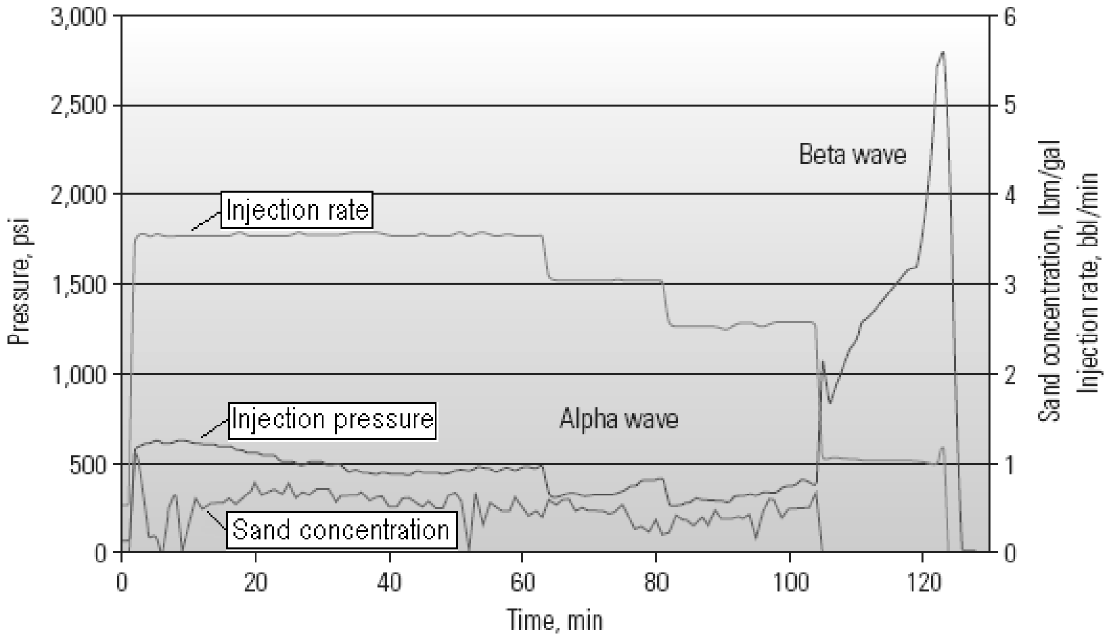

Fig. 6. QWSB-53 gravel-packing operation monitoring. Gravel-packing operations were performed at 0,56; 0,48; 0,4 and 0.16 m^3/min. The pumping profile showed pressure responses corresponding to both alpha wave and beta wave gravel deposition. About 75% of the gravel was deposited during the alpha wave, leaving only 25% for the beta wave deposition.

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Completarea sondelor orizontale lungi ce deschid strate neconsolidate, în sistem „gravel-pack”

Rezumat

Acest articol descrie în partea introductivă aspectele generale ale completării sondelor orizontale, în sistem „gravel-pack”. În secţiunea alocată consideraţiilor teoretice sunt evidenţiaţi parametrii cheie şi domeniul valorilor în cadrul cărora aceştia trebuie menţinuţi pentru reuşita operaţiei. Succesiunea operaţiilor pentru completarea sondei este descrisă în secţiunea”Metoda de instalare a completării”. În final este prezentat studiul de caz al instalării completării în sonda QWSB-53 Obigbo-North field, Niger Delta.