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Effective Well Stimulation Using Fluid Pulsing to Inject Surfactant Solutions

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ABSTRACT

In the oil and gas industry the use of chemicals in treating wells has greater efficacy when the fluids are placed along the completed interval with both maximum distribution and depth of penetration. Conventional static injection methodologies with chemicals are limited in their effectiveness to achieve these attributes because those approaches do not have the capacity to overcome difficult reservoir conditions such as low permeability streaks, very viscous oil, and sometimes even worse, the presence of fractures and thief zones.

Weatherford has developed an innovative stimulation approach to treat wells that have experienced lost or massive declines in oil production rates and require oil viscosity alteration to allow heavy oils to be mobilized for production. The novel approach includes the use of a highly successful Weatherford proprietary surfactant / solvent / dispersant product that is dynamically injected using Wavefront's multi-patented injection process.

The surfactant / solvent / dispersant has been used widely in Canada, Mexico, Colombia, and elsewhere. The product is capable of shear-thinning heavy oil at less than 1% concentration forming a weak oil/water emulsion without surface treating issues.

Demonstrated in hundreds of well stimulation applications, Powerwave is a dynamic fluid injection process that generates powerful fluid pressure pulses that cause momentary elastic flexure of the pore structure that overcomes difficult reservoir conditions, thereby allowing for greater depth of penetration and more uniform fluid distribution of well treatment fluids.

Together, Weatherford and Wavefront have been evaluating the efficacy of the combined technologies in Mexico, in an oil field located SW of the Poza Rica oil town[2] ("The oil field"). The oil field is part of the PEMEX North Region. This oil production region is widely known as the Chicontepec Basin and contains Mexico's largest certified hydrocarbon reserve.

This paper presents results of a 3-well evaluation of the combined technologies; 2 wells using fluid pulsing with the Weatherford product versus 1 well using the Weatherford product but with conventional injection. The results from the 2 wells using fluid pulsing clearly demonstrate that proper placement of the Weatherford surfactant / solvent / dispersant product leads to larger post-stimulation gains of 2,325% in incremental oil production as well as a viscosity improvement from 14° API to 15° API in Well # 1; and 791% incremental oil production as well as a viscosity improvement from 18° API to 27° API in Well # 2. The result of the comparative non-fluid pulsing Well # 3, showed a similar viscosity improvement from 13° API to 17° API with a production gain of 415%.

INTRODUCTION

The purpose of well stimulation is to remove wellbore "damage" to restore a well's productivity to its estimated decline rate. The depth of radial damage that may occur in a wellbore can extend to 20 feet or more and can emanate from drilling, completions, workovers, other stimulation procedures as well as production, water or gas injection, EOR activities, as well as pressure changes in the reservoir, mobilizing solids, asphaltenes, waxes, swelling clays etc.

Stimulations are accomplished through a variety of techniques but most commonly chemicals are added to wells to treat the existing conditions in the reservoir with an attempt to achieve better production. In limestone, matrix acidizing is widely used. Acids may also be used to dissolve clay minerals blocking sandstones pores in the near wellbore region. In heavy oils, diluents (e.g. naphtha), dissolving agents (e.g. xylene) or other fluid constituents are used for a variety of reasons to enhance well productivity.

THEORY AND APPLICATIONS OF FLUID PULSING

Before analyzing the stimulation results at the oil field in Mexico SW of Poza Rica, it is important to review the theory and application behind fluid pulsing.

The use of chemicals in treating wells has greater efficacy when the fluids are placed along the completed interval with both maximum distribution and depth of penetration. Conventional, static injection methodologies as well as jetting tools, acoustic tools or fluidic oscillators with chemicals are limited in their effectiveness to achieve these attributes because those approaches do not have the capacity to overcome difficult reservoir conditions such as low permeability streaks, very viscous oil, and sometimes even worse, the presence of fractures and thief zones. In addition, conventional steady state injection (bullheading) and production establish primary pathways thereby reducing treatment effectiveness as the chemical treatments merely follow the pre-established pathways.

Wavefront's fluid pulsing technology induces deep penetration and more uniform distribution of treatment fluids through high-amplitude fluid pressure pulses. This form of fluid pulse creates a "dynamic flow" environment which has been demonstrated to effectively overcome the difficult reservoir conditions previously mentioned.

How does a fluid pressure pulse work? When a fluid pulse is applied, the pore space elastically responds (Figure 1) giving rise to the pre-determined pore networks to momentarily increase in volume and interconnectivity as well as opening multiple, additional pathways to liquid flow. The result is greater dispersion of the injected fluid and, even more importantly, greater penetration into the formation. Overall, this represents greater productivity gains after well treatment, increasing oil recovery.

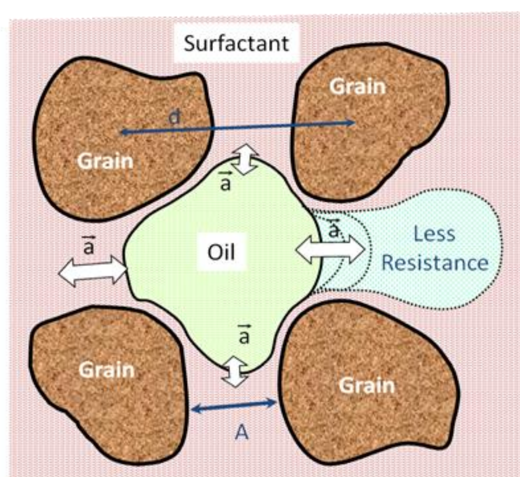

Figure 1: Pore Elastic Response to High-Amplitude Fluid Pulse.

TECHNICAL DIFFERENCES BETWEEN SONIC AND ACOUSTIC TOOLS, FLUIDIC OSCILLATORS, AND PULSING TOOLS

High-amplitude fluid pulsing tools are fundamentally different from fluidic oscillators, sonic tools, and jet nozzles, which are identified in the oil industry for well cleaning and often used by default in applications specific to stimulation. Table 1 compares depth of penetration of various stimulation tools and approaches. Fluidic oscillators alternate injection through 2 to 3 ports utilizing a well known process called the "Coanda effect." The waveforms created from this type of tool are very flat with low changes in pressure +/- 35 psi, and resemble a sine wave. The frequencies of the fluidic oscillators, sonic, and acoustics tools are significantly much higher than those related Powerwave as it applies to well stimulation. Fluidic oscillators, sonic, and acoustics tools have marginal (if any) control over the distribution of fluids in the reservoir.

TOOL TYPE	DEPTH OF PENETRATION	HIGH OR LOW AMPLITUDE DIFFERENTIAL	EFFECTIVE USE	WAVEFORM GENERATED BY TOOL	CONTROL OVER FLUID DISTRIBUTION ALONG COMPLETION	ADJUSTS FOR WELLBORE BLOCKAGES	PRESSURE DROP ACROSS TOOL
Conventional Coil Tubing Bullheading	< 2 inches	No Amplitude only pumping rate	Filter cake, scale, and paraffin removal	N/A	No, will not overcome permeability contrasts	No	N/A
All Jetting Tools	< 2 inches	Low Amplitude < 100 psi Differential	Filter cake, scale, and paraffin removal	None, "car wash affect"	No, will not overcome permeability contrasts	No	Yes
All Acoustic (Sonic) Based Tools	< 2 inches	Low Amplitude < 100 psi Differential	Filter cake, scale, and paraffin removal	Sinusoidal	No, will not overcome permeability contrasts	No	Yes
Powerwave Pulsating Jet Tool	< 2 inches	Low Amplitude < 100 psi Differential	Filter cake, scale, paraffin removal and sand clean-outs	Sinusoidal	No, will not overcome permeability contrasts	No	Yes
Powerwave Self Adjusting Nozzle	< 2 inches	Low Amplitude < 100 psi Differential	Filter cake, scale, paraffin removal and sand clean-outs	Sinusoidal	No, will not overcome permeability contrasts	Yes	Yes
Powerwave Odyssey	> 24 inches	High Amplitude 150 to 1200 psi Differential	Deep penetration of treatment fluids such as acids	Asymmetric wave form	Yes, will overcome permeability contrasts	No	No
Fluidic Oscillators	< 2 inches	Low Amplitude < 100 psi Differential	Filter cake, scale, and paraffin removal	Sinusoidal	No, will not overcome permeability contrasts	No	Yes

Table 1: Comparison of Various Stimulation Tools.

High-amplitude fluid pulses work effectively as a well stimulation method primarily because the dynamics of the pulse force injection fluids outside of the path of least resistance. The waveform itself has a saw-tooth shape (Figure 2 and Figure 3), which provides several benefits over other stimulation methods including fluidic oscillators. The sharp change in pressure (amplitude) in a very short period of time (rise time) directs flow radially into the formation with significantly more energy and depth of penetration than competing technologies and processes.

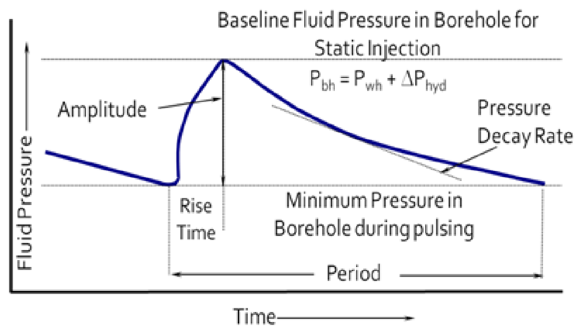

Figure 2: Theoretical High-Amplitude Fluid Pulse Saw-Tooth Shaped Waveform.

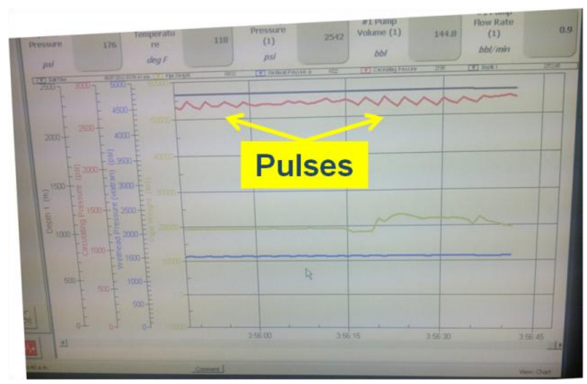

Figure 3: Actual Pulses noticed at the circulation pressure panel.

In addition, to the type of waveform, the amount of energy that is exuded under each pulse is significantly different as compared to other methods. Typically, fluidic oscillators, sonic, and acoustics tools create pressure pulses of <100 psi (change in pressure from valley to peak of the waveform) at the injection face of the formation. Powerwave creates much larger changes in pressure from 150 psi to 1,500 psi; determined specifically to the stimulation job. However, it is important to note that the difference in pressure is only a small piece of the puzzle; how the change in pressure is created is a significant difference in the two processes and ultimately the results that can be achieved.

High-amplitude fluid pulses are tailored for reservoir characteristics including permeability, fluid viscosity, and so forth. The fluid pulses are highly effective in controlling fluid distribution injection because:

- The pressure gradients involved in normal flow of fluids through the reservoir are generally very small when viewed at the pore scale, yet small differences between these pressure gradients determine the path of least resistance that governs normal flow of fluids. Typical amplitudes of the fluid pulses alter local pressure gradients and completely dwarf those associated with normal fluid flow in the reservoir causing diversion of fluid away from the traditional path of least resistance.

- High-amplitude fluid pulses force fluids into the spaces between the grains of rock or sand, causing a very small, and completely harmless, expansion and contraction of this space and thereby giving rise to an improved dynamic permeability.

- The increase in dynamic permeability and the fluid displacement pulses allow fluids to travel more uniformly through the reservoir.

Fluid pulsing tools provides a safe, reliable, and effective means for enhancing fluid injection with deeper penetration into the reservoir matrix.

TECHNICAL DESCRIPTION OF THE COMBINED TECHNOLOGIES FOR EFFECTIVE WELL STIMULATION TREATMENTS

Weatherford had previously used its surfactant with conventional injection tools. In the "oil field", they decided to test the results of their surfactant placed with conventional injection tools versus placement with Powerwave. This "oil field" served as a good test field particularly because of the complexity of the reservoir: low porosity, low permeability, low oil viscosity, and natural fractures. The hypothesis was that Powerwave would provide the needed physical mechanisms to effectively disperse the surfactant along the wellbore and deeper into the matrix thereby maximizing oil recovery.

In conventional injection with sonic or jetting oscillators, the fluid for stimulation is injected directly down the well, parallel to the wellbore. The hope is that some of the fluids will penetrate into the formation through the sides of the wellbore (Figure 4).

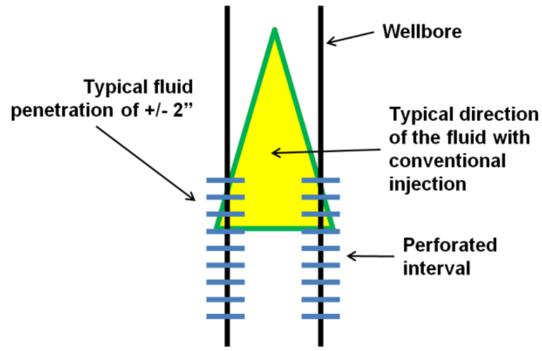

Figure 4: Direction and penetration of the fluid, with most remaining in the wellbore, with conventional tools used for stimulation.

In contrast, stimulations performed with Powerwave the tool is placed directly at the perforated interval (or open hole), and the fluid is injected out the sides of the tool, directly into the formation (Figure 5).

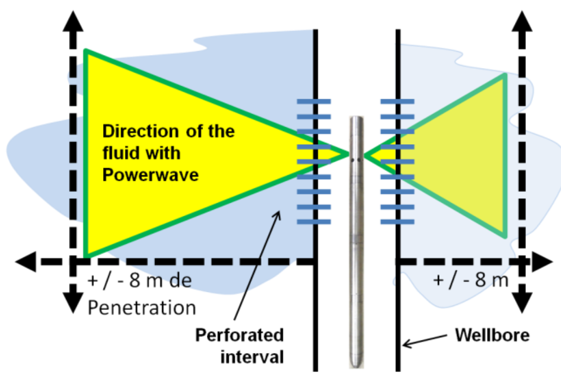

Figure 5: Direction and penetration of the fluid directly into the reservoir with Powerwave's pulsing tool used for the stimulation

Moreover, the fluid pulsing tool is moved up and down within the completed interval (or open hole), so that it stops at different stations 3-5 metres apart within the interval, injecting fluid at each station, for a pre-determined time and volume to achieve both maximum dispersion and matrix penetration. In creating a stimulation program, Wavefront's engineers consider the porosity, permeability, and oil viscosity in order to adjust the time and volume needed for each interval.

The energy with which the surfactant is injected into the formation comes from within the Powerwave tool itself. The surfactant flows into the closed tool where it comes under pressure (Figure 6).

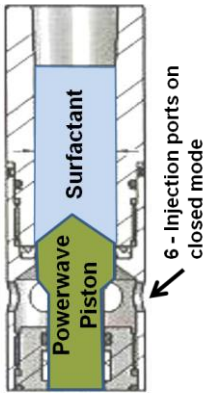

Figure 6: The tool is closed until a pre-set differential pressure is met, storing energy that will add acceleration to the fluid being injected rapidly as a fluid pulse into the formation

When the differential pressure is reached, the piston opens and the highly accelerated flow of surfactant is released into the formation, dilating the pore media and opening new spaces in the formation (Figure 7).

In well stimulations, to reach maximum benefit, it is as important to choose the best treatment fluid as well as the best placement approach to maximize fluid distribution and penetration into the formation. Thus Weatherford's surfactant / solvent / dispersant and Wavefront's high-amplitude fluid pulsing approach are complimentary for stimulation applications.

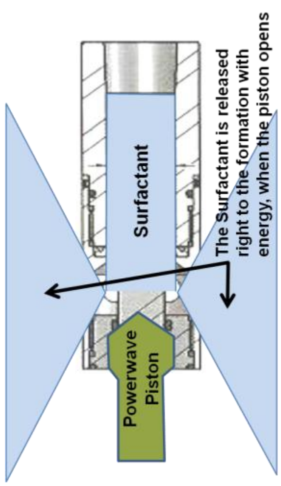

Figure 7: Once the pre-set differential pressure is met (in between 150psi to 1,500psi), the tool opens releasing a strong, highly accelerated pulse of fluid (in this case surfactant) enters the formation

THE PROJECT

FIELD RESULTS AND ANALYSIS

The field results below compare the performance of the surfactant in the stimulation when injected with the fluid pulsing tool (Figure 8 and Figure 9) versus the results achieved when the same surfactant is injected conventionally, with a sonic oscillator (Figure 10). These results show the success of the surfactant in well stimulation, and they also demonstrate that greater fluid distribution and penetration is achieved with high-amplitude fluid pressure pulses.

WELL # 1 (USING FLUID PULSING TO DISPERSE WEATHERFORD'S SURFACTANT)

Oil incremental recognized because of the treatment with Weatherford's surfactant and fluid pulsing: 2,325%

- Well: Producer
- Tubing: 2-7/8", 6.5 lb/ft
- Problem: Accumulation of Asphaltens
- Objective: To clean the perforated intervals, and to improve the heavy oil viscosity to improve the oil transportation.
- Treatment: Wec-Flow (from Weatherford), injected with the pulsing tool Powerwave (from Wavefront).
- Interval: 2,130 m to 2,531 m
- Viscosity: 15.2° – 16.3° API
- Porosity: 7 - 8 %
- Permeability: 0.11 – 0.17 mD
- Perfs pressure: 3300 psi
- WHP: 210 - 300 psi
- BHP: 691 - 889 psi
- Fluid # 1: Weatherford's surfactant at 5%
- Volume: 5 bbls
- Fluid # 2: KCl
- Volume: 152 bbls
- Total Volume: 157 bbls (25 m3)
- Treatment rates: 0.5 / 0.8 bpm
- Soaking time after the treatment: 24 hrs
- Production before the treatment: 0 bopd
- Historical pick production: 60 bopd
- Pick production after the treatment: 232 bopd
- Oil viscosity after the treatment (5%): 15° API
- WHP before the treatment: 0 psi
- WHP after the treatment: 210 – 740 psi

WELL # 2 (USING FLUID PULSING TO DISPERSE WEATHERFORD'S SURFACTANT)

Oil incremental recognized because of the treatment with Weatherford's surfactant and Powerwave fluid pulsing: 791%

- Well: Producer
- Tubing: 2-7/8", 6.5 lb/ft
- Problem: Accumulation of Asphaltens
- Objective: To clean the perforated intervals, and to improve the heavy oil viscosity to improve the oil transportation.
- Treatment: Wec-Flow (from Weatherford), injected with the pulsing tool Powerwave (from Wavefront).
- Interval: 2,253 m to 2,289 m
- Viscosity: 18.3^o API
- Porosity: 7 – 9 %
- Permeability: 0.7 – 0.17 mD
- Perfs pressure: 3300 psi
- WHP: 146.5 psi
- BHP: 3800 psi
- Fluids # 1: Weatherford's surfactant at 3%
- Fluids # 2: KCL
- Combined Total Volume: 33 bbls
- Treatment rates: 0.5 / 0.6 / 0.7 / 0.8 bpm
- Soaking time after the treatment: 24 hrs
- Production before the treatment: 22 bopd
- Production after the treatment: 174 bopd
- Average incremental after a conventional treatment without Powerwave: 40 bopd (December 2012)
- Oil viscosity after the treatment (3%): 28^o API
- WHP before the treatment: 100 - 220 psi
- WHP after the treatment: 330 – 860 psi

WELL # 3, (USING A CONVENTIONAL TOOL TO DISPARSE WEATHERFORD'S SURFACTANT)

Oil incremental recognized because of the treatment with Weatherford's surfactant and a conventional acoustic tool: 415%

- Well: Producer
- Tubing: 2-7/8", 6.5 lb/ft
- Problem: Accumulation of Asphaltens
- Objective: To clean the perforated intervals, and to improve the heavy oil viscosity to improve the oil transportation.
- Treatment: Wec-Flow (from Weatherford), injected with an acoustic conventional tool.
- Interval: 2,220 m to 2,400 m
- Viscosity: 18^o API
- Porosity: 7 – 9 %
- Permeability: 0.7 – 0.17 mD
- WHP: 100 psi
- Fluid # 1: Weatherford's surfactant at 3%
- Volume: 94.5 bbls
- Fluid # 2: KCl
- Volume: 93 bbls
- Total Volume: 187.5 bbls (22.4 m3)
- Soaking time after the treatment: 24 hrs
- Production before the treatment: 14 bopd
- Production after the treatment: 54 bopd
- Oil viscosity after the treatment (3%): 27^o API
- WHP before the treatment: 90 - 120 psi
- WHP after the treatment: 80 – 500 psi

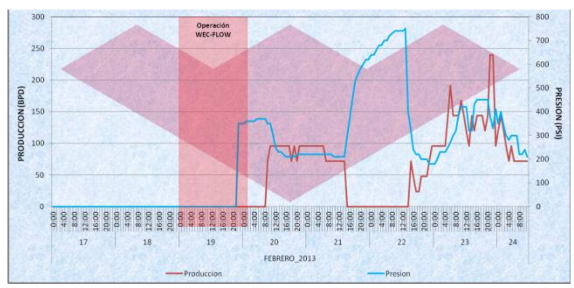

Figure 7: Production and pressure, before and after the treatment

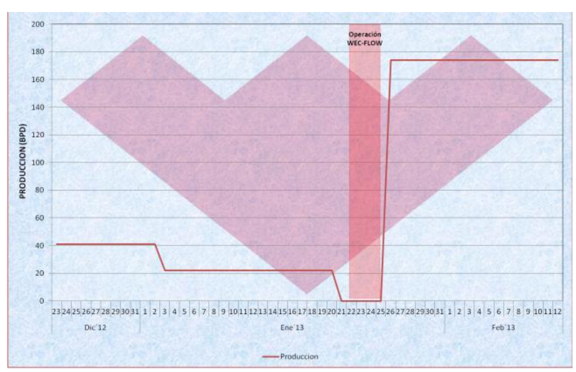

Figure 8: Production, before and after the treatment

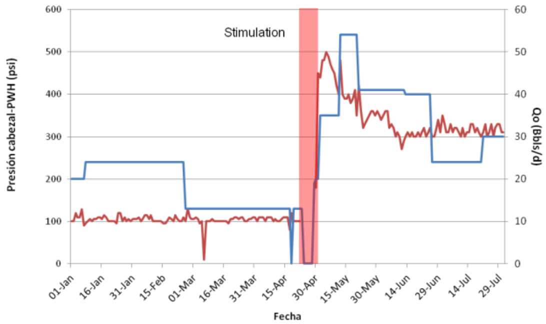

Figure 9: Production and pressure, before and after the treatment

CONCLUSION

The initial "oil field" results demonstrate that proper placement of Weatherford's surfactant treatment fluid using high-amplitude fluid pressure pulsing resulted in greater post stimulation oil production gains versus conventional placement methods. The initial results also demonstrate the Wavefront's high-amplitude fluid pulsing approach, provides for more efficient distribution and deeper penetration into the reservoir over other methodologies.

ACKNOWLEDGMENTS

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REFERENCES

1. Explanations in the section "Theory and Applications of Fluid Pulsing Technology" are taken from Earl Webb, Khalil Hassan, and John Warren. "Case Histories of Successful Stimulation Fluid Dispersion Using Pressure Pulsing Technology," 12th European Coiled Tubing and Well Intervention Roundtable, 2006.

2. Due to policies of PEMEX in Mexico, we cannot introduce in this paper the name of the wells, reservoirs, and field names.