Announcement

Unico Joins Regal Beloit Corporation

We are very pleased to announce that Unico, Inc., has signed an agreement to be acquired by the Regal Beloit Corporation (NYSE: RBC). As you can see from the statement below by Henry Knueppel, chairman and CEO of RBC, this is an important strategic addition to the Regal Beloit family of companies. That family includes producers of motors, gearboxes, and generators, which are important ingredients in many Unico systems.

Knueppel commented, "Unico is one of the most exciting acquisitions in RBC’s history. It is about bringing together a full electromechanical solution for customers. Investors should view this acquisition as the start of an adjacent platform. Unico has experienced great organic growth and built a platform for dynamic future growth. They have an incredibly talented leadership team that will create the nucleus of this new platform for Regal Beloit. We believe the marriage of our combined products will drive development and adoption of new energy-efficient and intelligent solutions. We simply could not be more excited about this marriage."

You can learn more about RBC on their website, www.regalbeloit.com, and read the full content of their recent statement regarding Unico.

Sincerely,

Thomas L. Beck
President and CEO of Unico
Seismic Stimulation for Enhanced Oil Recovery

by Jim McCrickard development engineer

Seismic stimulation is a new field-wide enhanced oil recovery technique. A source of low-frequency seismic waves is installed downhole in a centrally located, abandoned well at the depth of the oil-bearing formation. Oil production is typically enhanced by between 10% and 30% in producing wells in the region surrounding the source well. The size of the affected region is typically between one and two miles in diameter, but it can be larger depending on factors such as the strength of the source, the geology of the reservoir, and the gas/oil ratio. This article reviews some of the scientific evidence for seismic stimulation, discusses the primary mechanism by which researchers believe it works, and describes the Unico seismic stimulation system.

Scientific Evidence

Beginning in the 1930s, there have been reports by oil field operators that oil production increased in the aftermath of nearby earthquakes. Numerous laboratory studies conducted by Russian researchers, beginning in the 1970s, have confirmed that low-frequency acoustic waves have a positive effect on oil mobility. Russian oil field studies during the 1990s using surface vibrators, designed for seismic exploration, found that seismic waves resulted in increased oil production in shallow reservoirs. Beresnev and Johnson (1994) provide an excellent review of early research in this area, most of which occurred in Russia. It has only been during the last decade that there has been much research on this subject in the United States.

There have been a handful of laboratory studies in the United States during the past decade. One study, Li et al. (2005), used an etched-glass micromodel, consisting of a 50-by-50 square lattice of circular pores connected by straight pore throats, to replicate an actual reservoir. The sizes of the pores and pore throats were normally distributed over a range of values. Initially the pore space was completely filled with trichloroethylene (TCE), which had been dyed blue. TCE is insoluble in water and played the role of oil in this study. Water was pushed through the system at a constant pressure drop to simulate a water flood. The saturation of TCE as a function of time during the water flood was measured using an optical imaging system until the saturation of TCE reached an unchanging residual level. The entire simulated water flood was repeated multiple times, both without vibration and with vibration of a fixed amplitude and frequency. The
Figures 1 and 2 display the primary experimental results of the study. Figure 1 plots TCE saturation versus time for four different trials—one with no vibration and the other three with vibration at frequencies of 10, 30, and 60 Hz, all at a fixed amplitude of 3.5 m/s². One can see that TCE was removed from the system between two and three times as rapidly with vibration than without and that the residual saturation of TCE was less with vibration than without. Furthermore, it is evident that within the range of frequencies tested, lower frequencies were more effective at mobilizing TCE than higher frequencies.

Figure 2 plots TCE saturation versus time for five different trials—one with no vibration and the other four with vibration at amplitudes of 0.5, 1.8, 3.5, and 5.0 m/s² at a fixed frequency of 30 Hz. One can again see that TCE was removed from the system more rapidly with vibration than without and that...
the residual saturation of TCE was less with vibration than without. Moreover, within the range of amplitudes tested, it is clear that the higher the amplitude, the more rapidly TCE is removed from the system and the lower the residual saturation.

Roberts et al. (2001) obtained similar results in a laboratory experiment that used a sand core for the porous medium rather than a glass micromodel.

Applied Seismic Research Corporation, of Plano, Texas, has developed a downhole seismic stimulation tool that has been used in three field studies funded by the Department of Energy (DOE) during the past decade, including one that is just beginning in an oil field in Oklahoma. Figure 3 shows the results of one of these studies, *LBNL Report 50633*, which was lead by researchers from Lawrence Berkeley National Laboratory (LBNL) and Los Alamos National Laboratory (LANL). The test was conducted in a diatomite formation at the Lost Hills field in California.

![Figure 3—Lost Hills, California, results shows that 26 wells responded to both earthquakes and seismic stimulation.](image)

The Lost Hills field was stimulated using the ASR tool for a total of 50 days during two separate periods between July and November 2000. By the end of the stimulation, the 26 producers showed an increase in oil production of 26% and an increase in oil cut of 29%. The effect of the stimulation continued for a couple of months after the source was turned off. One interesting side note is that the researchers realized, after reviewing the historical production data, that an increase in oil production had occurred a
year earlier in response to two earthquakes that took place a month apart at a distance of 230 miles from the field. Remarkably, the increases in oil production and oil cut in the aftermath of the earthquakes, as well as the duration of the effect, were very similar to those produced by the ASR tool.

Figure 4 shows the results obtained by seismic stimulation of the Elk Hills field in California, a sandstone formation, during a pilot study conducted by Occidental Petroleum using the ASR tool. In this case, two tools were installed to cover an area that encompassed 68 producers. Oil production increased by 42%, a 686 bpd increase, and oil cut was up by 29%.

![Figure 4](image.png)

*Figure 4—Seismic stimulation of 68 wells at an Elk Hills, California, field produced a 42% increase in production and a 29% increase in oil cut.*

**Primary Mechanisms**

The leading theoretical explanation for the mechanism by which seismic stimulation works is that seismic waves mobilize some fraction of the oil ganglia, assumed to be the nonwetting phase, that are trapped on capillary pressure barriers in pore throat constrictions. Figure 5, taken from Li et al. (2005), shows an oil ganglion flowing to the right that has encountered a constriction in a pore throat. There is water, the wetting phase, in the pore throat to the right and left of the ganglion. As the oil ganglion enters the constriction, a capillary pressure imbalance develops between the leading and trailing edges of the ganglion as the radius of curvature of the right-hand meniscus decreases and becomes smaller than that of the left-hand meniscus. The size of the capillary pressure imbalance is given by the
Laplace equation,

\[ P_c = \frac{2s}{R_{\text{right}}} - \frac{2s}{R_{\text{left}}}, \]

where \( s \) is the oil/water interfacial tension. If the pressure difference across the ganglion, \( \Delta P \), due to the oil well toward which fluid is flowing exceeds the capillary pressure barrier at the narrowest point of the constriction, then the ganglion will flow past the constriction. If it is smaller, then the ganglion will be trapped and the pore throat will be blocked.

Figure 5—An oil ganglion, the nonwetting phase, is surrounded by water, the wetting phase. The ganglion is trapped by the increased capillary pressure at a pore throat constriction. Adapted from Li et al.

Figure 6—The combined force on an oil ganglion (red line), which is due to the static pressure difference across it (\( \Delta P_s \)) plus the vibratory force of a seismic wave, exceeds the capillary pressure barrier (\( \Delta P_o \)) for part of the sinusoidal cycle. Adapted from Li et al.

Seismic stimulation adds a time-varying pressure gradient to the picture. Figure 6, adapted from Li et al. (2005), shows graphically that if the sum of the static pressure difference across the ganglion due to the oil well and the time-varying pressure difference due to the seismic wave exceeds the capillary pressure barrier for at least part of the wave cycle, then the
ganglion has the possibility of being mobilized. There is an additional criterion, however. The frequency of the wave must be sufficiently low that the forward meniscus of the ganglion has enough time to advance to the narrowest point in the constriction before the forward force drops below the unplugging threshold. Based on these arguments, one would expect that the greater the amplitude and the lower the frequency of the seismic wave, the more effective it would be at mobilizing trapped oil ganglia. Thus, this theoretical model is able to account for the laboratory data that was cited earlier.

Pride et al. (2008) have performed computer simulations based on these ideas. Their simulations show that the coalescence of mobilized oil ganglia into larger units enhances oil production even further. Longer ganglia are less likely to be trapped on capillary pressure barriers than shorter ones since the static pressure difference across a ganglion is the static pressure gradient multiplied by the length of the ganglion.

Seismic Stimulation System

Unico has partnered with ASR to offer a seismic stimulation system consisting of the ASR source driven by a Unico HRP™ hydraulic rod pump system. The ASR tool is installed downhole at the end of a conventional tubing string and sucker-rod string and is driven by a surface sucker-rod pump. The well bore is plugged at the bottom and filled with water. On each upstroke of the surface pump, a volume of water downhole is compressed to a pressure of about 3,500 psi above the ambient hydrostatic pressure, storing almost 50,000 J of energy. Near the top of the stroke, the energy is suddenly released in the form a hydrodynamic shock wave that travels down the well bore and radiates from the bottom of the well into the reservoir in the form of a seismic wave.

The motion profile of the Unico HRP™ controller for the ASR tool has been specifically designed to extend the life of the tool in ways that are not possible when the tool is driven by a traditional beam pump. The Unico GMC® Global Monitoring and Control service allows the user to monitor and control the seismic source remotely via an Internet browser.

A large fraction of the original oil in place in a reservoir is left behind, stranded on capillary pressure barriers, at every stage of recovery. Typically 90% of the original oil in place remains at the end of primary recovery. Between 60% and 85% remains after secondary recovery, usually a water flood. Even after tertiary recovery techniques have been applied, between 40% and 70% or more of the original oil in place is left behind in the
reservoir. To this point, seismic stimulation has only been used in conjunction with water floods. However, when one considers the physical mechanism by which it works, it seems likely that it would act to enhance oil production at any stage of recovery.

References


In Future Issues...

Look for the following articles in upcoming issues of *Oil & Gas Automation Solutions*:

- Unico opens new offices in North and South America
- Field tests of methods to eliminate rod pump gas locking and interference
- Reducing power consumption and improving power factor of beam pumps
- Using a torque economizer mode to improve efficiency and reduce gearbox stress
- Control options to ride through power disturbances
- Loss of methane gas production due to overpumping CBM wells
- Use of low-profile CRP® and LRP® pumping units with traveling irrigation systems
- Air counterbalance increases LRP® linear rod pump lift capacity