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INDUCED CHANGES IN OIL FLOW BEHAVIOR

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Laboratory and Field Observations of Stress-Wave Induced Changes in Oil Flow Behavior

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Summary

We present recent results of laboratory and field experiments designed to validate and quantify the phenomenon of seismically enhanced oil production in marginal reservoirs. Controlled laboratory experiments were performed where mechanical stress oscillations at 100 Hz or less were applied to sandstone cores while flowing oil and/or brine at constant flow rates. Steady-state flow and simulated flooding experiments indicated that stress stimulation causes significant changes in the ability of one fluid to displace the other and on the preference that the rock has for trapping one fluid over the other. For Berea sandstone, which is highly water wet, stress stimulation caused oil production to be impeded during water floods and caused the bulk fluid pressure drop across the core to increase during steady-state simultaneous flow of oil and brine. A possible explanation of these observations is that stimulation caused the core to become more oil wet.

Field stimulation tests on producing reservoirs at Lost Hills, California were performed using a downhole fluid pressure pulsation device. Stimulation was applied in one well for 50 days total during July - November 2000. Two groups of producing wells were monitored for changes in oil cut and oil production during the test. A control group of 26 wells displayed an oil-cut increase of 29% and an oil production increase of 26% which are clearly correlated with the stimulation treatment. A larger group of 60 wells showed 11% oil-cut and 17% production increases. Similar increases were observed during the October 1999 Hector Mine earthquake, magnitude 7.1, in the Mojave Desert about 230 miles from Lost Hills. Downhole seismic monitoring of the stimulation wavefield is being used to help quantify the frequency range and energy threshold required for effective production enhancement.

Introduction

Roughly 60% of domestic oil resources remains unproduced, partially due to limitations in existing EOR methods. Anecdotal production data, as well as historic field and laboratory experiments performed by Russian and U.S. researchers, have shown that seismic (stress) wave stimulation can enhance oil mobility and total recovery in mature reservoirs. Low-amplitude seismic waves in the frequency range of roughly 10-500 Hz can directly increase oil mobility over large distances. Previous field tests with different seismic sources have yielded mixed or inconclusive results for enhancing oil production. In some cases seismic stimulation increased production rates by

50% or more, but in other cases production was unchanged or actually declined. This is due primarily to the fact that existing laboratory and field experimental data are not comprehensive enough to allow prediction of the physical conditions under which stress-wave stimulation is most effective. Recent laboratory and field research is beginning to provide the experimental data needed to identify physical mechanisms which govern the seismic stimulation phenomenon. The preliminary results presented here are compelling because they were obtained under controlled experimental conditions and show a clear correlation between applied stress waves and fluid production behavior. As more data are collected for a wider range of physical conditions and downhole source technologies, stress-wave stimulation should eventually become one of the most valuable and predictable enhanced recovery tools available to the oil and gas industry.

Experimental Results

2-phase fluid experiments were completed on stimulated enhancement of oil and brine flow for different flow-rate ratios. The results indicate that stress stimulation causes water-wet rocks to trap oil. This implies reservoirs that are at least partially oil wet are likely candidates for stimulation, as the treatment may cause formation water to be trapped and thus increase the oil cut.

For the water flooding tests a custom oil/water separation column was used to measure real-time changes in oil and water production history during drainage and imbibition runs. Numerous flooding runs were performed with brine and 10-weight oil. The resulting data indicated that stimulation enhanced brine production during the oil floods. Although contrary to the desired effect, discussions with industry partners indicate this may be due to the highly water-wet nature of Berea sandstone and that stimulation may be more effective in reservoirs that are at least partially oil wet. Tests on oil wet cores may confirm this hypothesis.

Several field tests were conducted by Chevron and Applied Seismic Research Corporation (ASR). The first test is at the Chevron Lost Hills site in Central California in the Diatomite formations. In this test ASR's downhole fluid pulsation source was placed in a well at approximately 800 feet depth and activated with pumping rods from the surface. This creates a pressure pulse wave in the wellbore fluid which travels down the well and out into the formation through the perforated casing at 2200 to 3600 foot depth. The hypothesis is that this pulse of energy

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stimulates the reservoir. A 12-day stimulation test was conducted with this device during July 2000. Due to the short duration of the test exact response to the stimulation is difficult to quantify but the initial results are encouraging. Twenty test wells at distances from 200 feet to 2300 feet showed possible production increases during stimulation, and a return to previous production after stimulation stopped. It is interesting to note that there was no overall increase in fluids, just an increase in the oil cut, which is what has been observed in other successful cases of stimulation. It was also noticed by Chevron and ASR that there was an apparent increase in production that occurred after the magnitude 7.1 Hector Mine earthquake on October 16, 1999 in the Mojave Desert, which is about 230 miles away. A set of 48 wells was used to observe production changes from the earthquake over about one square mile. The ground motion from a 7.1 event at the surface of the field would be on the order of 1 mm at this distance. The acceleration at 1 hertz would be about 0.1 percent of gravity. The energy from this earthquake is assumed to be much larger than that generated by the ASR source. Thus, since the ASR source appears to have increased production at Lost Hills, the threshold of energy required to stimulate production in this case is much less than that generated by the earthquake. The source measurements to be made during the next tests will allow us to better quantify this threshold.