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## **ELASTIC WAVE GENERATOR FOR ENHANCED OIL RECOVERY**

BY

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## THE OPPORTUNITY

A water-flooded oil field is considered depleted when it become uneconomical even though 50% to 60% of the oil remains in the field. Of the many techniques that have been tried to economically recover this residual oil, elastic wave or acoustic stimulation has been shown to be promising. Both laboratory and field tests have shown improved the oil recovery in these depleted fields, with elastic wave stimulation (below 100 Hertz) shown to be particularly effective. These tests have also shown that the optimum excitation amplitude and frequency depend on the specific geological characteristics of the reservoir and the properties of the oil in the field.

A cost effective means to recover the oil remaining in depleted oil fields can greatly increase the amount of recoverable oil in existing fields with worldwide economic effects.

## THE SOLUTION

Hydroacoustics Inc (HAI) has a 50-year history of providing high power, low frequency acoustic sources for both U.S. Government and commercial applications that require elastic wave or acoustic excitation in the frequency range from 5 to 500 Hertz. This mature technology can be applied directly to provide elastic wave stimulation to a depleted oil field. The amplitude and frequency of these HAI elastic wave generators can be selected to optimize the oil recovery in different oil field conditions. Whereas many of the enhanced oil recovery techniques considered to date generate the elastic wave within the well casing, the HAI approach will generate these waves directly in the water-filled cavity below an injection well. This approach applies the vibratory energy directly into the fluid medium containing the flood water and the trapped oil globules providing an effective, low cost procedure for enhanced oil recovery in depleted fields.

HAI is seeking a partnership to adapt the mature HAI technology to enhanced oil recovery, specifically to assist in the development, testing, and production of an HAI elastic wave generator as well as providing down hole design assistance, marketing and distribution support, and development funding.

## BACKGROUND

### ELASTIC WAVE STIMULATION BACKGROUND

Since the 1950's, hundreds of investigators, both in the U.S. and abroad, have explored the effects of elastic wave stimulation on the oil recovery rate. These studies included waves with frequencies as low as 1 Hertz to well above a megahertz. The higher frequency waves have a local effect (on the order of a few meters) and are used primarily for well cleaning. The lower frequency waves can have a much larger effective range (approaching hundreds of meters) and are useful in stimulating numerous recovery wells in a reservoir.

Recently the U.S. Department of Energy (DOE) has funded joint programs involving the Los Alamos National Laboratory, the Lawrence Berkeley National Laboratory, several universities, and several industrial companies. Tests in both the laboratory and field have shown that low frequency elastic waves (below 100 Hertz) can enhance the oil recovery rates by as much as 50%. These tests also show that pore pressure elastic waves as small as 70 Pa (0.01 psi) can improve the oil mobility and recovery rate.

Current research and analytical modeling are attempting to define the underlying mechanisms to explain how elastic wave stimulation can improve the fluid flow rates in abandoned oil fields. Several mechanisms have been suggested to explain why elastic wave stimulation increases the oil recovery rate. Oscillations caused by the elastic waves may induce the small, individual oil droplets to coalesce thereby increasing the oil flow. Elastic waves may increase the wettability of the formation material allowing the water flooding to be more effective. Exposure of laboratory samples to elastic waves has reduced the oil viscosity, perhaps caused by the heat generated by higher frequency stimulation. Elastic waves may increase the permeability of the oil bearing formation by “unplugging” the pores and pore throats in the formation. Elastic waves may also reduce the permeability by reducing the surface tension between the formation and oil-water mix.

When the current research is complete, the results will guide the selection of the elastic wave parameters (minimum amplitude and maximum frequency) that produce the optimum results for various geological and formation conditions and for different fluid properties. Until these studies are complete, the inherent flexibility of the HAI source can be used to generate elastic waves of different frequencies and amplitudes in order to experimentally arrive at the best elastic wave parameters for a particular oil field.

## HYDROACOUSTICS INC BACKGROUND

The HAI technology was initiated during a graduate program at Harvard University and was further advanced in the Hydroacoustics Laboratory of the Electronics Division of General Dynamics Corporation in the early 1950's. The main applications of this technology were anti-submarine warfare, vibratory welding of plastic, and impact rock drilling and pile driving. In 1972, the Hydroacoustics Inc was formed when the GD facility in Rochester New York was closed.

HAI has a 45,000 square foot facility in Henrietta, New York where it maintains its leadership role in the engineering and manufacture of unique, high power, low frequency acoustic devices that generate either continuous wave or impulse energy. Examples of current HAI product applications include covert, long-range, acoustic communications, anti-submarine warfare, mine counter-measures, protection of high value marine assets from underwater terrorist attacks, long-range acoustic scientific measurements, and underwater seismic exploration.

HAI is uniquely qualified to design, manufacture, and test a system for elastic wave stimulation of depleted oil fields.

## HAI ELASTIC WAVE GENERATOR BACKGROUND

The HAI elastic wave generator is configured to pass through a 5-inch casing with the wave generating hardware extending below the bottom of the casing and into the water-flooded chamber of an injection or production well and to withstand the challenging temperature and ambient pressure environment at the bottom a 5,000-foot deep well. The generator can be configured to produce either continuous waves or impulsive waves.

Electrical power from the surface is transmitted through cables in the drill string to an electrical motor, which drives a hydraulic pump in the wave generator. An electrical signal from the surface determines the amplitude and frequency of the elastic wave stimulation, which allows the operator to optimize the elastic wave properties for the specific characteristics of the oil field. The HAI elastic wave generator can also be configured to use the injection fluid itself to provide the power for the generator.

The HAI generator, which is based on proven Hydroacoustics Inc technology, converts the hydraulic energy from the pump into low frequency acoustic energy (elastic waves) within the water-flooded chamber and thereby into the flooded oil-bearing formation. The generator is designed for reliable, continuous operation, which will minimize the downtime for maintenance, service, and repair.