[AV]Role of Stress Field and Hydrofracturing in Enhanced Oil Recovery through 3-D Fluid-Injection*

By
Kenneth J. Hsu[1]

Search and Discovery Article #110065 (2008)
Posted August 5, 2008

*Adapted from oral presentation at AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008

[1]Lazarus Oil International, Haslemere, United Kingdom

Abstract

Artificial aquifers in hydrologic cells can be used in enhanced oil recovery by means of 3-D water-injection, with conventional hydrofracturing to make sets of vertical extensional fractures across two parallel horizontal boreholes. The direction of the horizontal drilling is chosen on the basis of regional stress distribution. The oil reservoir of the EOR system is divided into a series of production strips, which in effect become compartments, so that those strips are sequentially exploited. A first well, drilled into a first portion of the oil reservoir, is for water injection. A second well, drilled into a second portion of the reservoir, is for oil production. Hydrocarbons are driven by injected fluid (water or gas) under a pressure gradient to flow horizontally to sweep the oil of a reservoir in the direction from a source aquifer to a sink aquifer. Each production strip comprises a source aquifer formed by hydrofracturing across the first well and a sink aquifer also formed by hydrofracturing across the second well.

Feasibility studies and computer-simulation models suggest that sweep efficiency can be doubled. Although the technology was invented for EOR of depleted or abandoned fields, it is best applied to newly discovered fields with reservoir-permeability too small to be exploited by conventional technology. A production test at Changqing Oil Field, China, yielded an initial production rate of 280 barrels/day from an oil-bearing siltstone with ~0.1 millidarcy permeability.

This technology (described in US Patent 6,158,517) may also be applicable to exploitation of tar sands and gas hydrates, where hydrocarbons plug the pore space of the host-rock/sediment, so that hydrocarbons can be induced to move vertically across a large vertical cross-sectional area from a source aquifer to a sink aquifer.

Enhanced Oil Recovery with Three Dimensional Fluid Injection

For Depleted Fields

For Abandoned Fields

For Fields with very tight oil reservoirs

A Geometrical Solution Through the Increase of Sweeping Efficiency in EOR by Water (or CO2) Flooding, using current technologies in petroleum production:

Horizontal Drilling

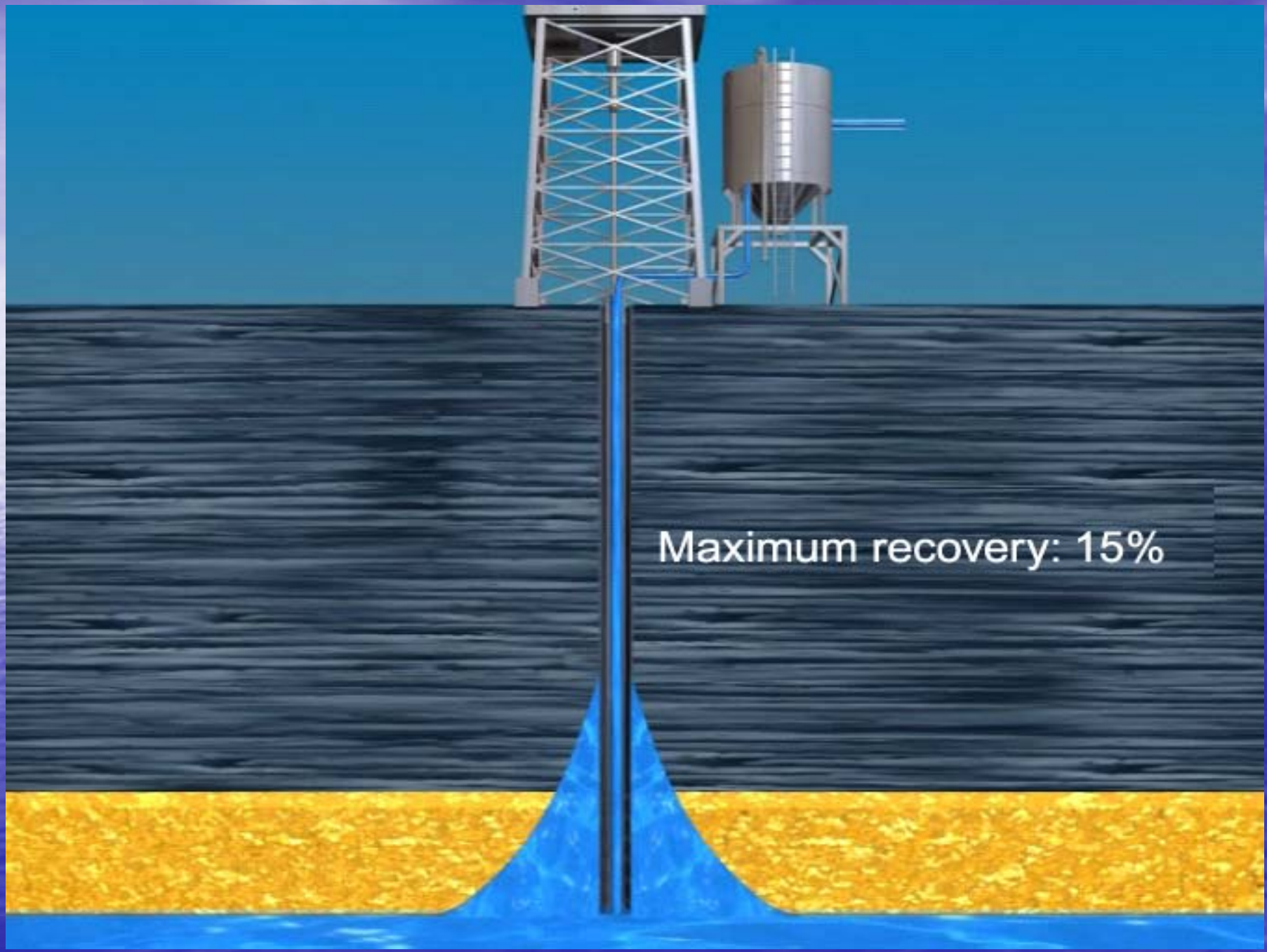
Stress Measurement to determine orientation of wells

Hydrofracturing to Produce Vertical fracture planes

Water Flooding, Steam injection, etc.

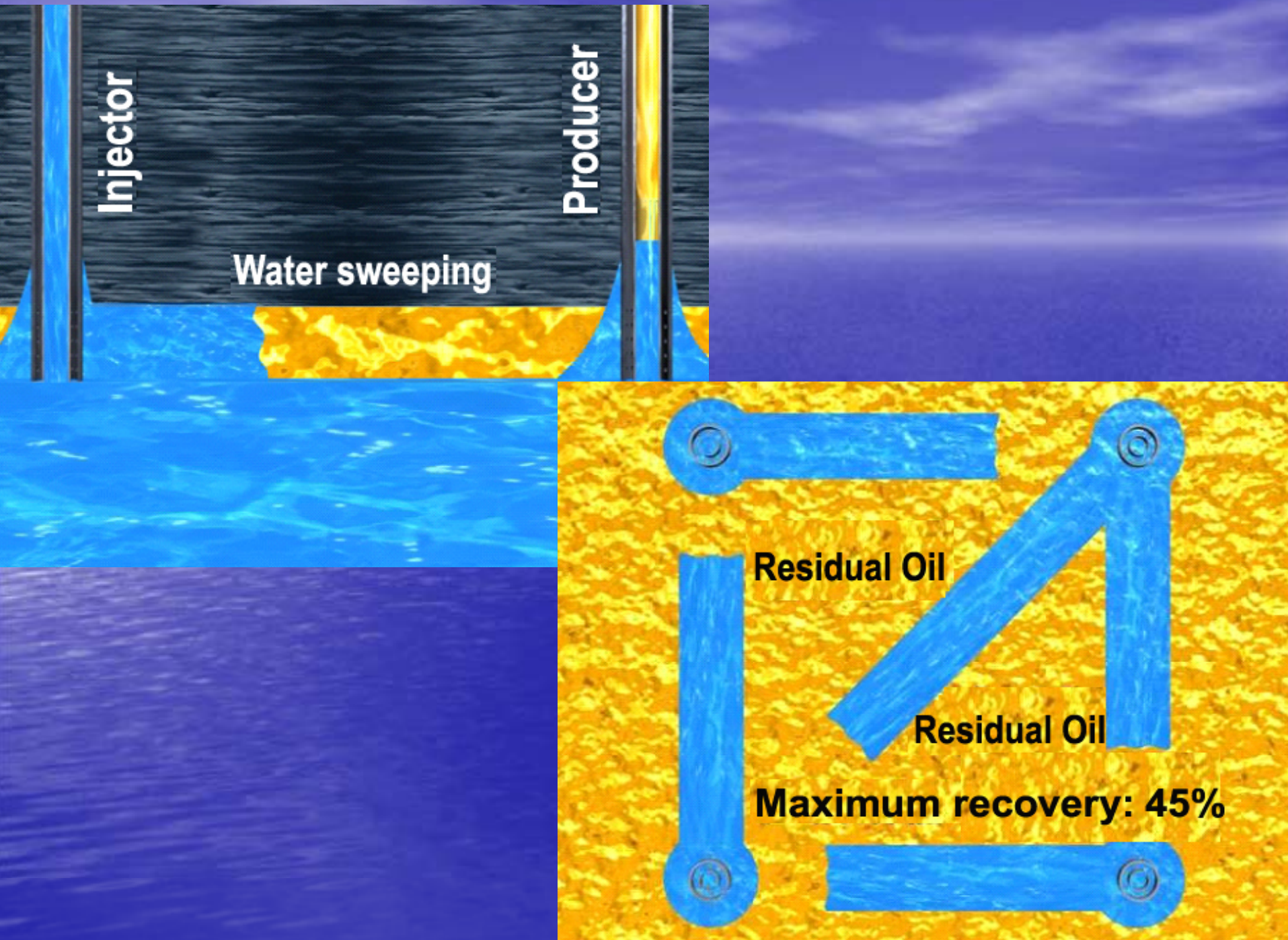
The Current Problem of Residual Oil

- Primary Production:
- Oil flows into the one dimensional point-source of production, under pressure difference.
- Growth of “Water Cone” around the borehole.
- Production stops when oil is prevented by the water cone to enter the borehole.
- Sweeping efficiency 25%


Maximum recovery: 15%

The Current Problem of Residual Oil

- Secondary Recovery
- Oil is driven under pressure from one well (line source) to another (line sink) – Two dimensional sweeping.
- Residual oil left between the path of fluid flow cannot be swept out.
- Sweeping Efficiency: < 50 %


Injector
Producer
Water sweeping
Residual Oil
Residual Oil
Maximum recovery: 45%

Solution to the Problem Sweeping out Residual Oil

- *Long Fracture Planes of definitive width, cutting through oil formations as source and*
- *sink of fluid injection to achieve theoretically possible 100 % sweeping efficiency.*

- ***Difficulties:***
- ***of producing such long fracture planes, such as one between***
- ***vertically drilled wells.***
- ***of building up enough pressure to produce such long fracture***
- ***planes, if fracturing is done by hydrofrac.***

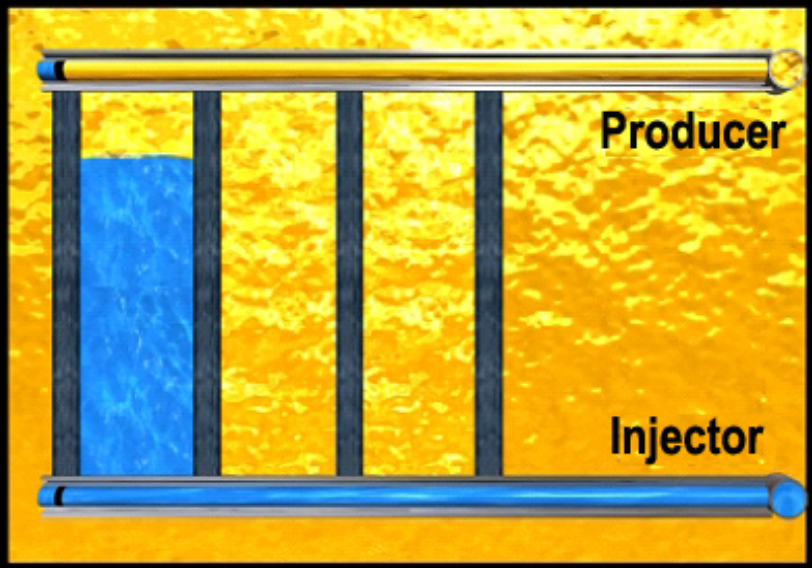
- ***Solution of Difficulties***
- ***Producing fracture planes along the length of horizontally drilling wells.***
- ***Choosing reservoirs with low permeability to build up pressure for hydrofracturing and for water-flooding***

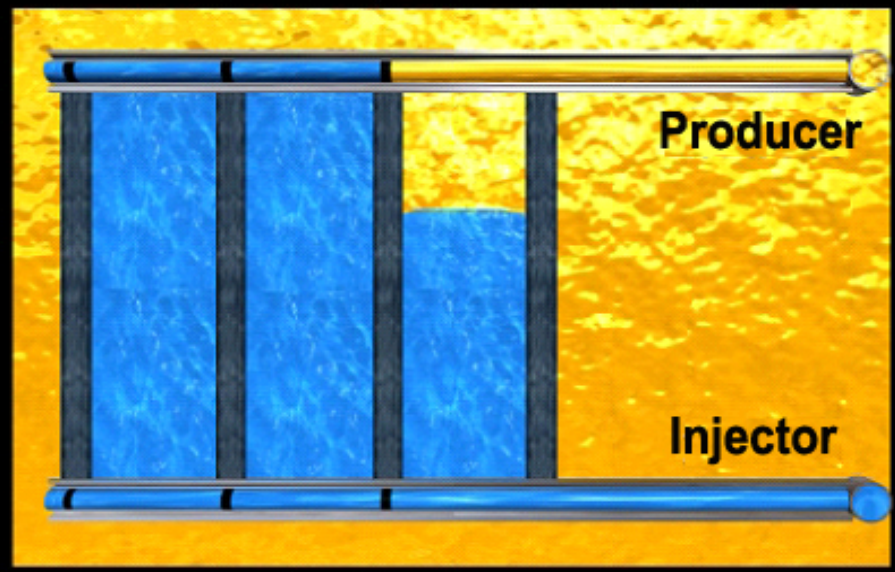
Current Technology of EOR by Horizontal Drilling

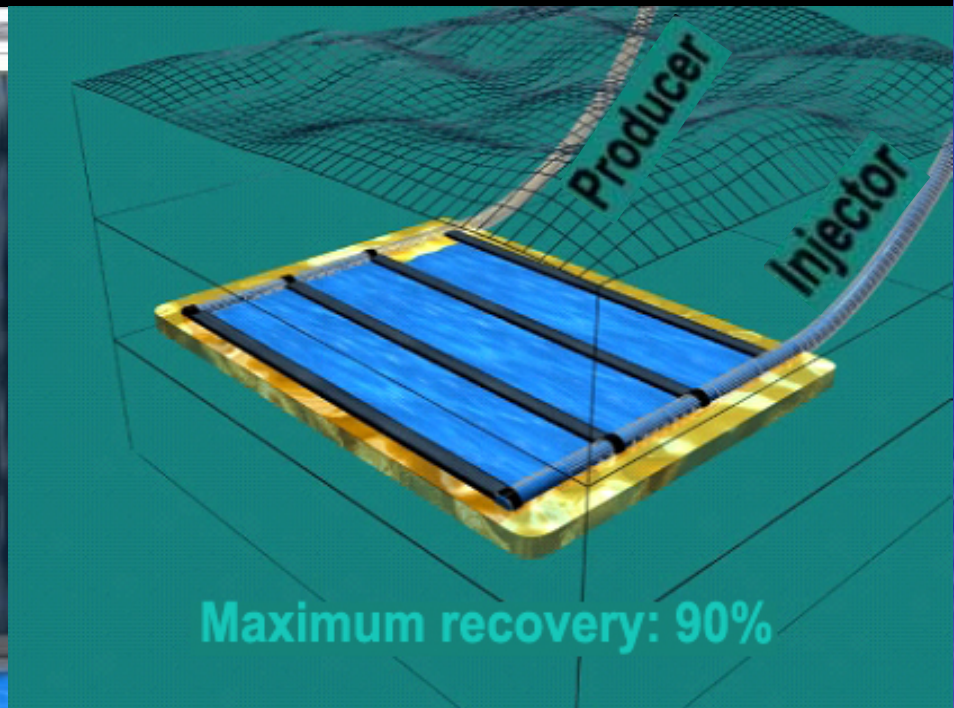
- Oil coming out of line-source of horizontal boreholes. Great boom of oil production after the invention of horizontal drilling.
- Hydrofracturing to increase the permeability around the
- horizontally drilled holes to enhance production.

The Hsu Technology of EOR through 3-Dimensional Water-Flooding.

- 1) Two or more parallel horizontal wells are planned.
- 2) Stress Measurement while a borehole is drilled vertically to determine to direction of horizontal drilling.
- Borehole is drilled in the direction of maximum principal stress, preferably to a depth where vertical, extensional fracture plane is produced by hydrofracturing.
- Proppants are injected to prop up the fracture.
- High pressure fluid is injected for fluid flooding to drived the oil between fracture plans of two parallel horizontally drilled wells.


Producer
Injector


Producer
Injector


Producer
Injector
Maximum recovery: 90%

The History of application

- Invention of the 3-D water-flooding technology by Hsu, and publication of the US patents in 2000, subsequently patents are granted in Canada, 9 Gulf-Coast States, Iran, & Nigeria.
- The technology is not economically applicable during 2000-2005, because of the relatively high cost when crude oil was sold for 12-20 USD per barrel.
- Hsu petitioned in September 2005 the Prime Minister Wen Jiabao of PRC after crude oil price rose above 50 USD per barrel.
- PM Wen immediately instructed the Chinese Petroleum Industry to study the Hsu Technology
- A conference in February, 2006 to evaluate the applicability of the Hsu technology
- Petro-China reported in April, 2006 their first test
- At Changqing Field

The February 2006 Conference

- The Hsu technology is a technologically feasible original invention.
- The Chinese oil industry is advised to apply the technology for EOR not only of oil fields in their possession, but also in fields to be purchased where the Hsu technology is most applicable.
- The Conference delegates appealed to Hsu's patriotism to suspend his activities to promote the licensing of his patents, so that Chinese oil companies could have a priority to purchase oil fields in foreign countries where the Hsu technology is applicable.

The Changqing Success Story I

- April , 2006. Report of the first test by Petro China, with three horizontally wells drilled in the direction of maximum principal stress.
- The reservoir permeability is very low, and is on the average 0.1 md.
- The first test produced 40tons oil per day, - a success considering the extremely low reservoir permeability.

The Changqing Success Story II

- Information from the Internet. Accuracy not guaranteed.
- Changqing field was first discovered in 1907, with 50 kg
- (less one barrel) oil production per day.
- Changqing field was not extensively developed.
- The 1997 annual production was some 10,000 tons per year.
- A new production method was discovered in 2004 - 2005.
- The annual production of the year 2006 was 10 million tons (or some 200,000 barrels per day).
- The annual production of the year 2007 was 20 million tons.

Recommendations

- Contact Ken Hsu by email
- kenjhsu@aol.com

- Contact Ken Hsu by post
- Lazarus Oil International Ltd., UK
- P.O.Box 27
- Haslemere, Surrey
- GU27 3PT
- England