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EOR Field Experiences in Carbonate Reservoirs in the United States

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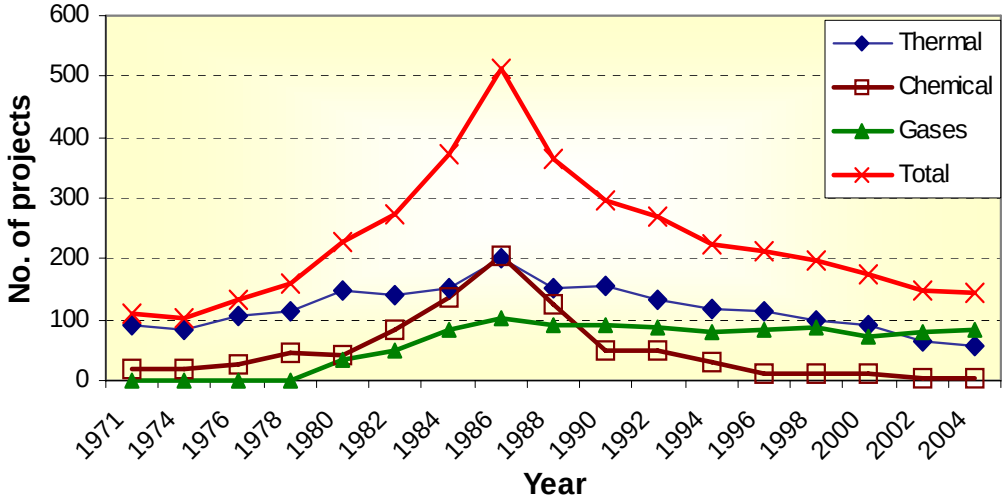
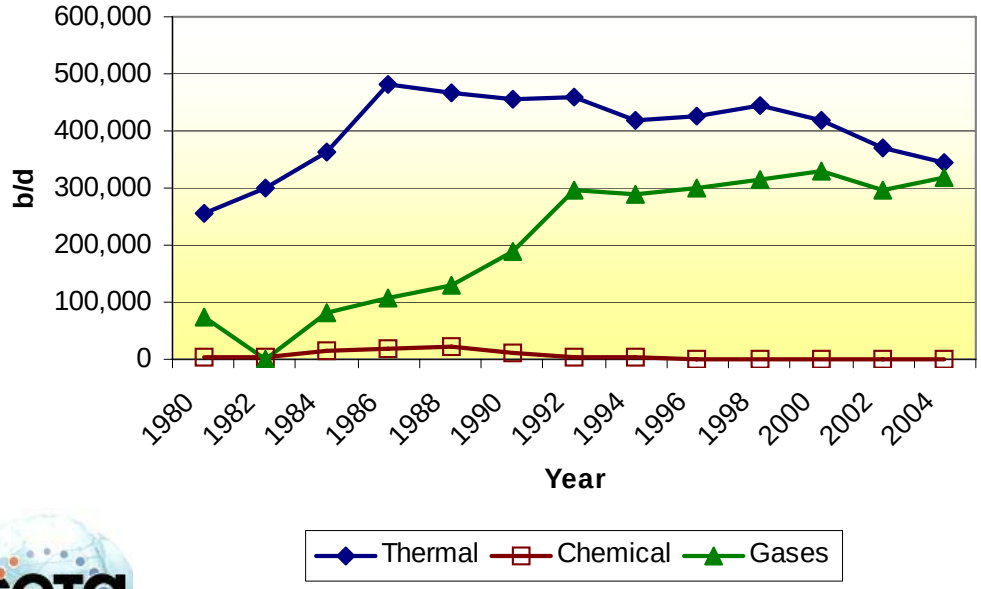
EOR Field Experiences in Carbonate Reservoir in the United States

OUTLINE

- Evolution of EOR projects in the United States.
- U.S. Shallow-Shelf Carbonate Reservoirs: Oil production and reserves
- EOR in U.S. carbonate reservoirs.
  - Gas injection
  - Thermal methods
  - Chemical methods
- New chemical additives.
- Conclusions.

EOR in the United States
Projects and Oil Production





- Number of EOR projects in the U.S have been declined since late 1980's, especially chemical and thermal methods.
- Total number of active EOR projects in the U.S. was 143 (April 2004).
- Total production of these active projects reached 663,451 b/d, 52% and 48% coming from thermal methods and gas injection (mainly CO_2), respectively.
- CO_2 floods are becoming more widespread and outnumber thermal projects since 2002.

Source O&GJ

CETA Center for Energy and Technology of the Americas
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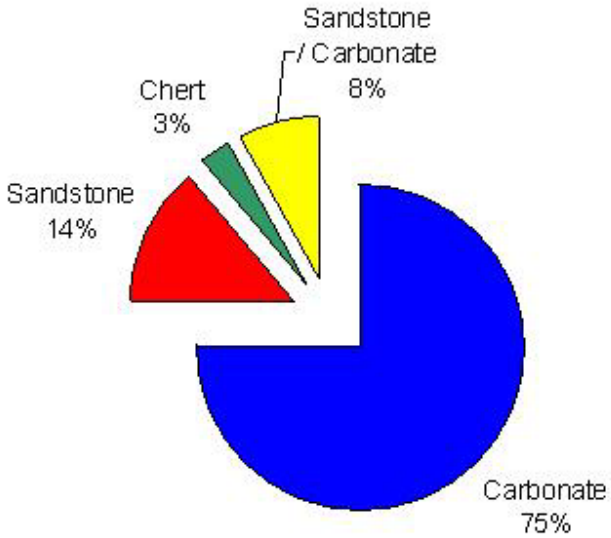
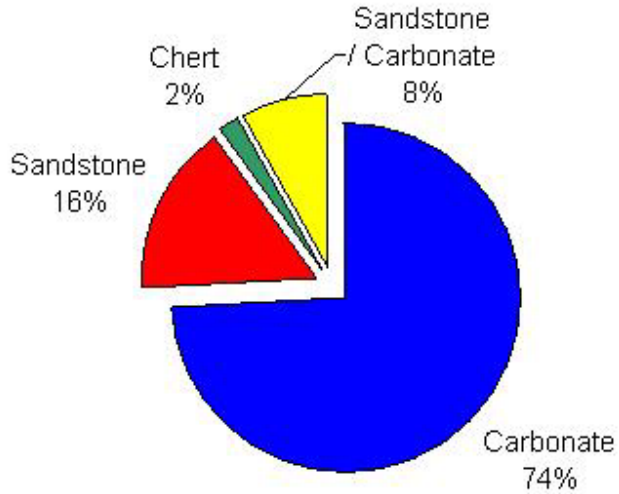
U.S. Shallow-Shelf Carbonate Reservoirs

Oil Production and Reserves



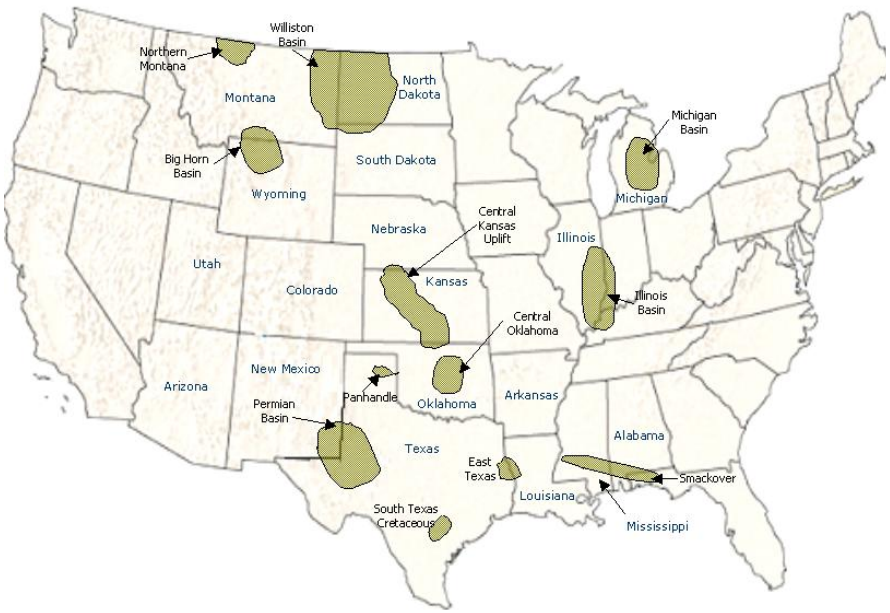
Permian Basin Cum. Oil Prod. through 2000 by lithology (28.9 Bbbl)



Permian Basin Total Oil Prod. in 2000 by lithology (301.4 MMbbl)

- Shallow-shelf carbonate reservoirs (SSCR) are one of the predominant types of light oil (>20°API) reservoirs in the United States.
- SSCR are distributed over 14 States, but the largest concentration is in the Permian Basin (West Texas and Eastern New Mexico).
- Permian Basin produced 17% of total oil production in 2002 and represents an estimated 22% of the proved oil reserves in the U.S.
- Although the Permian Basin reservoirs are approaching maturity, the potential for EOR is still very high, reiterating the importance of oil production from U.S. carbonate reservoirs in the years to come.

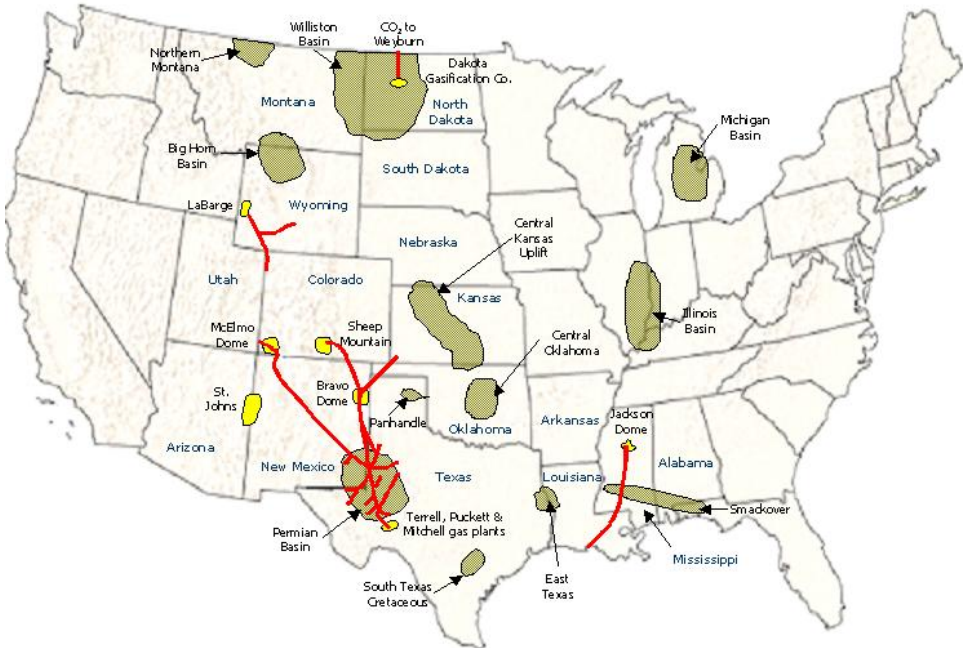
EOR in the United States
Carbonate Reservoirs



Location of Shallow-Shelf Carbonate Light Oil Reservoirs

- Waterflooding and CO_2 floods (WAG) combined with infill drilling strategies have been the most representative recovery methods during the last three decades.
- Of the139 EOR projects in carbonate reservoirs reviewed in the present study, gas injection (73) and chemical floods (57) have been the most field tested EOR methods compared with thermal methods (7).
- Of the 143 active EOR projects reported in April 2004, 58 (≈ 41%) are developed in carbonate reservoirs. Gas injection (50), especially CO_2, is by far the preferred EOR method in these type of reservoir compared with thermal (7) and chemical (1) methods.

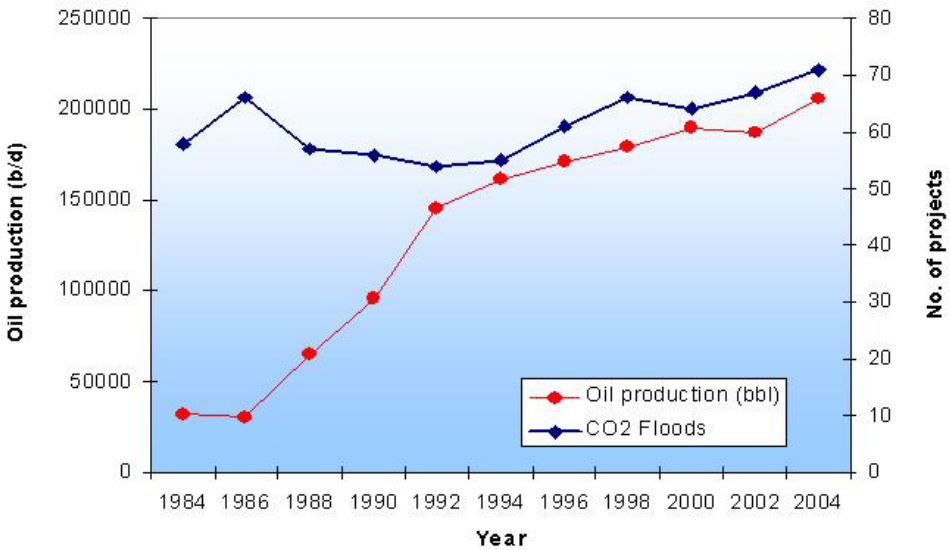
EOR in U.S. Carbonate Reservoirs
Gas injection: Carbon Dioxide

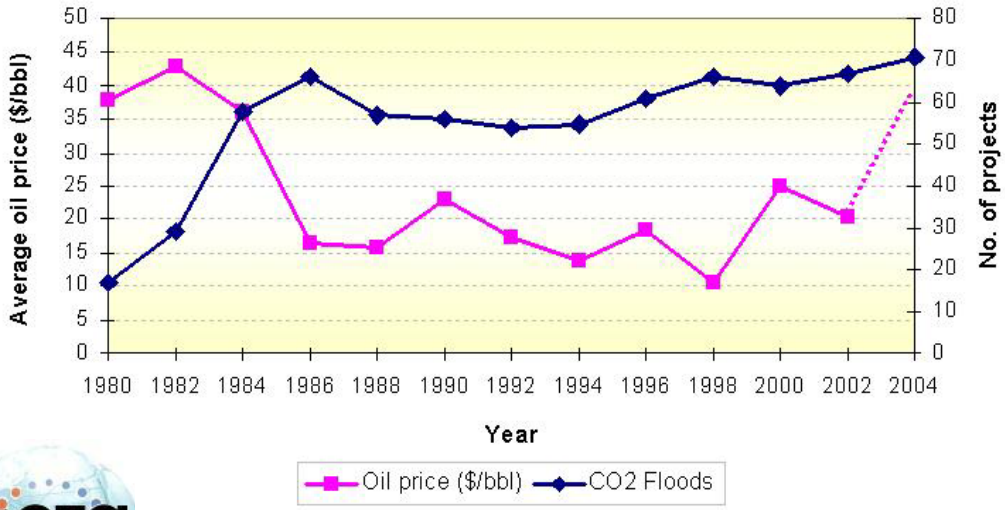


Location of Shallow-Shelf Carbonate Light Oil Reservoirs and some CO_2 sources and pipelines

- CO_2 injection have been the most important EOR process in U.S carbonate reservoirs since early 1980's.
- From the current U.S. active CO_2 floods (71), 48 (67%) are in carbonate reservoirs, mostly in the State of Texas.
- The growing number of CO_2 floods is usually tied to the availability of natural CO_2 sources and transporting pipelines relatively close to the oilfields, especially the Permian Basin, the largest consumer of CO_2.
- CO_2 floods in West Texas can be economically attractive at oil prices of 18$/bbl assuming that CO_2 prices remains below 1$/Mscf.

EOR in U.S. Carbonate Reservoirs
Gas injection: Carbon Dioxide





- The migration towards CO_2 floods is consistent with the rise of energy cost and natural gas prices.
- If we add recent initiatives on CO_2 Capture and Sequestration in United States the likelihood that the number of CO_2 floods will increase is high.
- To date, CO_2 flooding is mostly based on natural sources. If CO_2 projects is to increase, non-natural sources will need to be incorporated at competitive costs.
- Large scale CO_2 floods shows low sensitivity to oil prices mainly due to the availability of CO_2 and infrastructure.

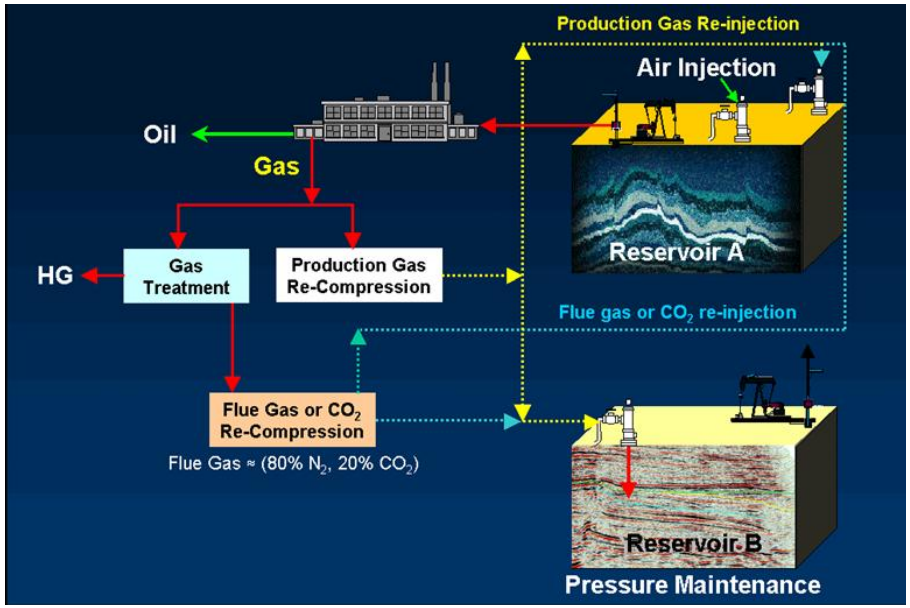
EOR in U.S. Carbonate Reservoirs

Gas injection: Hydrocarbon Gases (HG) and Nitrogen (N_2)

- Miscible and immiscible HG injection still is an important recovery process in U.S. sandstone reservoirs (Alaska).
- If there is no other way to monetize the natural gas, a “natural” use is in EOR processes (i.e.: Dolomite Dolphin Field in North Dakota).
- During the last 40 years over 30 N_2 injection projects have been developed in the United States, some of them in carbonate reservoirs in Alabama, Florida and Texas.
- At the present time there are only two (2) active N_2 injection projects in U.S. carbonate reservoirs, N_2-WAG at Jay LEC and as a pressure maintenance project in Yates Field.
- N_2 injection is not expected to growth significantly in the near future due to the expected increased availability of CO_2.
- One example is the recent announcement of a new immiscible CO_2 project in Yates field by Kinder Morgan. This “downstream” integration by a CO_2 producer is a novel attempt to better monetize its CO_2 reserves.

EOR in U.S. Carbonate Reservoirs

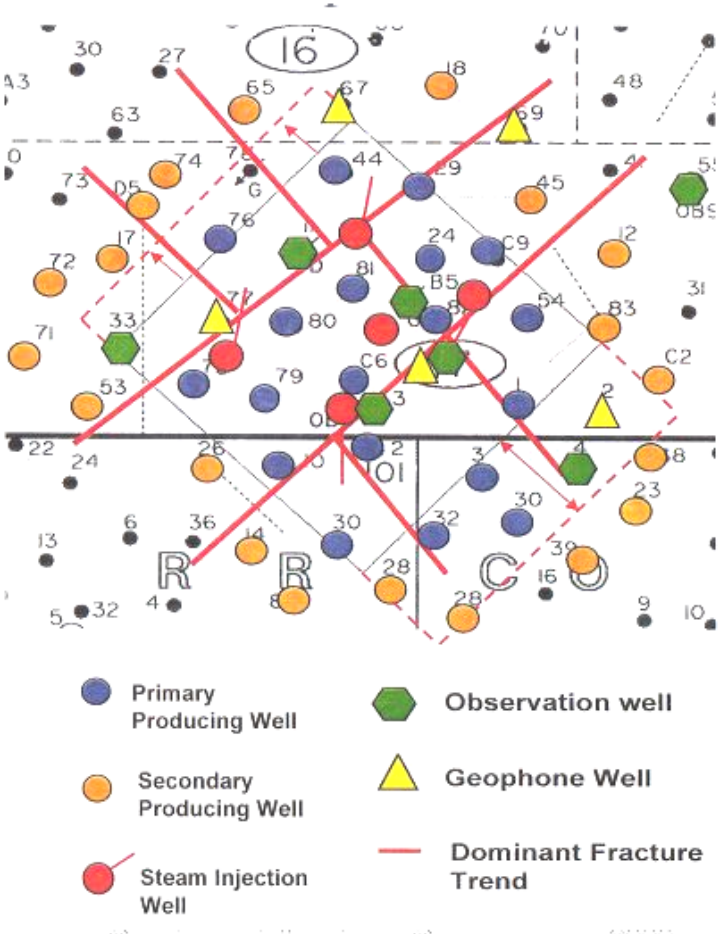
Thermal Methods: Air Injection (In-Situ Combustion)



Schematic representation of HPAI (High Pressure Air Injection) and produced gas / flue gas re-injection

- Air injection (AI) has proven to be an effective recovery method in a variety of reservoir types and conditions.
- Currently there are 7 active AI projects in the U.S., 6 of them in light crude oil (> 30°API) carbonate reservoirs in North and South Dakota (Horse Creek, South and West Buffalo and Medicine Pole Hill).
- AI can be considered an alternative for offshore and onshore mature fields with no access to CO_2 sources.
- Production results of recent AI projects in North and South Dakota (Williston Basin) may dictate the future of this recovery method in carbonate reservoirs in the United States.

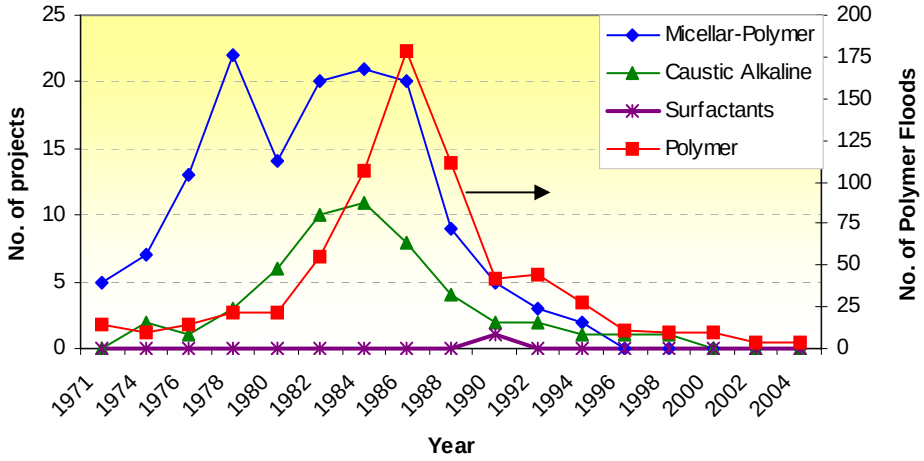
EOR in U.S. Carbonate Reservoirs
Thermal Methods: Steam Injection (SI)

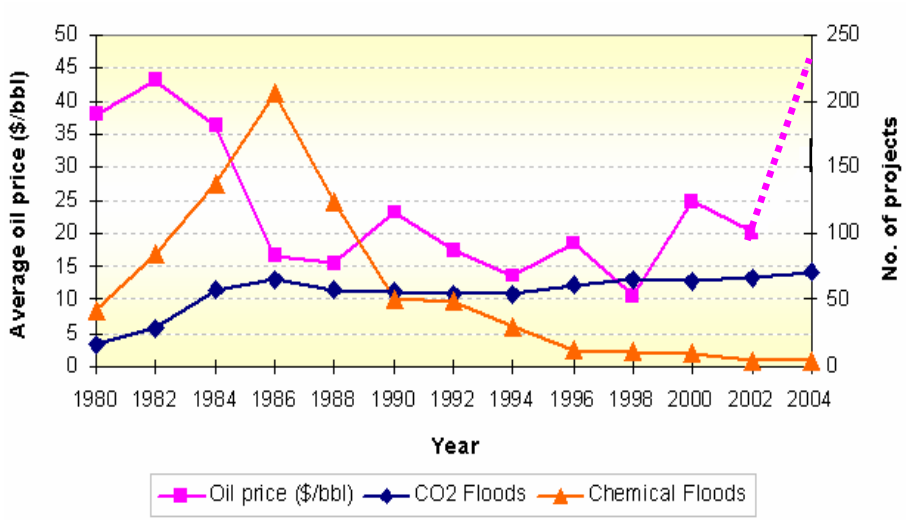


Courtesy Chevron - Marathon, Feb. 2000

- SI has been the most important EOR recovery process during the past decades in the U.S.
- SI has not been a common EOR method used in carbonate reservoirs or in light/medium crude oil reservoirs around the world. Garland (Wyoming) and Yates (Texas) Fields are two examples of U.S. carbonate reservoirs were SI have been tested.
- Of the 46 active projects reported in April 2004, only one is in a light crude oil bearing carbonate reservoir (Yates Field).
- Steamflood pilot project in Yates started in Dec. 1998. Main objective was to accelerate gravity drainage injecting steam into a secondary gas cap supported by N_2 injection.

EOR in U.S. Carbonate Reservoirs
Chemical Methods





- Total of active chemical floods peaked in 1986 having polymer flooding as the most important chemical method of EOR.
- Chemical flooding has been shown to be sensitive to oil prices, highly influenced by chemical additive costs, in comparison with CO_2 floods.
- Of the 320 pilot projects or field wide chemical floods have been identified in the literature, 57 projects have been conducted in carbonate reservoirs, most of them polymer floods.
- Surfactant injection in carbonate reservoirs seems to be the chemical method of choice, considered mostly as a stimulation strategy in recent years.

EOR in U.S. Carbonate Reservoirs
Chemical Methods: Polymer flooding

- The majority of polymer floods in carbonate reservoirs were developed in early stages of waterflooding.
- Most polymer floods used water-soluble polyacrylamides.
- Loss in polymer injectivity have been found as one of the major cause of poor performance in field projects.
- Carbonate reservoirs have made a relatively small contribution to polymer flooding in terms total oil recovered.
- Following table summarizes key information of polymer floods experiences in the U.S. :

	273 Projects (Sandstone & Carbonates)	26 Projects (Carbonates) [(a)]
Conc. (ppm)	50 to 3700	50 to 1000
Amount of polymer used (lb/acre-ft)	19 to 150	12 to 56
Oil recovered (STB/lb polymer injected)	0 to 3.74	0 to 2.82
Recovery (% OOIP)	0 to 23	0 to 13

(a) 11 Field projects and 15 pilots

EOR in U.S. Carbonate Reservoirs

Chemical Methods: Micellar Polymer (Surfactant Polymer -SP)

- SP has been the second most used EOR chemical method in the U.S. but the number of field projects are relatively low compared with polymer floods.
- This recovery method was considered a promising EOR process since the 1970's but high concentrations and cost of surfactants and co-surfactants required, combined with the low oil prices during mid 1980's, limited its use.
- Type of surfactants used in SP floods were mostly petroleum sulfonates and synthetic alkyl sulfonates, which usually requires the use of co-surfactants (non ionic surfactants) or co-solvents, mostly alcohols.
- Water-soluble polyacrylamides have been the most common polymer used in these projects with a few cases using biopolymers
- Although some projects reported significant oil recoveries (i.e.: Loudon, Big Muddy, Henry West and Bingham), oil recoveries were less than expected.
- Only 3 of the 55 chemical floods reviewed were micellar polymer floods at Wesgum Field (Arkansas) and Wichita County Regular and Bob Slaughter Block in Texas.

EOR in U.S. Carbonate Reservoirs

Chemical Methods: Alkali-Surfactant-Polymer (ASP)

- ASP flooding is an oil recovery method that has traditionally been applied to sandstone reservoirs and until now no field tests in US carbonate reservoirs have been reported in the literature reviewed.

- ASP has been tested in carbonate formations at laboratory scale (i.e.: Upper Edward's):

  - ASP formulations show better oil recoveries than polymer flood and alkaline-polymer formulations yielding excellent oil recovery from highly waterflooded oil-wet carbonate cores.

  - ASP solution was formulated with Na_2CO_3, commercial petroleum sulfonates and polyacrylamide polymer.

  - To minimize the precipitation of divalent cations salts due to the interaction of Na_2CO_3 and reservoir brine the use of sodium tripolyphosphate (STPP) was required. STPP also promoted oil emulsification and at the same time showed alteration of wettability to a more water-wet condition.

EOR in U.S. Carbonate Reservoirs
Chemical Methods: Surfactant Stimulation

- The main objectives of surfactant flooding in fractured carbonates are wettability alteration and reduction of the interfacial tension (ITF) promoting the imbibition process.

- Surfactant injection has been tested in carbonate reservoirs as chemical stimulation method (Huff & Puff) in the Cottonwood Creek and Yates Fields.

- Although the use of anionic, cationic and non-ionic surfactants have been tested at lab scale, non-ionic compound were considered for Cottonwood Creek and Yates projects:

	Yates Field	Cottonwood Creek Field
Surfactant	Ethoxy alcohol	Poly-oxyethylene alcohol (POA)
Conc. (ppm)	3100 - 3880	1500
Soak time	About a week	About a week
Main mechanism	IFT reduction	Wettability alteration
Results	Promising (Average oil production rate in pilot wells increased from 35 to 67 b/d)	Promising despite the difference in oil production responses (23 wells)

EOR in U.S. Carbonate Reservoirs
New Chemical Additives

- The evaluation surfactant injection for wettability alteration and reduction of IFT will be critical to recover by-passed and residual oil in carbonate mature waterflooded reservoirs.

- In addition to current efforts to evaluate the use of different types of surfactants to improve oil recovery in oil-wet carbonate reservoirs developed abroad and in United States, we propose expand the search of new “Far Market” products to increase oil recovery in both sandstone and carbonate reservoirs. The proposed research is focused on two major areas:

  - Selection of organic compounds with alkaline properties that improve chemical formulations conventionally used in EOR by chemical methods (ASP, AS or AP) and that reduce or eliminate the softening of injection waters due to their high solubility and their capability of sequestering divalent cations.

  - New fluid formulations based on new-engineered materials (“Nanomaterials”) able to modify, in a controlled way, rock-fluid and fluid-fluid properties and also behave as tailored surfactants improving the flow of oil in the porous media.

EOR in U.S. Carbonate Reservoirs

Conclusions

- Based on the crude oil prices in the last decade, EOR methods by gas injection processes have been the most used recovery methods for light and medium crude oil reservoirs, especially in carbonate reservoirs with low permeability/injectivity.
- Carbonate reservoirs to date seems to represent a case where EOR will continue to be dominated by CO_2 flooding unless more viable EOR strategies are developed in the near future.
- Even in the best scenario for CO_2 flooding, not all resources that will be targeted to meet the world's energy needs will be produced via CO_2 flooding.
- Air injection can be considered an alternative for fields with no access to CO_2 sources, specially carbonate reservoirs with low injectivity to water.
- EOR chemical methods in U.S. carbonate reservoirs have made relatively small contribution in terms of total oil recovered.

EOR in U.S. Carbonate Reservoirs

Conclusions (Cont.)

- EOR chemical floods are not expected to grow significantly in the near future, especially in U.S. carbonate reservoirs. However, the evaluation surfactant injection for wettability alteration and reduction of IFT will be critical to recover by-passed and residual oil in carbonate mature waterflooded reservoirs.

- Surfactant injection may be also benefit from the relatively low costs associated with waterflooding projects, even more if a waterflood is already in place.

- Current efforts on the evaluation surfactant injection for wettability alteration and reduction of IFT surfactant stimulation projects and Alkali-Surfactant injection to improve well injectivity in carbonate reservoirs in the U.S. and abroad will certainly provide new insights useful for future chemical floods in these type of reservoirs.