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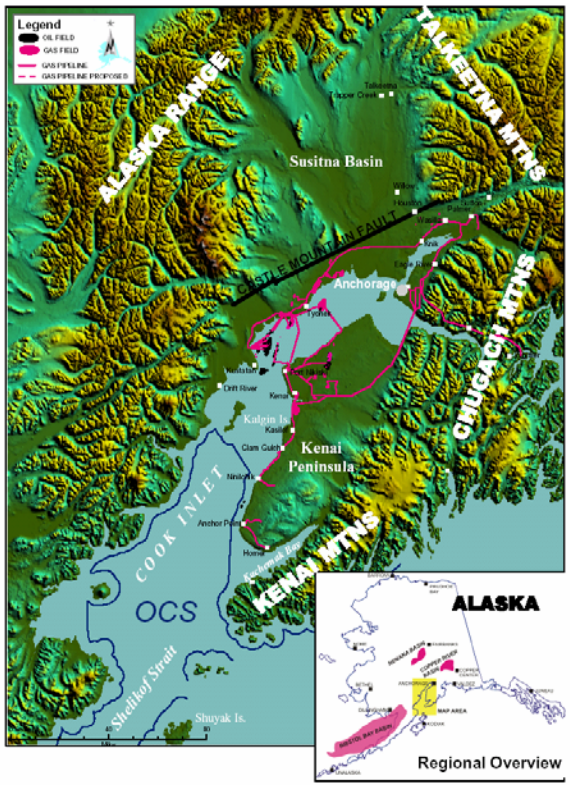

Use of CO_2 in EOR
Background and Potential Application to Cook Inlet Oil Reservoirs

South Central Alaska Energy Forum
Sept. 20-21, 2006

David M. Hite Ph.D.
Consulting Petroleum Geologist

Brent J. Sheets, National Energy Technology Laboratory (brent.sheets@netl.doe.gov)
Charles P. Thomas, National Energy Technology Laboratory, SAIC, (Charles.Thomas@saic.com)
David M. Hite, thiteconsult@acsalaska.net

CO_2 Enhanced Oil Recovery (EOR)

- **Purpose: Restore Formation Pressure and Improve Oil Displacement or Fluid Flow in the Reservoir**
- **Factors:**
  - Reservoir: Temperature, Pressure, Depth, Porosity, Permeability, Net Pay, and Remaining Oil and Water Saturations
  - Fluid Properties: API Gravity and Viscosity
- **Mechanisms:**
  - Miscible Flood: Pressures above Minimum Miscibility Pressure (MMP) – about 1,100 psi., API Gravity Greater than 22ºAPI, Viscosity less than 10 centipoise (cp)
  - Immiscible Flood: Low Pressures (800 to 1,100 psi), API Gravity 13 to 21.9ºAPI, and Viscosity greater than 10 cp
  - Failure: Depths less than 1,800 ft and API Gravity less than 13ºAPI

Depth vs. Oil Gravity Screening Criteria for CO_2 Flooding (Taber and others, 1996)

For CO2-Miscible Flooding	
Oil Gravity °API	Depth Must be Greater Than Feet
>40	2,500
32-39.9	2,800
28-31.9	3,300
22-27.9	4,000
<22	Fail miscible, screen for immiscible
For Immiscible CO2 Flooding	
13-21.9	1,800
<13	All oil reservoirs fail at any depth

Characteristics That Result in The Most Effective Miscible Floods Are:

- **Good response to water flood**
- **Prior to CO_2 flood and after the water flood the oil recovery factor should be between 20 & 50%**
- **Oil reservoir depth must exceed 2,500 feet, to attain CO_2 MMP, which is a function of lithostatic pressure, bottom hole temperature and oil composition**
- **Oil gravity greater than 27° API with an oil viscosity of less than 10 cp is ideal**

If a reservoir passes the screening process:

Several empirical rules of thumb can be applied to predict results and operating parameters of CO_2 miscible floods (Nelms and Burke, 2004).

These are:

- CO_2-EOR of the OOIP, in the best reservoirs, ranges from 8 to 11% for miscible floods,
- Immiscible CO_2 flood recoveries are usually 50% less than the recoveries from miscible floods,
- To achieve CO_2 miscible flooding the MMP is roughly equal to the initial bubble point pressure,
- The CO_2 injection requirement is 7,000 to 8,000 cubic feet of CO_2 per barrel of oil recovered, (others cite volumes as low as 2,000 cubic feet per barrel)
- Water and gas (WAG) is an alternative to reduce high CO_2 injection concentrations, and
- Water injection after primary production is required to fill gas voidage and to increase reservoir pressure to original conditions prior to CO_2 injection.

History of CO_2-EOR

- **CO_2 Floods began in the Permian Basin of West Texas in mid-1970s and large scale floods began in 1984**
- **More than 70 CO_2 floods worldwide**
- **Domestically, in 2004, USA CO_2-EOR equaled 206,000 bopd or 4% of total production; in Texas the rate is 170,000 bopd or 15% of that state's production**
- **CO_2 floods are underway in other states, notably Wyoming, North Dakota, Oklahoma, and Kansas**
- **Internationally, there are successful programs in Canada (Weyburn Field) and offshore Norway (Gullfaks Field)**

Cook Inlet oil fields – Production to 12-31-03

ERR, EUR, OOIP, and possible additional reserves from CO_2 enhanced oil recovery technology. The volume of possible additional reserves associated with an effective CO2 flood is estimated to be 8-11% of OOIP (Nelms and Burke, 2004).

Oil Field	Produced[1] MMbo (% of EUR)	ERR MMbo	EUR[2] MMbo (% of OOIP)	OOIP[3] MMbo	Theoretical "CO2" addition MMbo
Beaver Creek	5.7 (100%)	0.2	5.9 (96.6%)	???	N.A.
Granite Point	140.0 (94%)	9.0	149.0 (24.8%)	≈600.0	48.0-66.0
McArthur River	625.0 (96.3%)	24.0	649.0 (43.3%)	≈1500.0	120.0-165.0
Middle Ground Shoal	190.0 (96%)	8.0	198.0 (33.0%)	≈600.0	48.0-66.0
Redoubt Shoal	1.0 (16.7%)	5.0	6.0 (30.0%)	≈20.0	N.A.
Swanson River	230.0 (98.7%)	3.0	233.0 (46.6%)	≈500.0	40.0-55.0
Trading Bay	102.0 (97.1%)	3.0	105.0 (30.0%)	≈350.0	28.0-38.5
W. McArthur River	10.0 (71.4%)	4.0	14.0 (14.0%)	≈100.0	8.0-11.0
TOTALS	1,303.7 (95.9%)	56.2	1359.9 (37.0%)	≈3,670.0	292.0-401.5

Initial Screening of Cook Inlet Oil Reservoirs for CO_2 EOR

- **Prior Evaluations – Advanced Resources International (2005) for DOE**
- **Screening Process Found 12 Reservoirs Suitable for Miscible Flood and One for Immiscible Flood**
- **Cases – Assumed 3 Cases:**
  1. $25.00/bbl Oil and $1.25/Mcf CO_2 (Limited CO_2)
  2. $35.00/bbl Oil and $1.25/Mcf CO_2
  3. $35.00/bbl Oil and $0.70/Mcf CO_2 (Ample local supply of CO_2)
- **Case 3 was viable and up to 140 MMb of Incremental Oil Recovery was Achievable from the Swanson River and Middle Ground Shoal Fields**

Targets for Potential CO_2-EOR in Cook Inlet

- **Miscible Floods**
  - **Granite Point – Middle Kenai Group**
  - **Granite Point – Hemlock Formation**
  - **McArthur River – Hemlock Formation**
  - **McArthur River – Middle Kenai Group**
  - **Middle Ground Shoal – Hemlock Formation/Tyonek E, F, and G members**
  - **Middle Ground Shoal – Tyonek A member**
  - **Middle Ground Shoal – Tyonek B. C, and D members**
  - **Swanson River – Hemlock Formation**
  - **Trading Bay – Tyonek C member**
  - **Trading Bay – Tyonek D member**
  - **Trading Bay – Tyonek E member**
  - **West McArthur River (?) – Hemlock Formation**

- **Immiscible Floods**
  - **Trading Bay – Tyonek B member**

Predicted Production Yields

Using 25% of cumulative production to derive a reservoir-by-reservoir estimate of incremental production yields the following results for the major reservoirs:

- **McArthur River – Hemlock = 133 MMbo**
- **Swanson River – Hemlock = 57 MMbo**
- **Middle Ground Shoal – Hemlock = 44 MMbo**
- **McArthur River – Tyonek = 16 MMbo**
- **Granite Point – Tyonek = 35 MMbo**
- **Trading Bay – Tyonek = 18 MMbo**

TOTAL INCREMENTAL PRODUCTION = 303 MMbo

General Conclusions

- **There are more than 70 CO_2-EOR programs world-wide, the process works regardless of reservoir lithology. Expected incremental oil recovery is 8 to 11% of OOIP or approximately 25% of cumulative production.**

- **There are more than a dozen reservoirs, primarily the Hemlock and Tyonek in the five major fields of Cook Inlet, that pass the screening criteria for miscible CO_2 floods.**

- **Using the average range of incremental increase in production (8 to 11%) the five major Cook Inlet oil fields have the potential to produce an incremental 290 to 400 MMbo. Using only the major reservoirs and a 25% of cumulative production estimation tool the incremental production would be approximately 300 MMbo.**

General Conclusions- Continued

- **To realize an economic CO_2 flooding program in Cook Inlet's oil fields will require oil prices in the $45.00 to $65.00 range and a low cost reliable long-term supply of CO_2.**

- **With a viable CO_2-EOR program in place, the life of the five major fields would be extended for an additional 20 to 25 years and yield oil volumes equal to that of the last 20 to 25 years of Cook Inlet production (1980 to present)**

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