CYCLIC CO₂ INJECTION FOR LIGHT OIL RECOVERY:
PERFORMANCE OF A COST SHARED FIELD TEST IN
LOUISIANA

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OBJECTIVES

The ultimate objective of this research is to provide a base of knowledge on the CO₂ huff 'n' puff process for the enhanced recovery of Louisiana crude oil. Project goals include laboratory corefloods to investigate several parameters important to the process, and numerical simulation to interpret coreflood results. Additional activities include construction and analysis of a field test data base to facilitate target reservoir screening, and to identify sensitive operational parameters. The information from laboratory corefloods and data base evaluations will be used in the design and implementation of a Department of Energy sponsored field test. The results of all laboratory and field evaluations will be made available to the industry through workshops, periodic reports, and meetings.

SUMMARY OF TECHNICAL PROGRESS

Subtask 1: Laboratory Corefloods

Coreflood experiments were delayed during this reporting period due to student vacations and remodeling of the coreflood apparatus to facilitate experimental procedures. Two horizontal cores are now available for experimental use, allowing two experiments to be run simultaneously. Investigations of the effects of drive fluids and CO₂ injection rate have commenced.

One final horizontal coreflood was performed to examine the influence of remaining oil saturation. Earlier corefloods performed to investigate this parameter were described in the previous quarterly report. Preliminary results indicated that CO₂ utilization, and thus process performance, improved as remaining oil saturation increased. We were concerned, however, that the results were influenced by the oil saturation profile. Since cores were waterflooded and CO₂ flooded in the same direction, the oil saturation in partially waterflooded cores increased in the direction of flow (i.e. there was a lower oil saturation near the inlet of the core). A final coreflood was performed in which water and CO₂ were injected in opposite directions. There was no significant difference in oil recovery as a result of flow direction.

Subtask 2: Field Tests

As mentioned in the last report, a well site has been selected for field testing of the CO₂ huff 'n' puff process. The site chosen for this project is a producing well operated by Southwest Gas Producing Company, and identified as Frank J. Bollich, Jr. et al. No. 5. The well is located in Acadia Parish, Louisiana.

Current efforts are directed towards obtaining the necessary permits to perform the test. The Louisiana Department of Natural Resources (DNR) Office of Conservation requires that the operator

either prove that the process will not affect adjacent properties, or obtain letters of approval from offset operators and royalty owners. Since the well is located near a lease line, the operator elected to obtain letters of approval. Letters of approval from offset operators have been obtained, and approval from offset royalty owners is currently being sought.

The Louisiana DNR's Underground Injection Control Commission requires assurance that the process will not contaminate fresh water supplies. Since the existing completion was not expected to withstand the pressures required for injection, it has been decided to use rental tubing during the injection and production phases of the field test. The rental tubing will be pressure tested with nitrogen to assure mechanical integrity.

The Louisiana Department of Environmental Quality (DEQ) Air Quality Division requires information on the nature of the facilities, the equipment on site, current emission levels, and estimated changes in emissions due to process implementation. The specific environmental impacts associated with cyclic CO₂ or "Huff 'n' Puff" enhanced oil recovery was assessed to address the concerns of Louisiana's DEQ, and to comply with the National Environmental Policy Act (NEPA). The conclusions of the environmental assessment were the following:

1. The available information indicates that minimal environmental impacts are anticipated as a consequence of the proposed test.
2. No new surface-disturbing activities are proposed in association with the test. Existing access roads and production equipment will be utilized.
3. Impacts associated with water quality are expected to be negligible. Tubing will be pressure tested with nitrogen prior to CO₂ injection to insure mechanical integrity, and reduce the risk of contaminating fresh water supplies. The current practice of reinjecting produced waters into brine-containing formations will be continued.
4. Air quality impacts will be minimal. Some CO₂ and produced hydrocarbon gases will be vented to the atmosphere, but these emissions are not expected to influence the environment due to the small quantities involved. Hydrocarbon gas production is currently negligible, and is not expected to significantly increase during the production phase of the test. Fluid production rates will be limited in the initial phases of production. Gas production rates will be 250 Mcf/day or less. Previous studies have shown that producing the well on a small choke, and thus maintaining a backpressure in the reservoir is beneficial to ultimate oil recovery. If CO₂ alone is initially produced, the daily production rate of CO₂ would correspond to the amount of CO₂ released in 1.5 minutes from the operation of a typical coal-fired power plant.¹

5. No adverse effects on flora and fauna in the area are anticipated. The candidate well site is located within an isolated area of oil production activity which is surrounded by a large agricultural area consisting primarily of soybean and rice fields. CO_2 is a colorless, odorless, non-combustible gas that is a natural constituent of air (0.036%).² Elevated concentrations of CO_2 have been shown to be beneficial to plants.³ Extremely high concentrations of the gas have been shown to be harmful to humans, but these levels are usually only found in enclosed areas with poor ventilation.^{2,3}
6. There has been considerable concern recently about the contribution of elevated global CO_2 concentrations to the "greenhouse effect". CO_2 huff 'n' puff processes as a whole are not expected to significantly contribute to global CO_2 concentrations since the CO_2 quantities involved are relatively small compared to other industrial processes. In addition, since the CO_2 used in the process is not generated, but is purchased as CO_2 which would have been released into the atmosphere through some other process, the net concentration of CO_2 in the global atmosphere is not increased. In fact, since studies have shown that 20-23% of the injected CO_2 remains in the reservoir and is not produced, the net concentration of CO_2 in the global atmosphere is reduced.^{4,5}

Subtask 3: Numerical Simulation

A three phase, three-dimensional multicomponent reservoir simulator, SIMCO, developed by Continental Computer Bureau, Ltd. was used to model the CO_2 huff 'n' puff process. Computations were performed on a VAX-8800 mainframe computer made by Digital Electronics Corp. A rectangular grid-block geometry with 20 blocks was employed to describe the 6 ft. long core. Four additional blocks were used to model the transfer vessel connected to the outlet end of the core.

Measured values of porosity, absolute permeability, initial pressure, and initial fluid saturations were assigned to each block. Eight pseudo-components were used to describe the reservoir oil. Molar compositions, critical temperatures and pressures, acentric factors, and binary interaction coefficients were input to tune an equation of state. Variations in the flow of oil, gas, and water were controlled by relative permeability and capillary pressure curves for each of these fluids. The simulator allowed directional relative permeabilities to be assigned. Three-phase relative permeabilities were internally calculated.

Coreflood data included cumulative amounts of oil, gas, and water injected and produced during each of the oilflood, waterflood and huff 'n' puff stages. Production profiles of oil, gas, and water were obtained for the puff stage.

The model was tuned as described previously.⁶ After the model was calibrated for laboratory coreflood performance, it was used to investigate the effects of key parameters on the CO₂ huff 'n' puff process. Investigations of the influences of soak duration, remaining oil saturation, CO₂ slug size, and CO₂ injection rate have been completed. Simulated conditions were above the minimum miscibility pressure of the system.

Seven numerical simulation runs were performed to investigate the effect of soak time. The production process was terminated when a water cut of one was attained. The results of the study are shown in Figure 1 which depicts cumulative oil and gas produced versus soak time. As soak time increased, cumulative oil produced increased, and reached a maximum at an optimum soak time of 15 hours beyond which there was no additional improvement in recovery. Analysis of the model indicated that the number of gridblocks contacted by CO₂ increased with increasing soak time, reached a maximum at 15 hours, and remained constant for longer soak times. Thus, a minimum soak time was needed for CO₂ to migrate through the porous media and interact with the crude. Although the obtained optimum soak time of 15 hours was system dependent, this investigation confirms that a minimum soak time is required for optimum process performance.

Since enhanced oil recovery processes are usually applied before a reservoir is completely watered-out, the effect of remaining oil saturation was examined. Six simulations, one at waterflood residual oil saturation, and the others at various higher oil saturations, were performed to investigate this parameter. The percentage of remaining oil recovered versus remaining oil saturation is shown in Figure 2. Analysis of the model indicated that CO₂ pushed moveable oil away from the injection site which reduced the recovery efficiency of the process.

The effect of CO₂ slug size on process performance is shown in Figure 3. Oil recovery was found to increase with increasing slug size until it reached a maximum, after which there was no further improvement. Analysis of the model indicated that, in the case of the largest slug, CO₂ pushed oil too far away from the production outlet to be recovered. This finding is consistent with previous field test data base analyses.⁷

Four simulations were performed to investigate the influence of CO₂ injection rate on process performance. As shown in Figure 4, oil recovery appeared to decline slightly as injection rate increased; however, since the difference in recoveries for injection rates of 20 and 120 cc/hr was only 3.8% of the core pore space, and no physical explanation could be gleaned from the saturation profiles of oil, gas, and water, the results were inconclusive. The effect of injection rate is currently being examined experimentally using corefloods.

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EFFECT OF SOAK DURATION

FIGURE 1

EFFECT OF REMAINING OIL SATURATION

FIGURE 2

EFFECT OF CO₂ SLUG SIZE

FIGURE 3

EFFECT OF CO₂ INJECTION RATE

FIGURE 4

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