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Extraction of Dissolved Gaseous Hydrocarbons from Brine at an Engineered CO_2 Injection, Cranfield, Mississippi

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INTRODUCTION

Abstract

Injection of anthropogenic CO_2 into oil and gas reservoirs may extract fossil fuels through enhanced oil recovery while concurrently attaining long-term geological carbon storage. Inherent in this process is interaction of injected CO_2, brine, rock, and dissolved gases in brine, which contain light hydrocarbons. Controlled laboratory experiments are under way to simulate the changes in gas concentrations observed during an engineered CO_2 injection at the Cranfield oil field as part of the Department of Energy Southeast Regional Carbon Partnership study. Laboratory simulations are also being used to validate a gas-mixing model devised to separate the effects of physical mixing from chemical extraction processes in the reservoir.

During the injection period from December 2009 to May 2010, approximately 100,000 metric tonnes of CO_2 were injected into an oil and gas reservoir below the oil-water contact. Gas samples were collected from two observation wells (~3,000 m depth) using a pressure loop U-tube sampler (Freifeld et. al., 2005) and analyzed by gas chromatography. The target oil and gas reservoir has brines containing dissolved hydrocarbons, and the injectate gas is similarly complex (Fig. 7). Both C_2 and C_3 are enriched in the gas phase during CO_2 transport over 60 m. CO_2 and CH_4 versus He ratios show an initial increase then decrease after supercritical CO_2 arrives at the monitoring wells, suggesting an initial partitioning of CH_4 into CO_2, then depletion of CH_4 over time. Also, C_2:C_3 and C_3:C_4 ratios decrease dramatically. High-pressure-temperature experiments are designed to explain what chemical factors might account for the variability in extraction of CH_4 and other light hydrocarbons from brines observed during CO_2 injection at Cranfield.

Location

The SECARB Phase III injection test is located in the Cranfield oil field, which is operated by Denbury Resources, Inc. It is located 27 kilometers east of Natchez, Mississippi, USA. The Cranfield unit is part of the Upper Cretaceous Tuscaloosa-Woodbine Trend of the Mississippi Salt Basin.

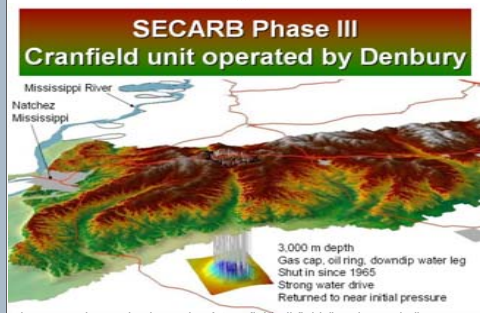
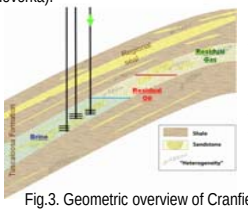


Fig.1. Location and schematic of Cranfield oil field (by Tip Meckel).

CO_2 FIELD INJECTION

Well Configuration

Fig.2. Photo of the DAS (detailed area of study), a closely spaced well array to examine flow in a complex reservoir (by Tip Meckel and Susan Hovorka).



The injection test, consisting of one injection well and two observation wells, is in the water leg of a subsurface dome structure with an oil ring and a gas cap. Observation wells are down-dip of injection well to avoid the oil leg. Pressure drive dominates transport during injection.

Fig.3. Geometric overview of Cranfield oil field (by Tip Meckel).

CO_2 Injection

Fig. 4. CO_2 injection began at the DAS December 1, 2009, at a rate of 175 kg/min, with a step up to 350 kg/min.

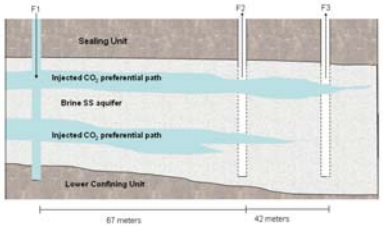


Fig. 5. Cross section of the Cranfield injection showing preferential CO_2 flow paths in the reservoir caused by geologic heterogeneity. Over the course of the injection, CO_2 differentially invades observation well bores in space and time.

Fluid Sampling and Analysis

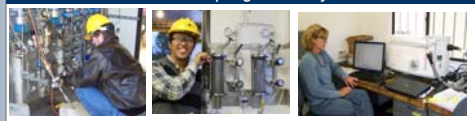


Fig. 6. High-frequency fluid sampling using the U-tube sampler (Freifeld et. al., 2005). Samples were analyzed on-site using a mass spectrometer.

GEOCHEMICAL OBSERVATIONS

Extraction of Hydrocarbons by Supercritical CO_2

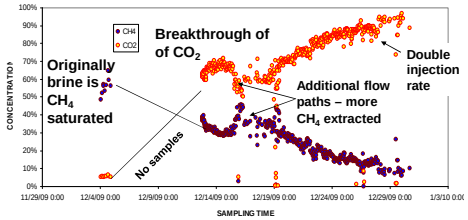
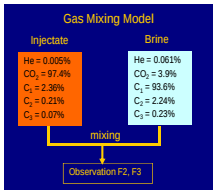


Fig. 6. Observed gas compositional change in observation wells over the course of CO_2 injection. Breakthrough of CO_2 occurred in observation well F2 on December 13, 2009.

Gas Mixing Model

A numerical model was constructed to help explain (1) evolution of gas compositions sampled through the U-tube sampler and (2) important chemical processes in the reservoir during CO_2 injection. Helium is used to determine the mixing ratio of each sample, which is then used to determine the expected gas composition for that mixing ratio.



$$f = \frac{C_{He}^{O} - C_{He}^{b}}{C_{He}^{I} - C_{He}^{b}}$$

O, b, I are observed, brine, and injectate, respectively, and *f* ranges from 0 to 1.

$$C_n^C = fC_n^I + (1-f)C_n^b$$

n = CO_2, CH_4, C_2, and C_3.

Fig. 7. Injectate CO_2 and brine compositions used in the gas mixing model.

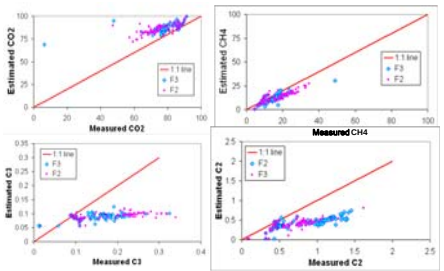


Fig. 8. Deviations from the mixing lines for various hydrocarbons.

Enrichment of hydrocarbons shows that CO_2/brine interaction occurs in the subsurface aquifer reservoir. The unit of measured and calculated gas concentration is in mole % by volume. Estimated values from the model were plotted against measured values. Deviations from the 1:1 line indicate a loss or gain of the gas in question.

LABORATORY SIMULATION

Supercritical CO_2/Brine/Rock Reactor

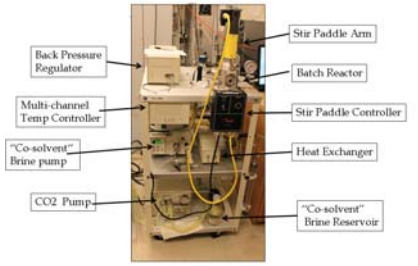


Fig. 9. Apparatus for supercritical CO_2-brine-rock reaction experiments up to 400 bars and 150ºC in batch or flow-through mode.

Apparatus for Gas Separation and Measurement

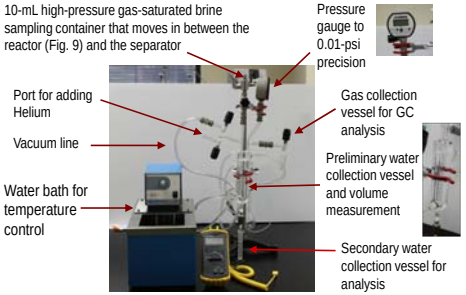


Fig. 10. Apparatus for extracting fluid from the supercritical reactor at ambient pressure and temperature and for dissolved gas solubility measurements necessary for calculating partitioning of CH_4 between supercritical CO_2 and brine.

Conclusions

A pilot CO_2 injection test at the Cranfield site shows preferential partitioning of reservoir hydrocarbons into supercritical CO_2. A numerical model designed to separate the effects of mixing from important chemical processes in the reservoir during CO_2 injection suggests a variable enrichment of light hydrocarbons in supercritical CO_2. High-pressure-temperature laboratory experiments are under way to simulate the partitioning of gases dissolved in brine into supercritical CO_2 and to identify the mechanisms by which it occurs.

References

Freifeld, B.M., Trautz, R.C., Yousif K.K., Phelps, T.J., Myer, L.R., Hovorka, S.D., and Collins, D., 2005, The U-Tube: A novel system for acquiring borehole fluid samples from a deep geologic CO2 sequestration experiment, *J. Geophys. Res., 110*, B10203.

Acknowledgements

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