ENHANCED OIL RECOVERY VIA CYCLIC GAS INJECTION
“HUFF AND PUFF” CONSORTIUM

EVALUATION OF BEST PRACTICE PARAMETERS FOR ENHANCED OIL RECOVERY IN UNCONVENTIONAL (SHALE/TIGHT/HYBRID) FORMATIONS USING CYCLIC GAS INJECTION

GEO_MARK RESEARCH, LTD.

A PROPOSAL
INTRODUCTION

GeoMark has initiated multi-well studies to develop a best-practice approach for cyclic gas injection (Huff and Puff) for Enhanced Oil Recovery (EOR).

Planned programed studies:
- Eagle Ford (initiated)
- Permian Basin Wolfcamp
- Permian Basin Woodford
- South Central Oklahoma Oil Province (SCOOP)
- Sooner Trend Anadarko Canadian Kingfisher (STACK)

Each program consists of the characterization and evaluation of numerous oil & gas production samples taken from multiple wells. These samples will be contributed by participating companies and will be analyzed for basic PVT fluid properties and their miscibility capacity when mixed with various injection gases. These data will be used to design specific EOR programs for participant submitted wells, and integrated with geological, geographical and production test information to develop a regional database-driven model for the design and implementation of future Huff and Puff programs.

Each company joining a project will be required to contribute oil & gas samples from two (2) wells for analysis, evaluation and inclusion in the study. Each specific program will not be initiated until a minimum of fluids from 12 wells have been submitted to the program.

The results of this study will be supplied to the participating companies along with an interpretive report explaining their significance. The final report will provide the expertise needed to design and implement a successful Huff and Puff program. The details of the analytical program and resulting report are explained in this proposal.

Figure 1. Eagle Ford Study area focuses on the oil and wet gas/condensate regions where the Huff & Puff technology will have the most positive impact on oil extraction.
Figure 2. Permian Basin Wolfcamp Study area will concentrate on the oil and wet gas/condensate regions, primarily in the Midland Basin.

The cost of joining the consortium varies depend on the number of prior participants and the number of wells already committed to the program. The price schedule is contained in the Pricing Section at the back of this proposal.

PURPOSE OF STUDY

Current oil production techniques for unconventionals are often estimated to recover just 5-7% of in-place oil using today’s technology. In response, a number of Enhanced Oil Recovery (EOR) techniques are being considered to boost this percentage and improve ultimate recoveries. One of the most promising techniques is “Huff and Puff” cyclic gas injection.

In the Huff & Puff technique separator gas from a nearby well or gas installation is injected (the Huff phase) into a depleted or partially depleted oil well at a high enough pressure to achieve miscibility. During the following soak period the miscible gas spreads through the formation, swelling the oil volume and decreasing its viscosity. After the soaking period, the well is put back on production (the Puff phase) with an expected increase in production rate due to the higher reservoir pressure and lower oil viscosity. The separated gas can then be sold, or reinjected in
another well to initiate a new Huff & Puff sequence. This process can be repeated as long as commercial quantities of liquids are extracted from each Huff and Puff cycle.

Figure 2. Simplified Huff and Puff cyclic gas injection.

GeoMark is conducting these studies designed to identify the best parameters for a successful Huff and Puff treatment program within various regions of each program.

Answers to the following questions will be developed in the study.

- When do you initiate the Huff & Puff program in the life of a well?
- What is the Minimum Miscibility Pressure required for gas injection?
- What gas composition is best for maximum miscibility?
- Is asphaltene precipitation a concern due to gas injection?
- What is the ideal “Soaking” period for maximum miscibility?
- When should repeat cycles be initiated?
- How many cycles are optimal for the life of a specific well and fluid type?
- Can miscibility still be achieved with a drier gas having its NGLs stripped?

Laboratory tests and reservoir simulation can provide the answers to these and other questions that will control success of future Huff and Puff attempts.

**PROJECT OBJECTIVES AND SCOPE OF WORK**

Depending on the regional consistency and number of horizons of fluid properties in your target formation, it is possible to predict regional trends in phase behavior once a calibration is established. GeoMark has accomplished this in the Eagle Ford by developing a database of PVT and geochemical measurements, and mapped these trends across the play. This type of approach will serve as a guideline for the selection and analysis of gas and oil samples, and it will assist in the application of the results in a regional framework.
Each participating company will be permitted to submit samples from two wells to conduct a pre-Huff and Puff laboratory analysis. This will provide a customized program for two specific locations and contribute to a regional database providing guidelines for the pre-well assessment of additional wells and regions.

![Figure 3. Example of (publicly) available Eagle Ford production data from the Henkhaus #1 Well in Gonzales County, TX showing increased monthly oil production following Huff and Puff Cycles.](image)

**ANALYTICAL OBJECTIVES**

The analytical objectives are focused on miscibility testing – both “first-contact” through swelling tests and “multi-contact” via slim tube studies. Representative recombined reservoir fluids and corresponding injection gases are collected from the field, or prepared in the laboratory, and run through an established laboratory program. Fluid compositions, densities and viscosities are measured frequently and used in reservoir simulation models to evaluate the effectiveness of the Huff and Puff process.

**INTERPRETIVE REPORT**

GeoMark will provide the analytical results as they are completed and consult with the company that contributed the samples to help design a customized Huff and Puff program. Reservoir simulation will be integrated to determine the most effective parameters for project execution.

At the end of the first year GeoMark will release an integrated interpretive report containing all analytical results, the analytical database, reservoir simulation predictions and newly developed correlations. Additional database updates and interpretive reports will be released semiannually as long as new fluids are added to the program.
ANALYTICAL PROGRAM

Sampling, Sample Handling and Restoration

Fluids are captured in the field and returned to the laboratory. Following restoration, validation tests are conducted including compositional analyses. Once confirmed representative, PVT testing can begin.

- Field Sampling
- Opening pressure at ambient temperature
- Sample restoration (agitation / heating for 24 hours)
- Separator Oil Bubble Point Confirmation
- Single stage flash of Separator Oils (includes Density, GOR, FVF, API)
  - Analysis of flash gas to C15+
  - Analysis of stock tank oil to C30+
- Separator / Injection Gas Analyses

PVT Analyses

Separator oil and gas are physically recombined to a specified GOR with composition and fluid properties checked by a Single-Stage flash. A Constant Composition Expansion (CCE) test provides the bubble point pressure, oil densities and compressibilities plus viscosities are measured at a series of pressures. These data are required for Equation of State tuning.

- Separator Fluid Recombination to Specified Gas Oil Ratio
- Single stage flash of Recombined Fluid (includes Density, GOR, FVF, API)
  - Analysis of flash gas to C15+
  - Analysis of stock tank oil to C30+
- Constant Composition Expansion
- Reservoir Fluid Viscosities at Multiple Pressures

Swelling Tests (Forward Contact Miscibility Evaluation)

A swelling test is used to evaluate first contact miscibility as discrete gas injections are made to the recombined oil in the PVT cell. After each gas injection a CCE experiment is conducted providing the new saturation pressure, swelling factor, compressibilities and viscosities – data particularly useful for the EOS modeling of miscibility. The light transmittance system is engaged to look for asphaltene instability.

- Add Injection Gas, Conduct CCE to Provide Swelling Factor, Saturation Pressure, Oil Compressibilities, Viscosity
- Repeat for 2 Additional Gas Injections

Repeat Swelling Test with different injection gas. The gas would likely be drier as heavies would be stripped as Natural Gas Liquids (NGLs).

- Charge PVT Cell with Fresh Recombined Oil
- Prepare Synthetic Gas based on Defined Composition
- Add Injection Gas, Conduct CCE to Provide Swelling Factor, Saturation Pressure, Oil Compressibilities, Viscosity
There may be some areas where the reservoir pressure is close to the bubble point pressure and it’s almost certain miscible injection can’t be achieved. In those cases the swelling test will be replaced with a “vaporization” or backward-contact miscibility experiment.

**Slim Tube Tests (Multi Contact Miscibility Evaluation)**

Slim Tube experiments are run to determine the MMP - Minimum Miscibility Pressure. The slim tube is ~40 feet long, packed with sand and saturated with recombined oil. Injection gas is slowly pumped through and oil recovery is measured. Four tests (two at high pressure, two at low) are used to identify the MMP. This value is used to determine when to start the Huff and Puff operation and the expected improvement in fluid properties (e.g. viscosity, density) that result.

- Charge Slim Tube with Live Oil and Run Gas Injection Experiment at Pressure Likely Below Minimum Miscibility Pressure (MMP), Providing Oil Recovery, Fluid Compositions, Density, Viscosity
- Repeat at 3 Additional Pressures (1 More Below and 2 Above Likely MMP)

Repeat Slim Tube experiments with second, drier, injection gas

- Charge Slim Tube with Live Oil and Run Gas Injection Experiment at Pressure Likely Below Minimum Miscibility Pressure (MMP), Providing Oil Recovery, Fluid Compositions, Density, Viscosity
- Repeat at 3 Additional Pressures (1 More Below and 2 Above Likely MMP)
Figure 4. Slim Tube schematic for determining Minimum Miscibility Pressure.

DELIVERABLES

Interpretive Reports

The first deliverable will be interpretive reports providing analytical data and recommendations for the design and implementation of a Huff and Puff program on the company submitted wells. Reports will include raw and processed data, charts, correlations and reservoir simulation predictions. Interpretive commentary is given in Adobe PDF and PowerPoint™ files. Microsoft Excel™, Access™, and ESRI ArcMAP™ are the data formats and mapping system used by GeoMark in this study.

Database

A dynamic database housing all the data developed during the study will be available to all participants. Analytical and supporting data for the study will be provided digitally and available on-line through GeoMark’s Rock and Fluid Database (RFDbase.com).

Final Report

An Interpretive Report will be produced at the end of the first year, and then bi-annually. This report will provide all analytical data, and well as interpretive plots and graphs. The report will also
include regional maps showing variations in the success of the Huff and Puff technique, where the techniques must be modified for best results, or where the technique may not successfully applied.

**COST**

The cost of joining a consortium varies depending on the number of subscribers and contributed samples for that program. The price for companies contributing reservoir fluids from two wells at the beginning of the study is $95,000.

As more companies join a project, and the database increases, the subscription price will escalate as outlined below.

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<th>Number of Subscribers</th>
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**TIMING**

Eagle Ford sampling and analyses are currently in progress. STACK and SCOOP programs will initiate once there are a minimum of 3 participants. New analytical data will be continuously uploaded as available through GeoMark’s RFDbase Database. Updated interpretive reports will be released every six (6) months as long as new fluids are contributed to the program.

**CONTACT INFORMATION**

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