Experimental Investigation and High Resolution Simulator of In-Situ Combustion Processes

Quarterly Report

Start date: July 2006
End date: September 2006

Margot Gerritsen
Anthony R. Kovscek

October 2006

DE-FC26-03 NT15405

Department of Petroleum Engineering
Stanford University
Green Earth Sciences Building
367 Panama Street
Stanford, CA 94305-2220

Abstract

Accurate simulation of in-situ combustion processes is computationally very challenging because the spatial and temporal scales over which the combustion process takes place are very small. In this current and **twelfth** report, we report our continuing experimental program. Because the period covered by this report was in the academic summer quarter, during which most of our students are interns with affiliated companies, progress in this quarter was limited to the experimental program.

Table of Contents

List of graphical materials

1. Introduction

In-situ combustion, or air injection, is the process of injecting oxygen into oil reservoirs to oxidize the heaviest components of the crude oil and enhance oil recovery through the heat and pressure produced. The emphasis of this work is to study and model numerically in situ combustion processes. The ultimate objectives are to provide a working accurate, parallel in situ combustion numerical simulator and to better understand the in-situ combustion process when using metallic additives and/or solvents combined with in situ combustion. For this purpose, experimental, analytical and numerical studies are conducted.

This report presents results of the final quarter of the third year of this project.

2. Executive Summary

2.1. Personnel

Current personnel include Prof. Margot Gerritsen (PI), Prof. Tony Kovscek (Co-PI), Dr. Louis Castanier (Technical manager), Mr. Rami Younis (PhD student). Mr. Rotimi Awoleke (MSc student) is also working on the project, albeit paid from departmental sources. We have also continued collaboration with Mr. Morten Kristensen (PhD student) from the Technical University of Denmark, and his advisors Prof. Erling Stenby and Prof. Michael Michelsen. Mr. Awoleke's work is the focus of this quarterly report.

2.2. Important accomplishments

During this summer quarter, our student Rotimi Awoleke stayed at Stanford to continue combustion tube experiments.
Rotimi's primary goal is to investigate the effects of rock heterogeneity on the performance of in-situ combustion processes. We are designing a series of experiments for a variety of oils to investigate whether, as in gas injection processes, combustion fronts propagate preferentially through high permeability flow paths.
To date, experiments on the effects of heterogeneity have not been performed, at least they have not reported on in the public domain, and it is unclear how in-situ combustion fronts interact with strong changes in heterogeneity. Because of the limitations of available solvers for ISC processes, we decided to focus on experimentation.

An initial tube run was attempted using heterogeneous media and Huntington Beach oil. Unfortunately, at the start of the summer, we ran into problems with the equipment. A hole caused by corrosion at the end of the combustion tube caused the experiment to fail. We are currently building a new tube, a time-costly process, which should be ready by December 2006.

The remainder of the summer, Rotimi studied samples of heavy oil from the NIMR formation in the South of Oman. This field has been classified as a potential candidate for thermal recovery with ISC.

3. Experimental

Figure 1 shows a diagram of the experimental setup in our Stanford Combustion Laboratory. It can be used to run both kinetic cell and combustion tube experiments.

Mixture Preparation
Sand and kaolinite were put in a beaker in pre-defined proportions and properly mixed. Crude oil and water were then added and the resulting substance was also thoroughly mixed. Attaining a reasonable degree of uniformity in the resultant mixture was paramount since the reactions depend on spatial molar concentrations & exposed surface areas and variations in these parameters from point to point may affect results. This mixture, prepared as a basis for comparison, was then fed into the kinetic cell.

Two ramped temperature oxidation tests were performed using the oil from Oman. The first run used a core made of Ottawa sand with 5 %by weight kaolinite clay added as described above. The second test used the same oil in a crushed core from the reservoir. The kinetic runs were performed at different inlet pressures of 50psig and 200psig.

4. Results and discussion

Figure 2 shows the material of the crushed core before (top) and after (bottom) the 200 psig experiment. Figure 3 shows the same for the experiment at 50 psig.

The presence of a significant percentage of organic matter in the reservoir brings about the need for a high oxygen content and partial pressure. As the pictures above indicate, performing the experiment at 50psig inlet pressure resulted in an incomplete combustion process within the experimental time frame. Increasing the supply pressure to 200psig resulted in a cleaner, more complete combustion.

The gas compositions for the first test, with the Ottawas sand core, is shown in Figure 4. The results from the second test, with the oil in a crushed core from the reservoir, which are shown in Figure 5, differ greatly. We attribute the difference in gas composition to the presence of a bitumen-like organic residue present in the reservoir matrix. In particular the oxygen uptake is higher in the reservoir core case. The carbon dioxide produced is also higher as shown in Figure 6.
Clearly visible in all of these graphs is the presence of two combustion regimes: a Low Temperature Oxidation (LTO) occurring first at a low temperature, followed by a High Temperature Oxidation (HTO). In the second test, a third regime is visible caused by the bitumen-like residue.

5. Conclusions

As part of our continuing education in In-Situ combustion processes, we performed several kinetic tests for one of our industrial affiliates over the summer quarter. The tests turned out to be very interesting because of unexpected behavior in the oil samples, which we attribute to the presence of a bitumen-like organic residue. Complete analysis of the results is in progress. Further runs will investigate the effect of pressure on the reactions.

We are grateful to Oman for receiving the oil and cores of the NIMR field. We are continuing these studies in the next quarter, and will report on them in December. In the next quarter, we also again pick up our work in numerical solvers for ISC processes.

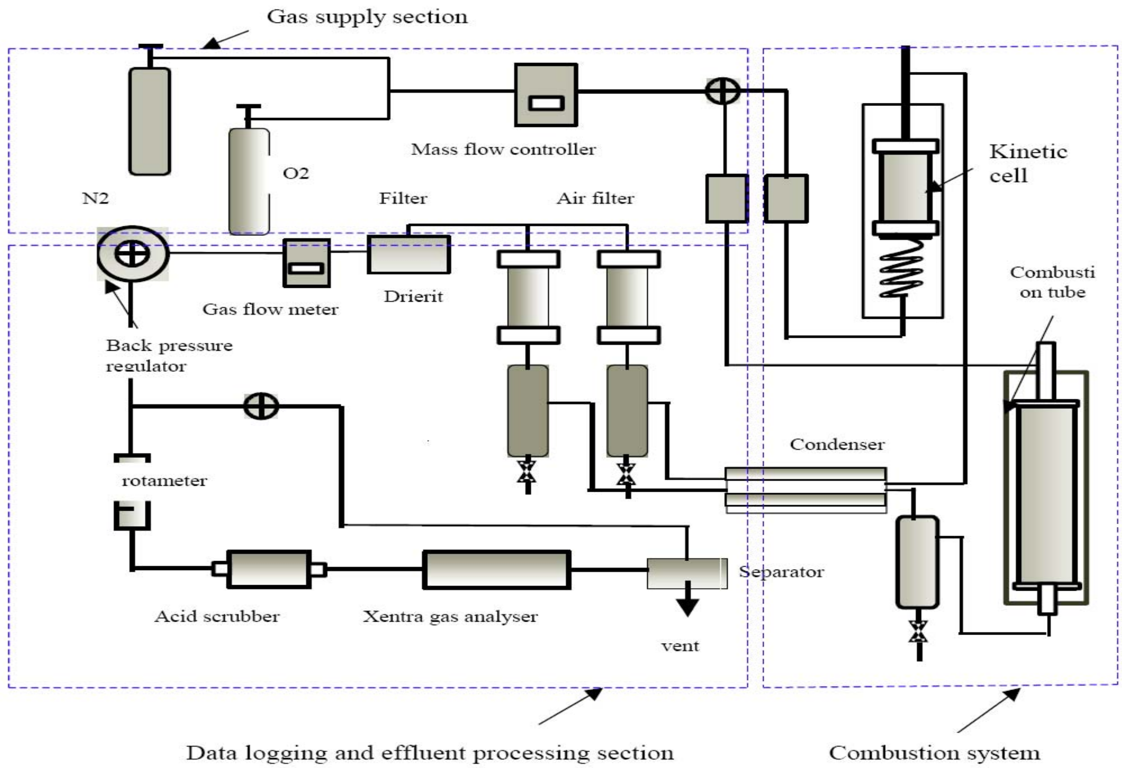

Figure 1. Experimental set-up for kinetic cell and combustion tube experiments.

Figure 2. Crushed core before (top) and after (bottom) 200 psig experiment with Oman oil.

Figure 3. Crushed core before (left) and after (right) 50 psig experiment with Oman oil.

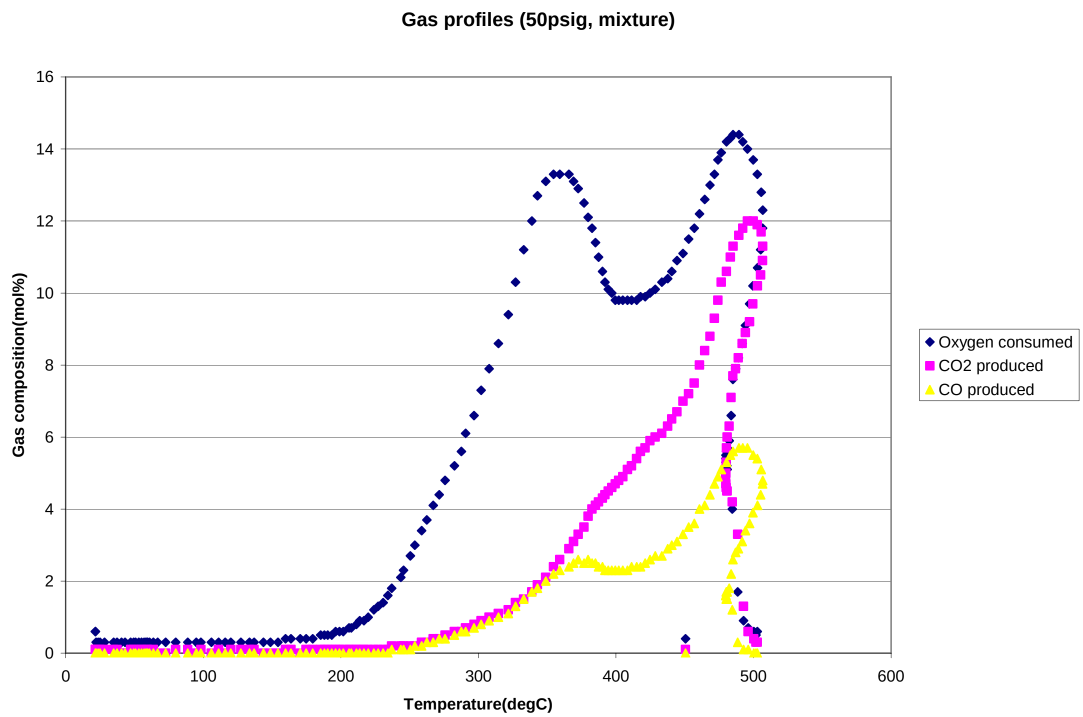

Figure 4. Gas profiles for first test using Ottawa sand packs. The LTO and HTO peaks are clearly visible in the graph of oxygen consumed. The experiment was performed at 60 psig.

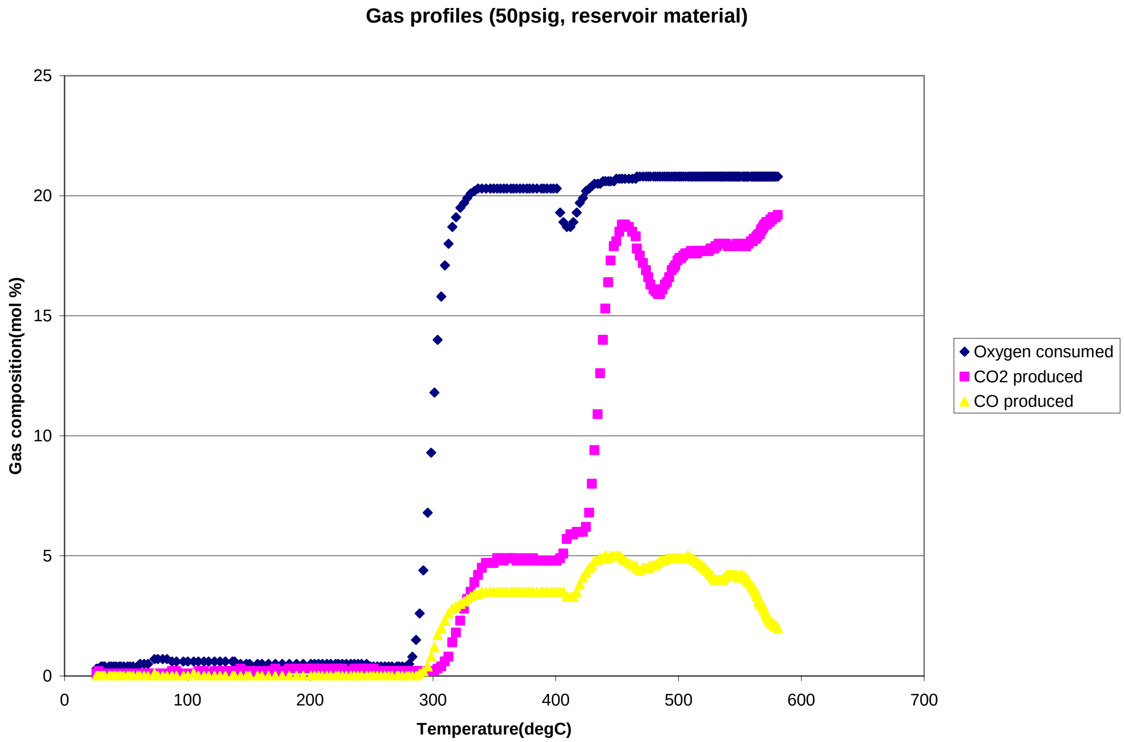

Figure 5. Gas profiles for first test using crushed Oman reservoir core. The behavior is clearly different from that in Figure 4. The experiment was performed at 50 psig.

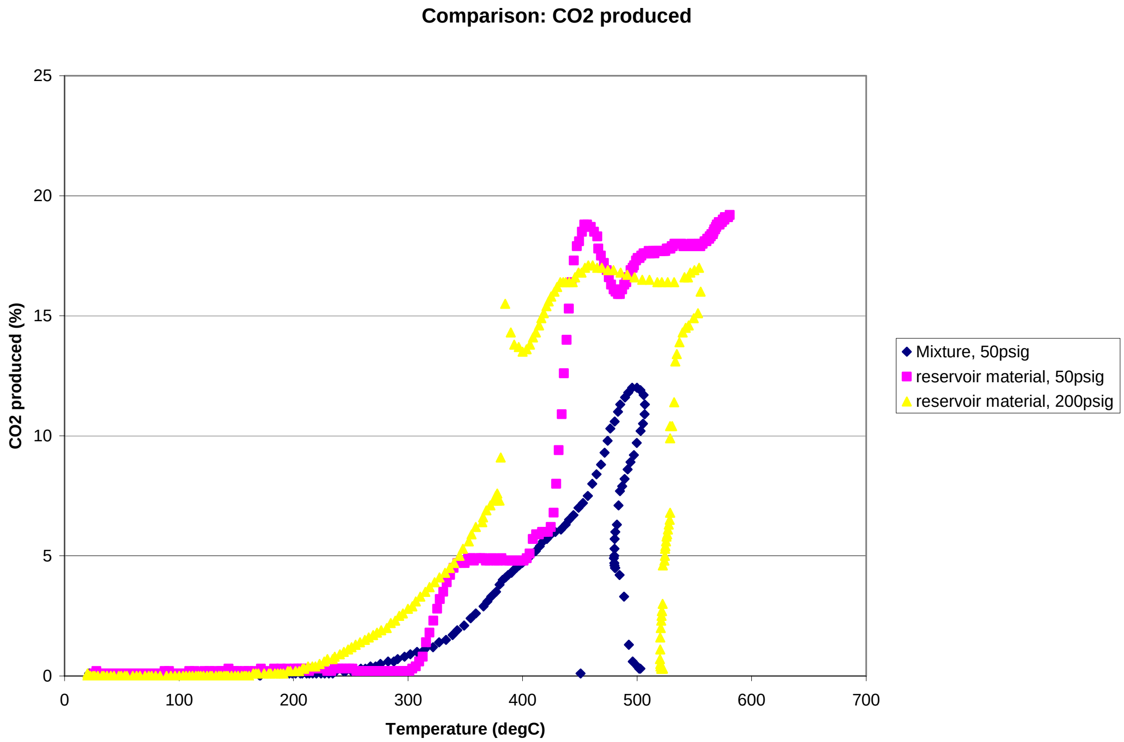

Figure 6. Comparison of the CO_2 produced for three different experiments: Ottawa sand pack at 50 psig, crushed Oman core at 50 psig, and crushed Oman core at 200 psig.