SUMMARY ANNUAL REPORT FOR AUGUST 1991 TO SEPTEMBER 1992

TITLE: A Novel Approach to Modeling Unstable EOR Displacements

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CONTRACTOR ORGANIZATION: The University of Texas at Austin

PRINCIPAL INVESTIGATOR: Elmore J. Petters

OBJECTIVES

This research is aimed at developing a methodology for predicting the performance of unstable displacements in heterogeneous reservoirs. A performance prediction approach that combines numerical modeling with laboratory imaging experiments is being developed.

Flow visualization experiments are being performed on laboratory corefloods using X-ray computed tomography (CT) and other imaging technologies to map the initial fluid saturations in time and space. A systematic procedure is being developed to replicate the experimental image data with high-resolution numerical models of the displacements. The well-tuned numerical models will then be used to scale the results of the laboratory coreflood experiments to heterogeneous reservoirs in order to predict the performance of unstable displacements in such reservoirs.

SUMMARY OF TECHNICAL PROGRESS

The research consists of the following four major tasks:

Task 1: Flow Visualization Experiments with CT Scanner
Task 2: Flow Visualization Experiments with Imaging Workstation
Task 3: Model Development and Testing
Task 4: History Match of the Flow Visualization Experiments

Presented herein is a progress report on all project tasks in the second year of the research.

Task 1: Flow Visualization Experiments with CT Scanner

The objective of this task was to conduct 3-D flow visualization experiments using the CT scanner to (1) obtain quantitative experimental data with which to calibrate high-resolution numerical models, (2) gain additional insights into the physics of unstable displacements, and (3) characterize the small-scale heterogeneities in laboratory cores.

Subtask 1.1: Visualization of Displacements in Homogeneous Media

Three additional CT imaging experiments of unstable displacements in sandpacks were completed in the second year. The objective of these experiments was to test the reproducibility of unstable displacements. Therefore, the experiments were designed to duplicate the three unstable displacements performed last year. The first experiment was an unstable first-contact miscible displacement; the second experiment was an unstable immiscible displacement (waterflood) in an oil-wet sandpack; and the third experiment was an unstable immiscible displacement (waterflood) in a water-wet sandpack. The repeat experiments were necessary because concern has often been expressed that unstable displacements might not be reproducible and therefore, might not be predictable. Our results show, however, that if properly scaled, unstable displacements are just as reproducible and predictable as stable displacements. This subtask has been completed.

Subtask 1.2: Characterization of Reservoir Rocks

One of the major difficulties in modeling fluid displacements in permeable media is the inability to characterize the heterogeneous permeable media. Last year, we developed a technique to measure and characterize the small-scale heterogeneities in laboratory cores by CT imaging and tested it on a sandpack. This year, we further validated the technique by characterizing the heterogeneities in a layered Berea sandstone core. We have also developed a technique to measure the dispersion and absorption coefficients of cores by CT imaging. These coefficients are useful in...
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the assessment of miscible displacements and the transport of contaminants in permeable media. This subtask has been completed.

Subtask 1.3: Visualization of Displacements in Heterogeneous Media

Actual reservoir rocks are nearly always heterogeneous at various length scales. The objective of this subtask was to conduct flow visualization studies in consolidated cores which more closely approximate reservoir rocks. This subtask was initiated this year. Two CT visualization experiments were performed on Berea sandstone cores. The first experiment was a stable, first-contact miscible displacement at a viscosity ratio of 1 and was used to characterize the heterogeneities in the core. The second experiment was an unstable, first-contact miscible displacement at a viscosity ratio of 10 and was designed to visualize unstable displacement phenomena in a consolidated core. The results from the consolidated cores will be compared and contrasted with those from unconsolidated sandpacks. This subtask will continue in the third year of the research.

Task 2: Flow Visualization Experiments with Imaging Workstation

The objective of this task was to acquire 2-D image data of unstable displacements in an areal model to complement the 3-D data from the CT scanner. Five unstable, immiscible displacements (wettability) in oil-wet media were completed. The fingering patterns observed in the immiscible displacements in the oil-wet media were found to be even more fractal than for the miscible displacements. This subtask will continue in the third year of the research.

Task 3: Model Development and Testing

The objective of this task was to develop fast and accurate high-resolution numerical models of selected EOR displacements of interest. To avoid duplication of previous research, we used existing numerical models at the University of Texas to accomplish this task. After testing several available numerical simulators, we selected UTCHEM for our subsequent numerical modeling task. UTCHEM is a versatile, flexible numerical reservoir simulator that was developed at the University of Texas under DOE’s sponsorship and is now widely used by oil companies and other universities. Because UTCHEM is vectorized to take advantage of the hardware architecture of the Cray X-MP supercomputer, it is an ideal simulator for implementing the modeling task (Task 4) of this research. It outperformed the other available numerical simulators in computational speed and can be used to simulate immiscible as well as first-contact miscible displacements. This subtask has been completed.

Task 4: History Match of the Flow Visualization Experiments

The objective of this task was to replicate the flow visualization experiments with a high-resolution numerical model to a degree never before attempted. Instead of attempting to match the production curve as is traditionally done in the literature, we are attempting to match the observed inject fluid saturations in time and space. This is a challenging undertaking. This task was subdivided into the following subtasks.

Subtask 4.1: Image Processing of Flow Visualization Data

The image data from the CT scanner is a much higher resolution than the numerical model. Therefore, the first step in the history match was to represent the CT data to reduce their resolution to that of the numerical model in order to permit direct comparison of the numerical and experimental results. We accomplished this subtask by averaging the 3-D saturation data into 1-D saturation profiles and by converting the 3-D saturation images into 2-D projection images that makes them directly comparable to the 2-D saturation images computed by our numerical model. This subtask has been completed.
Subtask 4.2: Geostatistical Generation of Displacement Parameters

The objective of this subtask was to create the heterogeneous permeable media that will be used to scale the unstable laboratory coreflood experiments to field conditions. We have generated twelve heterogeneous media geostatistically and characterized them by two measures of heterogeneity: the Dykstra-Parsons coefficient and the correlation length. The Dykstra-Parsons coefficient is a measure of the permeability variation in the permeable medium whereas the correlation length is a measure of the distance over which neighboring permeability values are related to one another. The twelve stochastic permeability fields were generated to cover the range of Dykstra-Parsons coefficient and correlation lengths normally encountered in petroleum reservoirs. These permeability fields will be used to scale the results of our unstable corefloods to predict their expected performance in heterogeneous reservoirs. This subtask has been completed.

Subtask 4.3: Development of History Match Methodology

The objective of this subtask was to develop a systematic procedure for matching the laboratory image data with the numerical model. We initiated this subtask with a comprehensive study on scaling laboratory experiments to other systems. The scaling study resulted in a new procedure for history-matching and scaling of laboratory corefloods to other systems. The procedure consists of the following steps: (1) we image the coreflood by CT to obtain the temporal and spatial saturation profiles, (2) we transform the saturation profiles by means of a dimensionless self-similarity variable to obtain a unique, dimensionless response function that is characteristic of the coreflood, (3) we history-match the characteristic response function for the coreflood with the numerical simulator, (4) after a satisfactory match, we compare the experimental and computed saturation profiles, recovery curves and saturation images, and (5) using the well-tuned numerical model, we scale the results of the laboratory coreflood experiment to heterogeneous reservoirs. The first four steps of the procedure were implemented this year. The fifth and final step will be implemented in the third year of the research.

SIGNIFICANT ACCOMPLISHMENTS

The most significant accomplishments in the second year of the research are as follows:

1. Acquisition of new quantitative experimental data for unstable displacements in sandpacks and consolidated cores.
2. Experimental verification of the reproducibility and predictability of unstable displacements.
3. Further validation of our procedure for characterizing the small-scale heterogeneities in cores by X-ray CT imaging.
4. Development of a systematic procedure for history-matching laboratory coreflood experiments with a numerical simulator.
5. Development of a strategy for scaling laboratory coreflood experiments to predict their expected performance in heterogeneous reservoirs.

SIGNIFICANCE TO EOR RESEARCH PLAN

The accomplishments of the second year of the research have moved us significantly close to achieving our research goal of developing a novel approach to modeling unstable EOR displacements which combines laboratory imaging experiments with numerical modeling. A systematic procedure for history-matching laboratory corefloods with a numerical simulator has been developed and implemented for immiscible displacements. A strategy for scaling laboratory corefloods to predict their expected performance in heterogeneous reservoirs has been developed and will be implemented in the third year of the research. Valuable new experimental data were acquired and will be used in future simulations.

FUTURE RESEARCH PLANS

Our future research plans include:
1. Continued acquisition of X-ray CT image data for unstable miscible and immiscible displacements in consolidated, heterogeneous cores.
2. Continued acquisition of unstable immiscible displacement patterns in the areal quarter five-spot model and further investigation of the fractal characteristics of these patterns.
4. Implementation of the final step of scaling the laboratory corefloods to heterogeneous reservoirs for immiscible and miscible displacements.

PUBLICATIONS

The following papers and thesis were published in the second year of this research:


ORAL PRESENTATIONS

The following oral presentations were made in the second year of this research:


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