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MODIFICATION OF RESERVOIR CHEMICAL AND PHYSICAL FACTORS IN STEAMFLOODS TO INCREASE HEAVY OIL RECOVERY

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University of Southern California

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DISCLAIMER

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OBJECTIVES

Thermal methods, and particularly steam injection, are currently recognized as the most promising for the efficient recovery of heavy oil. Despite significant progress, however, important technical issues remain open. Specifically, still inadequate is our knowledge of the complex interaction between porous media and the various fluids of thermal recovery (steam, water, heavy oil, gases, and chemicals). While, the interplay of heat transfer and fluid flow with pore- and macro-scale heterogeneity is largely unexplored.

The objectives of this contract are to continue previous work and to carry out new fundamental studies in the following areas of interest to thermal recovery: displacement and flow properties of fluids involving phase change (condensation-evaporation) in porous media; flow properties of mobility control fluids (such as foam); and the effect of reservoir heterogeneity on thermal recovery. The specific projects are motivated by and address the need to improve heavy oil recovery from typical reservoirs as well as less conventional fractured reservoirs producing from vertical or horizontal wells.

VAPOR-LIQUID FLOW

During this quarter, work continued on the development of relative permeabilities during steam displacement. Two directions are pursued, one based on the use of a pore-network description of steam displacement (1), and another based on a double-drainage process. The pore-network simulator is being used to predict the behavior of steam injection in a fractured system, which was previously examined experimentally in our laboratory (2). We have also developed a model for double drainage which allows for the calculation of three-phase relative permeabilities as a function of the saturation of the respective phases, the history of the displacement and the ratio in interfacial tensions. This work is completed (3) and a technical paper is in preparation. In addition, work continues in the analysis of the stability of phase change fronts in porous media using a macroscopic approach.

In a related study, we continued our investigation of the effect of gravity override during injection of a gas phase (such as steam) in porous media. Published work todate cannot predict the thickness of the gravity tongue, as a function of the various process parameters. An analytical fromalism was developed that predicts the shape of the interface in the presence of gravity override in a homogeneous porous medium, in the absence of capillary effects. We are now investigating the effect of the gravity and capillary numbers on the thickness of the gravity tongue. It is shown that the thickness scales as a power-law of the inverse of the capillary number and that it vanishes at large values of the latter. This has implications to the prediction of gravity override by conventional computer simulations, where in the absence of capillarity, the tongue thickness should scale with the simulation grid size.

Finally, we are also investigating the countercurrent flow of liquid and vapor in the presence of gravity. This process finds a variety of applications in heavy oil recovery. We are presently interested in the displacement mechanisms which are studied by pore-network simulation and experiments.

HETEROGENEITY

Work continues on the optimization of recovery processes in heterogeneous reservoirs by using optimal control methods. The theory addresses the injection strategy that maximizes the recovery efficiency of a multiple-well system at various defined targets (e.g. at water breakthrough, or at a fixed water cut). During the past quarter we carried out experiments in a Hele-Shaw cell with two controlled injection wells and one production well. Experiments were conducted in homogeneous, as well as heterogeneous cells with a particular form of heterogeneity. The results agreed reasonably well with the simulations based on optimal control theory. Current work involves conducting additional experiments and improving the numerical scheme for optimal control. The emphasis is on the effect of heterogeneity on the optimal control predictions.

On the subject of heterogeneity, work was completed on the effects of correlations (for example, with the use of *fractional Brownian motion* statistics) during invasion percolation with gradients (e.g. due to viscous or gravity forces) in long-range correlated systems. Work was also completed on the problem of inverting capillary pressure data to infer the true pore-size distribution, using a pore-network approach (4). Finally, we developed an approach to explain the origin of stabilized displacements in immiscible displacements in porous media from pore-network level studies (5). This explains the remarkable ability of the Buckley-Leverett equation to simulate displacements.

Finally, we have started two new projects dealing with the identification of permeability heterogeneity. The first involves the development of a new technique that allows the identification of the permeability semi-variogram from multiple well pressure transients (6). This technique utilizes the theory of small fluctuations, which leads to a Volterra integral equation describing the ensemble-average behavior of the well pressure, from the inversion of which the permeability semi-variogram can be obtained. The second deals with the identification of the entire permeability field from tracer profiles (e.g. those obtained from a CT scan). We have developed the particular algorithm to invert the data and find good agreement with synthetic data, so far.

CHEMICAL ADDITIVES

In the area of chemical additives work continued on the behavior of non-Newtonian fluid flow and on foam displacements in porous media. As pointed out in our previous report, work in this area proceeds in two parallel directions: One involves the development of a generic theory for finding the minimum threshold path in a disordered system. This part is almost complete and a technical paper was prepared on this subject (7). The other effort involves the application of this theory to pore networks to determine the conditions for foam formation and mobilization. A technical paper summarizing the results was written (8). This work shows how to compute parameters related to foam flow in porous media, such as the minimum pressure gradient for onset of foam flow, the fraction of trapped foam, etc. In this quarter, a Ph.D Thesis was also completed on this subject (9).

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