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INVESTIGATION OF MULTISCALE AND MULTIPHASE FLOW, TRANSPORT AND REACTION IN HEAVY OIL RECOVERY PROCESS

Quarterly Report
July 1, 1999-September 30, 1999

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INVESTIGATION OF MULTISCALE AND MULTIPHASE FLOW, TRANSPORT AND REACTION IN HEAVY OIL RECOVERY PROCESSES

OBJECTIVES

The emphasis of this work is on investigating the mechanisms and factors that control the recovery of heavy oil, with the objective to improve recovery efficiencies. For this purpose, the interaction of flow, transport and reaction at various scales (from the pore-network to the field scales) will be studied. Particular mechanisms to be investigated include the onset of gas flow in foamy oil production and in in-situ steam drive, gravity drainage in steam processes, the development of sustained combustion fronts and the propagation of foams in porous media. Analytical, computational and experimental methods will be utilized to advance the state of the art in heavy oil recovery. Successful completion of this research is expected to lead to improvements in the recovery efficiency of various heavy oil processes.

Specifically, four different areas will be studied: internal phase change in porous media, which accompanies foamy oil production and in-situ steam drives; the effect of pore microstructure on flow, transport and reaction processes inside the steam zone and the combustion zone, in thermal oil recovery processes; the effects of large-scale permeability heterogeneity on the propagation of thermal fronts in porous media and the development of methods for their upscaling; and the flow and displacement properties of fluids with a yield stress in porous media.

Reported below is the progress made during this period in the four Tasks identified in the proposal.

I. INTERNAL PHASE CHANGE IN POROUS MEDIA

During this period, work continued in the following areas: the study of mass transfer in the pore-space of vapor-liquid systems, the upscaling of mass transfer processes in systems involving phase change, the onset of gas flow in internal phase change processes and the formation of foamy oils. The study on mass transfer emphasizes diffusion and convection in the pore space. Pore-network models are used to develop relations between mass flux and concentration differences in the various systems undergoing internal phase change. These include evaporation and drying processes (1), as well as processes related to well deliverability. As pointed out before, this approach will be also applied to in-situ steam drive processes. It is also applicable to the recovery of light components from oils in fractured systems by gas injection. During this period, a manuscript was accepted for publication (2). Work is also conducted to investigate the effects of corner films in the mass transfer processes involving phase change. Upscaling of mass transfer from the pore-network to the macroscopic scale is attempted using transverse averages, where it is found that under relatively strong convection, the conventional approach based on volume averaging fails. The work on the onset of the mobilization of gas bubbles in phase change is aimed to understand the properties of foamy oils. Experiments involving micromodels and Hele-Shaw cells are being conducted for this purpose.

II. EFFECTS OF MICROSTRUCTURE ON STEAM ZONE AND COMBUSTION PROCESSES

During this period, work continued in the following two areas: the properties of steam-water flows and more generally the relative permeabilities of condensing/evaporating flows, and the study of combustion processes at the pore-network scale. The work in the first area explores two issues: the effect of heat transfer on the relative permeabilities of steam-water phases, and the mechanisms and relative permeabilities of gravity-driven counter-current flows of vapor-liquid systems. The theory outlined in (3) and pore-network simulations are used to carry out the first study. Both theoretical and experimental work is used in the second study. A model for counter-current flow processes is being developed, based on concepts of ganglia motion and mobilization, and on the instability of the flow. Experimental work is also under way to study counter-current flow by visualization in rough-walled Hele-Shaw cells.

To study the effect of microstructure on in-situ combustion, pore-network models are being developed that account for the relevant mechanisms in typical combustion processes: These include mass transfer by convection and diffusion in the pore space, reaction between injected gases and fuel, following Arrhenius kinetics, heat transfer by conduction and convection, heat generation due to the reaction, and pore-structural changes due to the combustion process. The model predicts interesting effects of the microstructure on combustion performance. We are particularly studying possible instabilities, the sensitivity to various reaction and transport parameters and the scale-up of the information from the pore-network scale to the macroscopic scale. The results are currently compared to existing models for filtration and smoldering combustion, which are closely related to our task. Experiments in Hele-Shaw cells are also in the planning stage.

In addition, work is being conducted to capture generic features of reaction, convection and diffusion in evolving porous media, due to pore-structural changes, in random envirnoments.

III. EFFECTS OF LARGE-SCALE HETEROGENEITY ON THERMAL FRONTS

In this period, work continued mainly on the stability of countercurrent flows, involving vapor and liquid, and on effects of heterogeneity during the propagation of combustion fronts. In the first direction, we have completed a stability analysis of steam-water countercurrent flows, in vapor-dominated and in liquid-dominated systems (4). As we pointed out before, this work is relevant to steam injection from horizontal wells and the SAGD process. The effect of heterogeneity on such instabilities was studied and found to be of second order. Additional effects, such as the injection rate of vapor or liquid, or of a third phase, are under consideration. To examine the effects of heterogeneity on macroscopic combustion fronts, we continued the development of a mathematical model which treats the combustion front as a discontinuity, the microstructure of which is not ingored, however. Based on asymptotic methods, the model will capture the relevant flow and transport processes upstream and downstream of the front, which are coupled acorss the latter with jump conditions. Such a description is useful for the subsequent scale-up in numerical simulation and th incorporation of heterogeneities.

Related to this area of heterogeneity, we have completed a study for the identification of permeability heterogeneity from the arrival times of displacement fronts, both for isotropic and anisotropic media. A manuscript was submitted for publication (5). In addition, various effects of heterogeneity on the stability of displacement fronts are still being explored. As in I. above, the applicability of transverse averaging methods is being pursued.

IV. FLOW OF FLUIDS WITH YIELD STRESS

In this area, efforts are underway to extend our recent methods on the phase diagram of drainage for Newtonian fluids to non-Newtonian flows. Form this work, the relative permeabilities of such fluids can be obtained. In parallel, we study the applicability of our previous work on Invasion Percolation with Memory to describe the development of wormholes in porous media during heavy oil production.

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