**CHARACTERIZATION and MODIFICATION of FLUID CONDUCTIVITY in
HETEROGENEOUS RESERVOIRS to IMPROVE SWEEP EFFICIENCY**

Contract Number: DE-19-89BC14474

The University of Michigan

Contract Date: September 26, 1989

Anticipated Completion Date: August 30, 1992

Government Award: \$117,000 (current year)

Principal Investigator: H. Scott Fogler

Project Manager: Robert E. Lemmon

Reporting Period: January 1-March 31, 1992

MASTER

ENCLOSURE

Diagenesis Report-Second Quarterly

To optimize the petroleum recovery process from a formation, it is essential to accurately characterize potential reservoirs in terms of porosity, permeability, and hydrocarbon content. The quality of a given reservoir is determined by diagenetic processes that have been occurring over very long periods of time. The term diagenesis can be defined as the chemical and physical changes occurring in sediments during and after their deposition but before consolidation. In the first quarterly report of this year, we identified some of the more important diagenetic processes (precipitation and dissolution of calcite, production and subsequent breakdown of carboxylic acids, etc.) and reviewed some of previous mathematical models that were formulated to describe the diagenetic process. The ability to mathematically model diagenetic processes and to predict a reservoir's characteristics provides a great tool to help evaluate formations. In this second quarterly report, we will describe, in detail, the model that we are currently using to perform these tasks.

Previously, we discussed a two-dimensional network model that was developed at The University of Michigan to describe flow, precipitation, dissolution, and migration of various species in an interconnected network of capillary tubes (Rege and Fogler, 1988). The premise behind this type of model was that the interconnected capillary tubes represent pore throats while the intersection of these tubes (points of mixing) represents pore chambers. The permeability and heterogeneity of this simulated porous media was dictated by the assigned bond lengths and diameters, as well as the interconnectivity between the bonds. The pressure was calculated at each node by solving a matrix of Hagen-Poiseuille equations. Finite reaction rates were assigned to the model while the changing permeability due to precipitation/dissolution was accounted for by changing bond diameters. Hoefner and Fogler first used this model to qualitatively describe the acidization of limestone with HCl (Hoefner and Fogler, 1987). A comparison of Wood's metal castings with the network model indicated the ability of the model to accurately depict flow channels in a porous media. Rege and Fogler later used this model to study the precipitation and dissolution in a ferric chloride-limestone system. This study showed the ability of the model to accurately predict the permeability response in this type of system. This past success indicates that network modeling can be an effective tool in simulating diagenetic processes, especially considering the fact that many processes occurring during diagenesis are precipitation/dissolution reactions.

During the second quarter of the year, we have upgraded the existing network model to more realistically simulate a porous media. Although many of the features from the

previous model remain, two major modifications were made to improve upon the previous model: 1) the extension of the two-dimensional model into three-dimensions; and 2) the inclusion of pore bodies in the network model. A 2x2x2 pore-pore throat representation of the upgraded model is shown in Figure 1. The advantages that this model has over the previous model include: 1) a more accurate geometric representation (3-D vs. 2-D) of a reservoir; 2) pore bodies with finite volumes where reactions can occur (as opposed to points of mixing); 3) a more distinguishable picture of various flow phenomena (wormholing, dominant flow paths, etc.); 4) the potential for observing back flow in the media; and 5) more realistic changes in porosity, i.e. pore body effects. The fact that this model is in 3-dimensions and has accounted for pore space makes it a more realistic replica of an actual porous media. As with its predecessor, this model is capable of calculating the changing permeability and porosity in the network matrix. As stated earlier, this will provide a great tool in examining how the diagenetic processes affect these two parameters over extended period of times.

A simulation is performed by assigning either a constant pressure drop across the matrix or a constant flowrate through the matrix. Over the course of the simulation, discrete time steps are chosen (the time step is an adjustable parameter) during which flow through the pores and pore throats occurs. The fluid flow during each time step is distributed based upon the pore throat diameters in the matrix. Larger pore throats receive more fluid than smaller pore throats. After every time step, the pressure drop across each pore throat is calculated using a successive substitution algorithm. The precipitation and dissolution during the time step are taken into account by solving the flow system (reaction, flowrate, stream concentration, etc.) in each pore throat and determining the amount of precipitation or dissolution. The changes in pressure drop across a pore throat due to precipitation/dissolution are accounted for by adjusting the throat diameter. This process is continued until the fluid has percolated through the matrix. Flowrate and concentration data can be collected and placed in a file during each time step. The resulting files are read by a visualization program (apE 3-D in our case) and displayed.

The model was tested for the acidization of limestone with HCl. In this particular system, the important parameter studied was the effect of the Damkohler number (ratio of acid consumption rate to acid convection rate) on the propagation of acid through the porous limestone. Hoefner and Fogler showed that at high Damkohler numbers, a single dominant channel formed in which the acid flowed (Hoefner and Fogler, 1987). As the Damkohler number was decreased, branching occurred, and the channels tended to become more uniform, representing more and more closely the structure of the original

pore space (Figure 2). The 3-D network model simulation of the effect of the Damkohler number on acid penetration is shown in Figure 3. The network size used for this simulation was $20 \times 10 \times 10$. It is evident from this figure that the network model is accurate in showing the increased branching with a decreasing Damkohler number. This figure shows the effectiveness of the 3-D network model in simulating precipitation/dissolution reaction systems in porous media.

In the next quarter of the year, we will incorporate the important diagenetic reactions (cementation of calcite, breakdown of carboxylic acids, etc) into the simulator. The time step parameter will be adjusted to account for the long time frames associated with diagenesis. With this simulation, we will be able to quantitatively, as well as graphically, describe the evolving reservoir characteristics (permeability, porosity) during the course of diagenesis.

Figure 1
Representation of porous media as a three dimensional network of interconnected pipes (pore throats) and spheres (pore bodies), both of which could vary in size.

Decreasing Damkohler number

Figure 2 Effect of Damkohler number (rate of acid consumption/rate of acid convection) on the structure of channels etched during the acidization of limestone (Hoefner and Fogler, 1987)

Decreasing Damkohler number

Figure 3 3-Dimensional computer simulation depicting the effect of the Damkohler number on the propagation of acid into a porous media (brighter bonds indicate larger pore throats)

END

DATE

FILMED

3/29/94