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OIL RECOVERY FROM NATURALLY FRACTURED RESERVOIRS
BY STEAM INJECTION METHODS

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OIL RECOVERY FROM NATURALLY FRACTURED RESERVOIRS BY STEAM INJECTION METHODS

OBJECTIVES

The objective of this study is to develop accurate models for predicting oil recovery in naturally fractured reservoirs by steam injection. This objective is being met through an integrated experimental, numerical, and analytical study of the recovery mechanisms that control oil recovery for this process. These mechanisms include capillary imbibition, thermal expansion, gas generation from chemical reactions, and temperature-dependent thermal properties.

SUMMARY OF TECHNICAL PROGRESS

Recovery Mechanisms

During this reporting period, the construction of the high-temperature apparatuses and the development of a closed-form, analytical model for capillary imbibition into matrix blocks continued. A third experimental apparatus to validate the analytical model has been assembled and data are being collected. A paper has been submitted for review that expands previous work on the oil recovery mechanisms in naturally fractured reservoirs during steamflooding.

During the next quarter, the development of analytical models for oil expulsion will continue, as will the construction of the experimental apparatuses.

The capillary imbibition model for one-dimensional, linear imbibition has been extended to two-dimensional imbibition into a four-sided square. Imbibition is assumed to occur simultaneously in all faces.

The cumulative oil recovery until the imbibition front reaches the center of the square is given by the following equation:

$$\frac{Q_o}{Q_\infty} = L_D \left(1 - \frac{L_D}{3} \right), \quad (1)$$

where L_D is given by

$$L_D = \frac{3}{2} \cos \left\{ \frac{a \cos \left(1 - \frac{40t}{27t^*} \right)}{3} + \frac{4\pi}{3} \right\} + \frac{3}{4} \quad (2)$$

and t^* is the time required for the imbibition front to reach the centerline of the square,

$$t^* = \frac{5L^2 \phi \Delta S_o \left[\frac{\mu_w}{k_{rw}} + \frac{\mu_o}{k_{ro}} \right]}{36kP_{c,Soi}}. \quad (2)$$

The oil recovery after the front has reached the center of the square, is given by

$$\frac{Q_o}{Q_{\infty}} = 1 - \frac{1}{3} \exp \left\{ \frac{5}{6} \left(1 - \frac{t}{t^*} \right) \right\} \quad (3)$$

Thermal Properties

The primary goals for this quarter were to devise the method, specify and order the extra components needed to adapt the apparatus, and to develop the data treatment procedure.

A survey on transient methods of measuring thermal properties was carried out in order to select the most adequate method. The main concerns were to minimize the modifications in our apparatus and to avoid introducing probes into the sample body. None of the methods seen in the literature completely satisfied these demands. The alternative was to propose a new method, using the recently developed technology of film sensors to measure heat flux. With the film sensor we are technically able to measure heat fluxes directly at the proper intended surface. It also allows measurement of fluxes that dynamically vary with time, given the relatively negligible thermal inertia of its sensors. In our case, the aspect of not interfering with the sample constitution was a definitive issue.

After determining the proper characteristics of the film sensor to be used, the parts were specified and purchased. Minor modifications on the lab setup are needed and the film sensor is expected to be mounted by the end of the next quarter.

The development of a data treatment procedure was also carried out. The procedure involves deconvolving measured temperature and heat fluxes as time functions, so that simpler mathematical models can be generated for the same physical configuration. Because the data treatment procedure necessarily contains different levels of numerical integration, the scheme needs to be tested. The accuracy of our numerical algorithm was tested with artificially generated data. The scheme has proven to be very accurate and adequate to treat the data, from the computer time and memory occupancy standpoint.

For the coming quarter we foresee the mounting of the heat flux sensor film onto the steady-state apparatus. Several runs of preliminary tests to verify the proper functioning of the data acquisition system in the transient mode are also envisioned.

Simulation

In this quarter we continued the theoretical work on flow transfer functions seeking analytical solutions for the capillary imbibition problem. We also initiated a study of heat transfer functions for dual porosity thermal models.

The research on imbibition-dominated flow transfer functions proceeded, looking into the configuration of a single matrix block with one face open to fracture flow. Two basic cases have been considered. In the first case the matrix block is totally immersed, with the fracture-open boundary fully water saturated. In this condition, an analytical solution is possible if the problem is linearized. A semi-analytical solution is also possible when considering the non-linear, more general problem. The solutions reveal that the classical exponential transfer function is valid only after the imbibed water front reaches the center of the matrix block. Before this time the flow behaves as an infinite acting system with the oil flux varying inversely with the square root of time.

In the second case the matrix block is surrounded by partially immersed fractures. The partial immersion is modeled by injecting water into one end of the fracture and producing oil and/or water from the other. The varying fluid distribution in the fracture is obtained from the

solution to the saturation equation describing the fluid flow in the fracture. The oil flux from the matrix to the block is then expressed in terms of the convolution between the oil flux of a totally immersed block and the fracture saturation change. The results obtained from the solution to this problem show that before water breakthrough, the oil flux at the production end of the fracture increases to a maximum value. After water breakthrough and a short transition period, the oil flux curve converges to the value of the totally immersed case.

In parallel and using similar guidelines to the previous work, the development of heat transfer functions between matrix blocks and fractures is underway. The approach is to look for proper transfer functions by modelling in detail the heat and mass transport between a single matrix block and surrounding fractures.

The mathematical formulation has been completed, including the discretization of the governing equations for a fully implicit algorithm. The simulator being built is of the thermal-black oil type, allowing simulations in three-dimensional geometries. In the first version only two phases, oil and water, are considered. Both compressible and incompressible flow modes can be simulated. We have started coding the program on the Department's VAX-6520 computer and we expect to have the simulator ready to run by the end of this quarter.

REFERENCES/PUBLICATIONS

There were no publications during this reporting period.

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