4-04

DIRECT CALCULATION OF RESIDUAL OIL SATURATION AFTER WATERFLOODING IN FRACTURED ROCKS

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The efficiency of waterflooding in a fractured rock, in particular in chalk, very much depends on the efficiency of spontaneous imbibition of water from the fractures into the blocks of rock. "Without a strong imbibition process to pull water from the fracture system into the matrix, the potential for losing production of vast amounts of oil is great", Ref.[1], p.85. Nevertheless, oil recovery may only as a first approximation be evaluated from spontaneous imbibition experiments. Since other physical mechanisms, that is, gravity and viscous forces, also play a role in the oil recovery process, this static estimate gives exaggerated values of remaining oil saturation.

To elucidate the influence of viscous and gravity forces on residual oil saturation a numerical model *REST2D* can be implemented. The model computes the oil saturation remaining in the block after waterflooding is completed, with account for all 3 forces: viscous, capillary and gravitational. Thus the geometry of the flow both through the block and bypassing the block is fully taken into account. The case described by the model is a very particular one, i.e., only one phase (water) is moving, steady state flow, and therefore the computations can be arranged more efficiently and accurately then in a standard black oil simulator, like, e.g., *ECLIPSE*. In contrast to a standard simulator, *REST2D* computes the final stage of the waterflooding process directly, without a sequence of time steps. More details about the numerical model, as well as comparisons with *ECLIPSE*, can be found in Ref. [2].

TABLE - Simulation Results

N	Pressure drop, atm	Rate, sq.cm/sec	Velocity, m/day	Average water saturation	Effective permeability to water, Darcy	Average oil saturation
1	0,05	2,40E-03	0,03456	0,39	0,036	0,61
2	0,075	4,79E-03	0,06898	0,42	0,0479	0,58
3	0,113	8,68E-03	0,12499	0,45	0,0576	0,55
4	0,169	1,49E-02	0,21456	0,484	0,0661	0,516
5	0,253	2,45E-02	0,3528	0,562	0,0726	0,438
6	0,38	3,96E-02	0,57024	0,671	0,0781	0,329

Calculation of residual oil. The problem is formulated in a cross section. The size of the domain is 80cm × 60 cm. The size of the grid is 41 × 31. The absolute permeability field consists of a low permeable (10 *mD*) inclusion into a high permeable (1 *D*) background, see Figure 1. The upper and lower boundaries are impermeable. On the left and right boundaries constant pressures are fixed. The injection is through the left boundary of the domain, and the production is through the right boundary where capillary pressure is set to zero. Inside the domain capillary pressure is correlated with absolute permeability through the Leverett *J*-function.

Six different pressure drops are considered, see Table. The resulting water saturation fields are presented in Figure 2, and Figure 3. The remaining oil saturation depends on the pressure drop applied to the rock. It decreases from 61% at low rate, which is close to capillary limit value of 72%, down to 33% at high rate. The dependence of the remaining oil on the average total velocity is shown in Figure 4.

Discussion and Conclusion. Generally, the distribution of residual oil depends on the balance of capillary, viscous and gravity forces and on reservoir heterogeneity. For a given reservoir heterogeneity field the fluid velocity in different points of space strongly differs. The velocity ratio between high permeable zones and low permeable ones, close to the wells and away from them may easily reach several orders of magnitude. This makes it unreasonable to expect capillary dominance in the whole flow domain, which is often assumed.

A rapid and accurate evaluation of residual oil saturation after waterflooding in fractured rocks can be obtained by implementation of the developed model.

References

1. Andersen, M.A.: *Petroleum research in North sea chalk*. RF-Rogaland Research, Stavanger, 1995.
2. Virnovsky, G.A., Skjaeveland, S.M., A. Skauge, Helset, H.M.: "A Model to Quantify Residual Saturation Distribution in Heterogeneous Reservoirs." SPE 39538, to be presented at the 1998 SPE-India Oil and Gas Conference held in New Delhi.

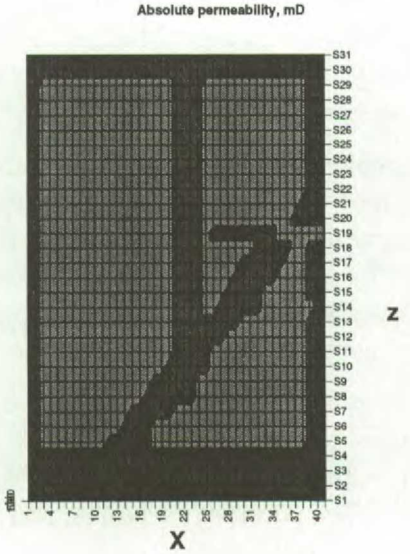

Figure 1. Absolute permeability field for the test case 2. Darker color corresponds to 1D.

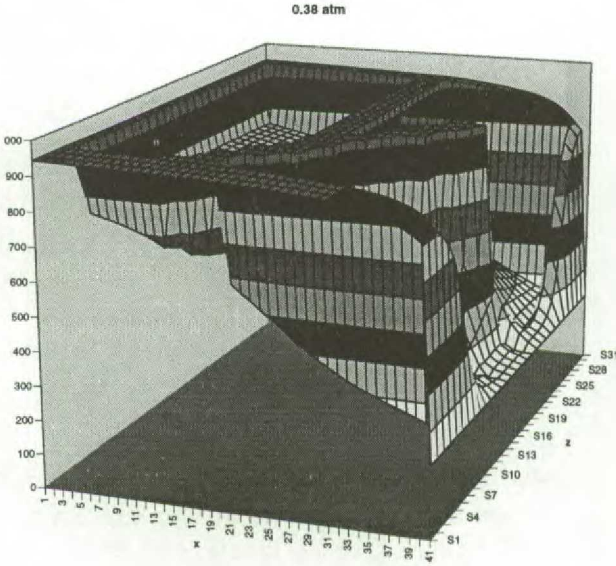

Figure 3. Water saturation distribution at pressure drop 0.38 atm.

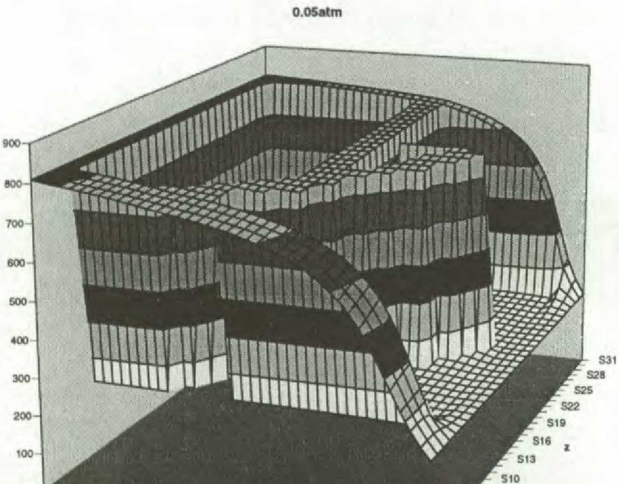

Figure 2. Water saturation distribution at pressure drop 0.05 atm

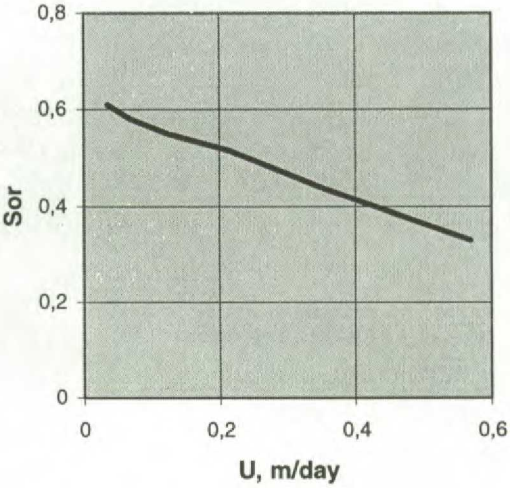

Figure 4. Capillary trapped oil as a function of total rate