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Reservoir rock fluid imbibition experiments: complex study using X-ray computer tomography and ultrasonic techniques

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Quantification of fluid flow through porous media is an essential part of hydrocarbon recovery and reservoir characterization. In particular, the controlled replacement of one fluid by another is a common procedure in order to stimulate reservoir performance. When injecting fluids in a rock, acoustic data (through seismic surveying) can indicate the presence of the fluid and help localize the fluid front. However, its interpretation requires a well-founded knowledge of heterogeneous porous media, particularly of acoustic signatures in multi-phase reservoirs.

Forced imbibition was performed in a reservoir sandstone (porosity 16 %; permeability 67 mD) by injecting water into a dry sample. The fluid injection was monitored through X-Ray Computer Tomography (CT) and Acoustic Ultrasonic measurements. In this way, the time-space distribution of the fluid can be, simultaneously, observed in the CT scans and quantified through measuring ultrasonic velocities and saturation. The sample was covered by epoxy and only the opposite side to the area of injection was open (in direct contact with atmospheric pressure).

We present two sets of experiments. For SET-3, water injection started at 5 mL/h and at 1 mL/h for SET-5 and both injection rates were decreased to 0.1 mL/h after 3 and 5 hours of injection, respectively.

Through the CT scans, we can clearly see the water front moving and both sets presented a significant dependence of P-wave velocities, saturation and geometry of the water front with the initial injection rate. Regarding the acoustic response, upon decreasing the injection rate, the P-wave velocities and saturation decreased. This behaviour seems to be connected to the partially saturated conditions of the sample (between 72 % and 76 %) before decreasing the injection rate. This means that, locally, there is still gas trapped in the pores that can be released and/or expand when the injection rate decreases. This liberty for expansion/diffusion of gas bubbles is facilitated by the decrease of pore pressure that the initial higher injection rates no longer forces. After a sudden decrease, the saturation level starts increasing (the water starts filling the new empty spaces that the gas bubbles were occupying previously) and they reach the level they achieved before the change of injection rate and, consequently, increasing P-wave velocities.

Another important result is the geometry of the water front. For SET-3, the shape of the water front changed from flat to round (height of curvature higher in the centre of the sample than near the walls) after we decreased injection rate from 5 mL/h to 0.1 mL/h. For SET-5, it changed from flat to round while still injecting at 1 mL/h but the curvature was enhanced when the injection rate was decreased to 0.1 mL/h. Lower injection rates seem to promote a rounder front while higher injection rates can sustain a flatter front. This behaviour seems to be influenced by the boundary conditions of the sample: closer to the walls, the atmospheric gas pressure is higher due to a smaller, limited area of contact between atmospheric gas and water front. At higher injection rates, the pressures between the systems matrix/water and matrix/gas tend to balance faster throughout the whole fluid front surface.

Our results suggest that, while injecting water in a dry sample, fluid distribution (and consequently, acoustic response and saturation) have a strong dependence on the initial injection rate since it appears that it is this parameter that influences the final balance of the gradient pressures between matrix/water and matrix/gas.