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Stress Dependent Permeabilities of Sandstones and Carbonates: Compression Experiments and Pore Network Modeling.

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Abstract

Mechanical effects are of great importance during reservoir production and induce sensible changes of the transport properties. This work focuses on the forecast of the change of porosity and permeabilities of reservoir rocks submitted to hydrostatic and deviatoric stress states representative of the field conditions. To predict these evolutions, we need to perform flow experiments with representative stress conditions. Our triaxial cell was designed to achieve this purpose and allows the measurement of permeabilities in the directions along and transverse to the principal direction of stresses. A good knowledge of the rock microstructures is also fundamental to choose the correct set of parameters for the simulation tools, and the input from our micro scanner facility is therefore of great importance. Using our directional permeability triaxial apparatus, we applied different stress paths to sandstones and carbonates samples and the evolutions of porosity and permeabilities were monitored during loading. We performed a microstructural analysis of these rocks using Mercury Porosimetry and Computed Micro Tomography imaging. From the 3D reconstructions, we extracted the poral network skeletons and the associated pore and throat size distributions. Then we performed two kinds of pore network modeling, one based on the real pore geometry and another based on a statistical description, to calculate the macroscopic transport properties. We included a model of pressure dependence of pore and throat sizes, based on deformation of porous inclusions in the framework of elasticity theory, to simulate the evolution of the transport properties with pressure. This model requires the knowledge of the elastic moduli of the rocks which were determined experimentally from the compression experiments. We show that the experimental determination of the evolution of directional permeabilities under hydrostatic and deviatoric stress conditions is feasible. The pressure dependences can be of valuable importance and therefore influence of mechanical effects should be investigated in experimental transport studies. Finally, we show that pore network modeling associated with CMT imaging can be used to forecast the pressure evolution of transport properties and therefore to understand the reservoir response to production.

Introduction

The decrease of pore pressure during production of oil reservoirs induces significant modifications of the field stress, which results in an increase of the effective vertical and horizontal stresses applied on the reservoirs[1-2]. The compaction induced by this stresses increase may have an important impact on the microstructures and thus the petrophysical properties of the rocks.

Numerous experimental studies have shown the effect of the stresses increase on the evolution of most common petrophysical properties, namely, the porosity and the permeability. In most cases, the porosity loss resulting from the compaction is associated with a permeability reduction.[3-6] However, some authors have also reported an increase of the permeability with pressure due either to the stress paths reported in the references[4,7] or to some preferential orientations of microstructures bearing fluid flows, such as the microcracks, compared to the direction of principal stresses application.[2,8] Those results support the importance of performing flow experiments under true reservoir conditions, i.e. triaxial conditions.

In deviatoric loading conditions, the permeability evolution depends on the strain regime. In the brittle regime, experimental results obtained on sandstones[9-10] showed a dependence of permeability evolution with the initial porosity of the rock, and highlighted two different behaviors; in the case of low-porosity sandstones, the brittle failure induces a permeability increase[11-12] due to an augmentation of the porous network connectivity and possibly to the apparition of strongly preferential flow paths; for the high-porosity sandstones, the diminution of the permeability is mainly due to the reduction of the pore throat sizes[13] or to the increase of the network tortuosity [9]. In the shear-enhanced compaction regime defined by Wong et al.[10], the authors observed a drop