Experimental investigation of changes in petrophysical properties and structural deformation of carbonate reservoirs

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Abstract: To examine the effect of pressure on pore structure and petrophysical properties of carbonate rock, the porosity, permeability, CT scanning, SEM and elastic wave velocity of two carbonate core plug samples from an oilfield in Southwest Iran were analyzed under cyclic pressure. One of the plugs was calcite and the other was dolomite with anhydrite nodules. The cyclic pressure exerted on the samples increased from 13.79 MPa to 27.58 MPa in six steps, and the variations in petrophysical properties of the two samples at different pressure loading and unloading steps were counted and analyzed. The results show that the calcite sample decreases in porosity and permeability with the increase of pressure, which is consistent with the results from compression and shear wave velocity tests. In the dolomite sample, the decreasing trend was not observed; fluctuations of compressive and shear velocities were observed during the loading stage, which may be due to different geometries of the pores and the porosity variation in the sample. Understanding the variation of carbonate petrophysical properties with pressure is helpful for optimizing reservoir development scheme.

Key words: cyclic pressure loading; petrophysical property; carbonate reservoir, CT scan; rock physical property; structure deformation

Introduction

Porosity and permeability are two of the most important rock properties parameters to characterize the ability to store and transport hydrocarbons in porous media[1-7]. Porosity and permeability usually decrease with increasing stress in both consolidated and unconsolidated porous media[8-9]. The trend of porosity and permeability changes during the production processes depends on chemical, physical, and mechanical factors[10]. Therefore, since carbonate reservoirs are typically heterogeneous and anisotropic, the full understanding of the changes of these two parameters plays a significant role in determining strategies for hydrocarbon production[11-13]. Karacan et al.[3] investigated the porosity and structural changes in sandstone porous media under triaxial loading conditions to measure the relationship of porosity and permeability. They concluded that in the ductile failure condition, the porosity was reduced by applying pressure in all directions, and it increased after approaching to ductile-plastic deformation condition. There was also a gradual reduction in the permeability due to loading; with the onset of fracturing, an increase in permeability was observed. If the stress is applied repeatedly, which is also called 'cyclic loading', the damage to the rock sample will increase gradually. The rock will deform correspondingly, and may experience fatigue failure and decrease in strength[14-15]. Teklu et al.[16] investigated the overburden permeability and hysteresis of cores from different carbonate reservoirs, and proposed cyclical changes of permeability during pressure loading and unloading cycles. They found that the permeability decreased with the increase of stress and the process had some hysteresis.

The development of imaging technology in recent decades, which is referred to as digital rock physics (DRP), improves the ability to evaluate the reservoir rock properties and examine the internal structure of the rock[17-19]. Vinegar and Wellington[20] used computed tomography (CT) to monitor the oil production process for the first time. They described the rock physics using CT scanning and X-ray methods and proposed a protocol for multiphase fluid flow. Afterward, many researchers used CT scanning to measure the physical properties of