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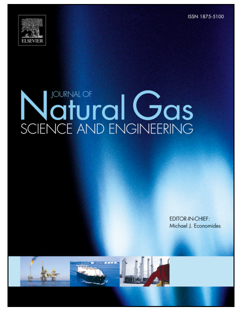

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Experimental study of mechanics and seepage characteristics of sandstones after liquid-nitrogen stimulation

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Abstract: Because the conventional method of treating hydraulic fracturing uses a large amount of water, a waterless fracturing technology is needed urgently in those areas lacking sufficient water resources. This study experimentally investigates the mechanical and seepage characteristics of sandstones at four saturations (dry, water, oil, mixed water and oil) after being immersed in liquid nitrogen for a long period. After becoming fully saturated, the samples are tested for their acoustic velocities, elastic modulus and uniaxial compressive strength. Only the dry samples have an increase in all of these attributes; the rest of the samples decline in all of these attributes. Deformation measurements and microstructural studies are conducted to explain the mechanical observations. For the dry samples, shrinkage occurs without damage; for the remaining samples, there are incompatible deformations between rock skeletons and pore fluids that might lead to the generation of damage. Along with the changes in mechanical properties, the permeability of all sandstone samples declines. Based on the microstructural analysis and the Scanning Electronic Microscope (SEM) images, we suggest that the shrinkage of small pores (10 nm < radius < 700 nm) is the main reason for the permeability decrease of dry samples, the blocking of small pores and the closure of large pores (700 nm < radius < 10 μm) lead to the permeability decrease of water saturated, oil saturated and water-oil-saturated samples.

Keywords: liquid-nitrogen stimulation; sandstones; saturated conditions; frozen deformation; permeability decline; microstructure

1. Introduction

With the large-scale exploitation of unconventional reservoirs of oil and natural gas using hydraulic fracturing, the problems caused by hydraulic fracturing result in more attention being paid to such issues as the waste of water resources and environmental pollution [1-7]. Currently, with the growth of environmental awareness, Germany, France and Spain, among others, have issued related policies and regulations of forbidding petroleum companies to exploit oil and gas resources through hydraulic fracturing [8-10]. Thus, the petroleum industry needs a fracturing technology that is waterless and environmentally friendly; to that end, liquid-nitrogen fracturing may be a good choice. The concept of liquid-nitrogen fracturing relies on the idea that the large thermal gradient between liquid nitrogen (-196 ℃) and the formation rocks can induce fractures [11]. In contrast to hydraulic fracturing, liquid-nitrogen fracturing does not require water resources, produces no pollution to harm the environment, and will not cause the hydration expansion of clay, among other issues. In addition, liquid nitrogen cost less than other waterless fracturing methods.

The development of oil and gas resources using liquid nitrogen has been attracting much more attention since the end of the 20th Century. In 1991, thermal shock was applied as a means to alter the physical conditions of reservoir rocks and to increase oil and gas production [12, 13]. In 1997, McDaniel et al. observed the thermal effects on coal [14]. In their research, coal samples were submerged in liquid nitrogen. The effects observed were an audible cracking sound that was heard while the samples were cooling. When competent coal samples came into contact with liquid nitrogen, the samples fractured and separated into smaller cubical units. McDaniel et al. [14] also carried out field applications using liquid nitrogen as a