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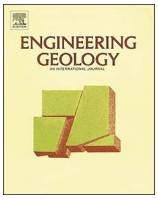

Experimental investigation on the mechanical behaviours of a low-clay shale under water-based fluids

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ABSTRACT

The interactions between drilling/fracking fluids and shale formations have great effect on shale gas exploitation. Previous studies have shown that water/brine saturation will cause clay-rich shale swelling and strength decreasing. However, little research has been done to investigate such effect on resource shales which mainly have low clay contents. This paper presents an experimental study of the impact of water-based fluids on the mechanical properties of a low-clay shale. Uniaxial compressive strength (UCS) tests were performed on shale samples soaked in NaCl, KCl and $CaCl_2$ solutions with saline concentrations of 0%, 10%, 20% and 25.4%. The crack propagation and the failure mechanism of the shale samples were recorded using acoustic emission (AE) sensors in combination with Digital Image Correlation (DIC) technique. Scanning electron microscopy (SEM) analysis was used to understand the micro scale variation of shale samples after soaking in saline solutions. According to the experimental results, water-saturated samples have the highest swelling increasing and the largest strength reduction. The swelling potential and UCS values decrease with increased saline concentration. Potassium ions have a significant effect on shale strength enhancement when compared to sodium ions and calcium ions. The failure pattern of the samples is mainly splitting breakage. NaCl and $CaCl_2$ saturated samples present more axial fractures than the KCl saturated samples when failure occurs. The SEM results show that crystals of NaCl, KCl and $CaCl_2$ were observed on the surface, and the amount of crystals increases with increasing saline concentrations. The AE results also show that saline saturation could increase the cumulative AE energy.

1. Introduction

The production of shale gas has increased rapidly in the last few years. Fracking is the main technique used in the exploitation process. However, the problem of wellbore instability caused by the detrimental interaction between the drilling/fracking fluids and shale formations still plagues shale gas exploitation and even the petroleum industry. This interaction changes pore pressure, swelling/shrinking potential and compressive strength around the wellbore, which result in shale formation collapse. As shale accounts for over 75% of drilling formations and > 90% of compressive wellbore failure occurring in these shale formations, the mechanical properties of shale need to be considered as a matter of urgency (Asef, 2013; Favero et al., 2016; Ghanbari and Dehghanpour, 2015; He et al., 2016; King, n.d.; Lyu et al., 2015a; Ramos da Silva et al., 2008).

Shale is a kind of sedimentary rock which the particles are mostly of silt and clay size (Blatt et al., 2006). Shale will expand while absorbing liquids or gas (White et al., 2005). Shale swelling will create more fractures and make shale weaker (Emadi et al., 2015; Lin and Cerato, 2014; Makhanov et al., 2014; Saadeldin and Henni, 2016). Based on the Mohr-Coulomb failure diagram, the decrease of effective normal stress shifts the Mohr circle to the left, and the decrease of strength shifts the safe/failure envelope line closer to the Mohr circle. Therefore, wellbore instability is assumed to occur easily (Al-Bazali et al., 2008).

A fairly extensive research literature is available on the mechanics of shale, especially for clay-rich shale, which are affected by temperature, gas adsorption, confining pressure, pore pressure and mineralogical structure (Bol et al., 1994; Bostrom et al., 1998; Bu et al., 2015; Kuila et al., 2011; Li et al., 2017; Lyu et al., 2016a, b; Mody and Hale, 1993; Roshan et al., 2015; Tan et al., 2014; Teixeira et al., 2017; Valès et al., 2004). The type and concentration of saline solution in the wellbore or aquifer are also important factors which influence the shale's swelling/shrinkage and strength (Busch et al., 2016; Dehghanpour et al., 2013; Li et al., 2016; Lyu et al., 2015b; Ma and

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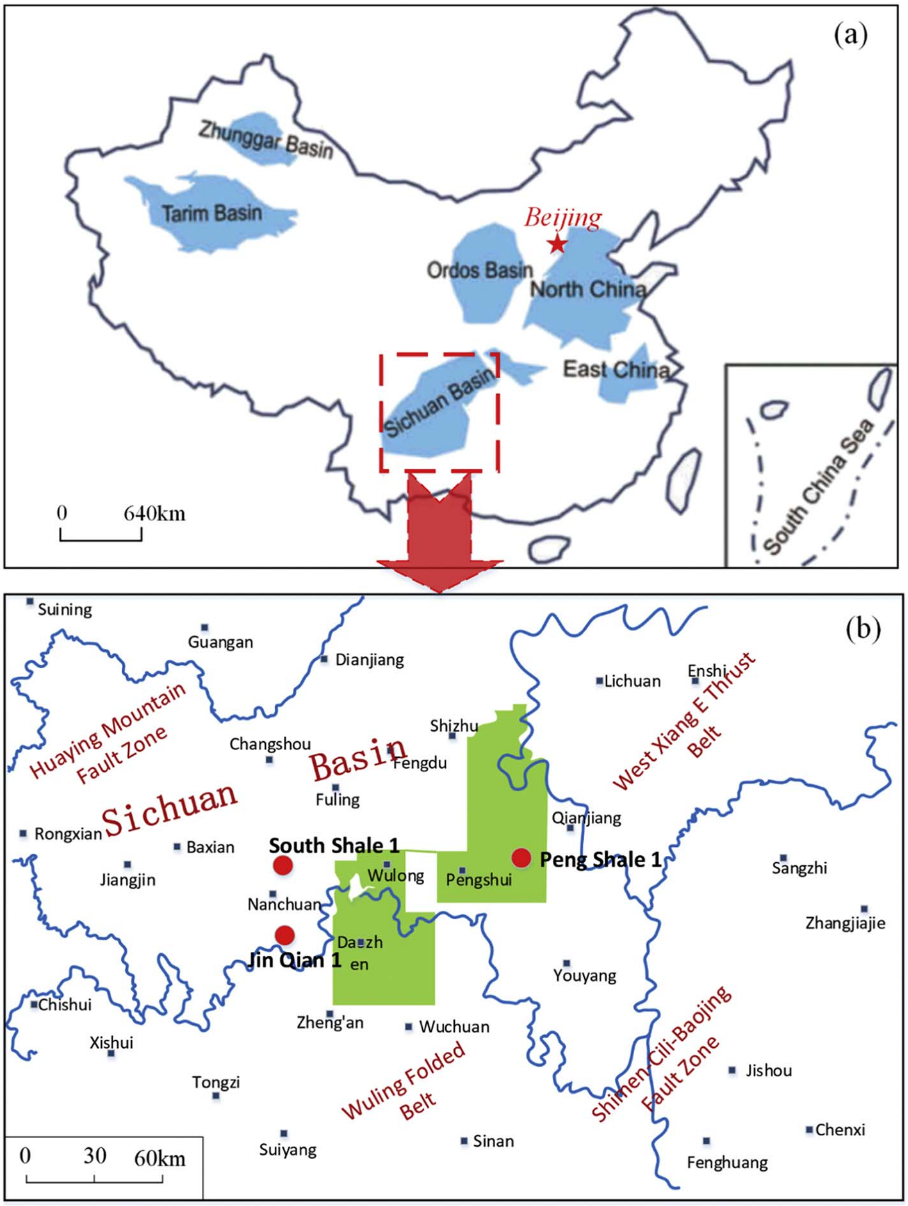

Fig. 1. Location of Shichuan Basin (a) and Pengshui Block (b), modified after Tan et al. (2015) and Hou et al. (2015).

Table 1
Mineralogical composition of shale.

X-ray diffraction analysis	Value (%, w/w)
Rigid component (total)	72.95
Quartz	55.50
Feldspar	14.57
Cristobalite	2.88
Clay component (total)	5.85
Kaolinite	1.00
Illite	1.42
Smectite	3.43
Others (total)	20.97
Pyrite	4.08
Calcite	4.44
Muscovite	5.57
Annite	1.41
Marble	5.10
Braunite	0.37

Table 2
Element composition of the shale.

Element	O	Si	Al	K	Fe	Mg	Ca	Na	Others
wt%	47.0	35.3	8.5	4.6	2.6	1.1	0.4	0.3	0.2

Chen, 2015; Shukla et al., 2013; Wen et al., 2015; Yu et al., 2001). Bostrom et al. (1998)found that, when the confining pressure is 7 MPa and the temperature is 80 °C, the deformation percentage of shale samples increased with the increase of KCl concentrations. Horsrud et al. (1998) tested the deformation of smectite-rich shales exposed to NaCl, KCl and $CaCl_2$ solutions. After 20 h' adsorption, swelling occurred for samples in NaCl and $CaCl_2$ solutions, while the normalised length of specimens in KCl solutions decreased. Wong (1998) performed swelling tests of La Biche shale samples in NaCl solutions of different concentrations. The results showed that water adsorption creates the largest axial and lateral swelling strain, the swelling potential decreases with increasing salinity concentrations and the Young's modulus decreases with increasing swelling, while the Poisson's ratio appears to be independent. Al-Bazali et al. (2008) studied the stress and acoustic