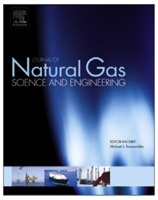
Journal of Natural Gas Science and Engineering 35 (2016) 362–371

Contents lists available at ScienceDirect

Journal of Natural Gas Science and Engineering

journal homepage: www.elsevier.com/locate/jngse



Permeability and elastic parameters under different pressures of tight gas sandstones in eastern Ordos basin, China

Yong Li [a,*], Daiyong Cao [a], Shangzhi Meng [b], Xinlei Niu [a], Peng Wu [b], Hao Xu [a], Jincheng Liu [a]

[a] *College of Geoscience and Surveying Engineering, China University of Mining and Technology, Beijing, 100083, China*
[b] *China United Coalbed Methane Co. Ltd, Beijing, 100011, China*

ARTICLE INFO

Article history:
Received 25 May 2016
Received in revised form
22 August 2016
Accepted 30 August 2016
Available online 31 August 2016

Keywords:
Linxing area
Tight gas sandstone
Porosity
Permeability
Elastic parameter

ABSTRACT

The porosity, permeability and elastic parameters are important to the design and engineering of tight gas sandstone wells. Based on experimental tests of sandstones sampled continuously from newly drilled well cores, the porosity, permeability, and elastic parameters were characterized with a discussion of their controlling factors. The porosity lies in a range of 0.1%–13.8%, with 96.6% of all the samples being lower than 10%. The permeability is generally under 0.1 mD, with 43.4% clustered <0.01 mD. The permeability is much more sensitive to the confining stresses than the porosity is, which endured almost five times damage as the confining stresses increased from 500 to 5000 psi. The Young's modulus (E) and Poisson' Ratio (υ) values were tested by uniaxial (UA), triaxial (TA) and acoustic velocity measurement methods. Different methods show different scales and also different variation trend. The E values are similar between the UA and TA methods in a range of >2000 Psi, however, the TA results are generally higher than the UA results in $E < 2000$ MPa range. The υ values of UA are higher than the TA results in $\upsilon > 0.175$, vice versa in $\upsilon < 0.175$. The compressive strength values both from TA and UA methods show a linear relationship, with the TA results three times of the UA results. In general, the dynamic υ values increase sharply (>10%) as with the axial stress increases, while the E values show less of an increase (approximately 5%). The permeability is relatively high at a depth of 1700 m, and then decreases in deeper strata; this is likely caused by the higher stress conditions and complex clay compositions. The elastic parameters show no clear relationship with depth, as they are mainly affected by the combined influences of rock compositions and the diagenesis effect. The results improve the understanding of tight gas sandstone properties and will be useful in gas reservoir engineering.

1. Introduction

Permeability and elastic parameters are both of great importance in the design of rock engineering projects and numerical analysis and require extensive attention in the development of tight sand gas (Zou et al., 2012). The porosity and permeability determine the gas/water flow ability, and the elastic parameters are closely associated with the reservoir reconstruction and well design. Both theoretical and experimental investigations in the laboratory and the field have been conducted to reflect the porosity and permeability evolutions, under a continuum of prescribed confining stresses with both steady state and transient flow methods (Stokkendal et al., 2009; Pan and Connell, 2012; Wang et al., 2013, 2014). The stress dependences of porosity and permeability are generally described as exponential or power law relationships (Brace et al., 1968; Zoback and Byerlee, 1975; Morrow et al., 1984; David et al., 1994; Dong et al., 2010).

The tight gas sandstone properties, such as Young's modulus (E) and Poisson's ratio (υ), are generally determined from the measurement of the strength and stress-strain relationships of a cylindrical specimen. In addition to the common methods of cores under a uniaxial and triaxial (simulated) stress conditions, the dynamic properties of E, υ and compressive strength can be determined by the measurement of compression and shear wave velocities (Smith et al., 2009; Dürrast et al., 2012). The static and dynamic elastic parameters in tight sandstones have been reported with results of differentiated sensitivity under different confining stresses (Freund, 1992; Ray et al., 1999; Fortin et al., 2005). Different

---

[*] Corresponding author.
E-mail addresses: liyong@cumtb.edu.cn, cugbliyong@gmail.com (Y. Li).

http://dx.doi.org/10.1016/j.jngse.2016.08.073
1875-5100/© 2016 Elsevier B.V. All rights reserved.

methods generally produce different evaluation results, thus a systematic evaluation of sandstones with different methods would be of great importance in understanding the tight gas reservoir characteristics.

The eastern margin of the Ordos basin is famous for its largely distributed coalbed methane resources and potential tight gas development (Li et al., 2014a,b, 2015). Currently, the tight gas sandstones are generating attention, as a number of wells have been drilled. The complex burial and diagenetic histories of the Permian and Carboniferous sandstones in the coal-bearing strata present significant challenges for gas well development with regard to the reservoir quality and rock property prediction. In this study, we present a fundamental investigation into the behaviors of physical parameters under different stresses, with the following innovations: (1) a combination of static and dynamic elastic parameters under different stresses; (2) systematic analysis of tight gas sandstone parameters, e.g., porosity, permeability and elastic physics; and (3) the controlling effect of rock composition and depth on physical parameters. The tested parameters form a basis of sound engineering treatment design in petroleum engineering. Moreover, the results would improve our understanding of the permeability and rock mechanical parameters of tight gas sandstones and their behavior under different confining/axial stresses.

2. Methodology

2.1. Porosity and permeability variations

A total of 261 plugs cut parallel to the sedimentary bedding with a diameter of 1.5 inch were prepared for porosity and permeability tests. An automated permeameter–porosimeter was used to measure the gas permeability and porosity; porosity measurements utilized a Boyles's law technique and absolute permeability was determined by the unsteady pressure drop method. Analyses of eight cores were conducted for use in the discussion of permeability and the confining stress relationship. The confining pressures used were 500, 1000, 2000, 3000, 4000 and 5000 psi, with a static inlet air pressure of 2 MPa and a pulse overpressure equal to 0.5 MPa. A similar testing method has been reported by Li et al., 2014a,b.

2.2. Triaxial (TA) compression

Core plugs with fixed dimensions of one inch diameter and two inch length cut perpendicularly to the bedding were used for tests. These plugs were saw-cut and end ground parallel to tolerances of 0.001 inch as required by ASTM and ISRM standard. The samples were then kept under vacuum for at least 24 h before the saturation with brine solution. The mechanical parameters of the rock samples were measured with an RTR-1000 type triaxial geomechanical testing system from TerraTek. The maximum axial pressure can be as much as 1000 KN, and confining pressure of 140 MPa. The core preparation was conducted in the Rock Mechanics Laboratory Langfang Branch of the Research Institute of Petroleum Exploration and Development, Petrochina.

The cores were sealed with steel endcaps and a Teflon jacket to simulate the reservoir conditions and also prevent the intrusion of confining fluid. Each sealed specimen was then placed into a servo-controlled pressure vessel, after axial and radial deformation transducers had been mounted on the specimen. The in-situ conditions, including confining pressures (P_c, the mean stress at the corresponding depths), and pore pressure (P_p, calculated by assuming normal pore pressure gradients), were calculated from the strata depth according to experience. After the primary confining pressure had been established and equilibrated, confining and pore pressures were then raised up to reservoir pressure. Finally, confining pressure was raised up to the mean horizontal stress. The data were collected in real time and could then be used for data analysis.

The E and υ were obtained from the differential stress loading segment and used to calculate skeleton compressibility (c_s) and bulk compressibility (c_b) as follows:

$$C_b = \frac{d\varepsilon_{Vb}}{dp_c} \tag{1}$$

$$C_s = \frac{d\varepsilon_{Vs}}{d\sigma_c} \tag{2}$$

$$E = \frac{\sigma_a}{\varepsilon_a} \tag{3}$$

$$\upsilon = \frac{\varepsilon_r}{\varepsilon_a} \tag{4}$$

where, C_b, bulk compressibility, 1/MPa; C_s, skeleton compressibility, 1/MPa; E, Young's modulus, MPa; υ, Poisson's ratio; P_c, confining pressure, MPa; ε_{vb}, bulk volumetric strain; ε_{vs}, skeleton volumetric strain; σ_a, axial differential stress, MPa; ε_a, axial strain; ε_r, radial strain.

2.3. Uniaxial (UA) compression

The specimen preparation for the UA compression tests was similar to that for the TA compressions test, sealed with steel endcaps and a Teflon jacket. The E, υ and compressive strength were obtained from axial stress loading under stress/strain control (ASTM, 2002).

2.4. Acoustic velocity measurements

The acoustic velocity measurement provides a dynamic modulus whereas the stress-strain measurement yields a static elastic modulus. The acoustic velocities were tested by an impulse that traveled through the entire specimen as P (compression) and S (shear) waves as an electric signal (Fortin et al., 2005; Mashinskii and Pashkov, 2005). Based on the travel times of P and S waves and on the specimen length, velocities of the P and S waves were

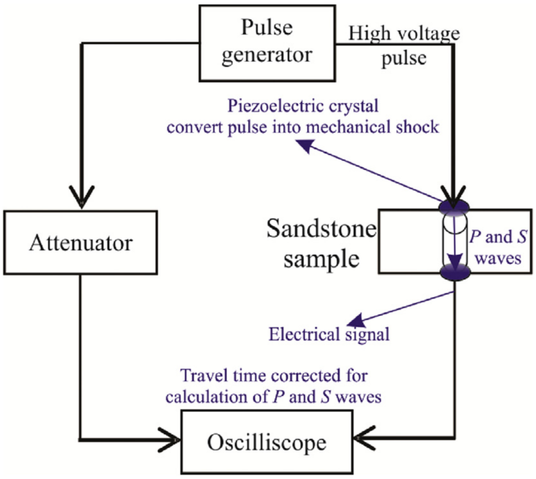


Fig. 1. Schematic configuration of pulse propagation system used to determine ultrasonic velocities.