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Effective porosity in lignite using kerosene with low-field nuclear magnetic resonance

Hao Xu[a,b,*], Dazhen Tang[a,b], Yanpeng Chen[c], Ying Ming[a,b], Xiangyang Chen[a,b], Haoxin Qu[a,b], Yunxing Yuan[a,b], Song Li[a,b], Shu Tao[a,b]

[a] School of Energy Resources, China University of Geosciences (Beijing), Beijing 100083, China
[b] Coal Reservoir Laboratory of National Engineering Research Center of Coalbed Methane Development & Utilization, Beijing 100083, China
[c] Research Institute of Petroleum Exploration and Development, Beijing 100083, China

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ABSTRACT

Effective porosity is a key factor in subsurface fluid flow. However, lignite is soft, may swell in water (depending on saturation state), and is friable. Thus the conventional saturated water NMR method has challenges when applied to lignite (coal swelling, and fragmentation during the centrification process to remove the pore water. Here an improved experimental method for effective porosity is demonstrated for lignite. To prevent sample breakage, the cores were wrapped with a heat shrinkable plastic and kerosene replaced water as the saturated fluid. The kerosene low-field NMR signal and porosity relationship was established and demonstrated for lignites from the Lower Cretaceous Saihantala Formation in the Shengli coalbed reservoirs in the Erlian Basin of Inner Mongolia, China. The lignite had a relatively high total porosity of 37.2–47.0% and an effective porosity of 25.0–34.6%. Thus, from this and additional reservoir considerations, this area is likely conducive to the production of coalbed methane.

1. Introduction

The commercial development of coalbed methane (CBM) occurs in low-rank reservoirs such as the Powder River Basin in the United States [1,2] and the Surat Basin of Australia [3,4]. Coalbed methane wells can have high gas yields (the highest daily gas production is > 2000 m^3) in the Lower Cretaceous lignite reservoir of the Erlian Basin of Inner Mongolia, China [5]. So Chinese low-rank (including lignite) reservoirs are of interest for CBM exploration and development. The effective porosity is most commonly considered to represent the porosity of a rock available to contribute to fluid-fluid and is used in the calculation of hydrocarbon reserves [6,7]. The effective porosity of coal can be obtained by subtracting the residual porosity from the total porosity based on mercury injection [8,9], but unfortunately this is a destructive approach and the pore structure can be altered by the compressive forces used. Thus, for coal the often non-destructive approach determining the water-saturated and centrifuged porosities by low-field nuclear magnetic resonance (NMR) is more attractive [10]. Low field NMR technology has been widely used in quantitative microstructural characterization and porosity for coal and other reservoirs [11–14], but the coals should usually be soaked in 100% distilled water for approximately 48 h to achieve water saturation [15–18]. Depending on the initial water saturation of the lignite — the samples can swell (impacting porosity values) and will also often fragment during centrifugation. To achieve accurate effective porosity data here an improved low-field NMR approach is demonstrated (using sample core wrapping and with kerosene as the saturation fluid) for lignite samples from Inner Mongolia, China.

2. Experimental

2.1. Samples

The lignite samples were obtained from the No. 5 coal seam, Lower Cretaceous Saihantala Formation, from the Shenhua coal mine of the Shengli coalfield, Erlian Basin, within Inner Mongolia, China. This area is one of the main lignite CBM exploration target in that basin. Six samples were collected directly from the working faces of open cuts. These were carefully packed prior to shipped to the laboratory. Each sample was divided into a large block (approximately, 15 × 15 × 15 cm), a moderate block (approximately, 5 × 5 × 5 cm), and small pieces for thin sections. Subsamples were prepared as polished sections of 3 × 3 cm for random vitrinite reflectance ($R_{o,ran}$) analysis. Powdered samples were used for the proximate analysis.

* Corresponding author at School of Energy Resources, China University of Geosciences (Beijing), Beijing 100083, China.
E-mail address: Xuhao600@163.com (H. Xu).

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Cylindrical samples with a diameter of 2.5 cm and ~4 cm in length were used for the low-field NMR and helium porosity analysis.

2.2. Experiments

The random mean vitrinite reflectance ($R_{o,r}$) measurements were performed on the polished pellet using a Leitz MPV-3 photometer microscope, according to China National Standards GB/T 6948–2008 [19]. Proximate analysis, following the Chinese national standard GB/T 212–2008 [20].

To avoid damage to lignite samples during subsequent handling and centrifugation, the lignite core was wrapped with a heat shrinkable plastic. The use of kerosene as the saturation fluid prevented coal swelling. In the traditional analysis, the low-field NMR approach can identify the ^1H signal in water. The data is obtained after water saturation and following centrifugation to remove pore water. Here however as kerosene was used as the saturation fluid the analysis detects the ^1H nuclei of the kerosene. The instrument collects the spin echo string of the kerosene magnetic signal in the sample. Since the amplitude of the initial signal obtained by the multi-index inversion is proportional to the kerosene content in the sample, the effective pore volume of the sample can be calculated. The ratio of the pore volume to the sample volume is the porosity. Following centrifugation the signal reflect the residual fluid volume. The maximum cumulative T2 amplitude in the saturated kerosene state is calibrated to total porosity, and the cumulative T2 amplitude in the residual kerosene state can be calibrated to the residual porosity. Therefore, low-field nuclear magnetic resonance technology to measure the effective lignite porosity. The specific steps are shown in Fig. 1:

Table 1
Proximate analysis and vitrinite reflectance for samples from the Erlian Basin.

Samples No.	R_o%	Mad%	Aad%	Vad%	Fcad%
NM-1	0.34	22.04	12.34	19.80	45.82
NM-2	0.29	23.65	14.30	21.47	40.58
NM-3	0.36	29.45	7.13	22.25	41.17
NM-4	0.38	19.61	12.21	19.03	49.15
NM-5	0.39	24.31	3.81	17.51	54.37
NM-6	0.38	29.25	7.02	18.30	45.43

Mad = Moisture content (wt%, air dry basis), Aad = Ash yield (wt%, air dry basis), Vad = volatile matter (wt%, air dry basis).

Table 2
NMR signal values of standard samples.

Standard samples No.	Kerosene volume (ml)	Peak value of NMR	Basal signal value of NMR	Difference
1	0.3	3531.70	116.79	3414.91
2	1	10464.57	116.79	10347.78
3	2	20354.34	116.79	20237.54
4	3	30736.55	116.79	30619.76

2.2.1. To determine the kerosene calibration curve

Various volumes of kerosene within a glass vial were placed in the low-field NMR apparatus, to measure the attenuation spectrum. Before the lignite samples were measured 0.3, 1, 2 ml and 3 ml of kerosene were used to calibrate the NMR signal strength. The echo time was set to 0.4 ms and the waiting time was 4 s. The 4 standard samples were

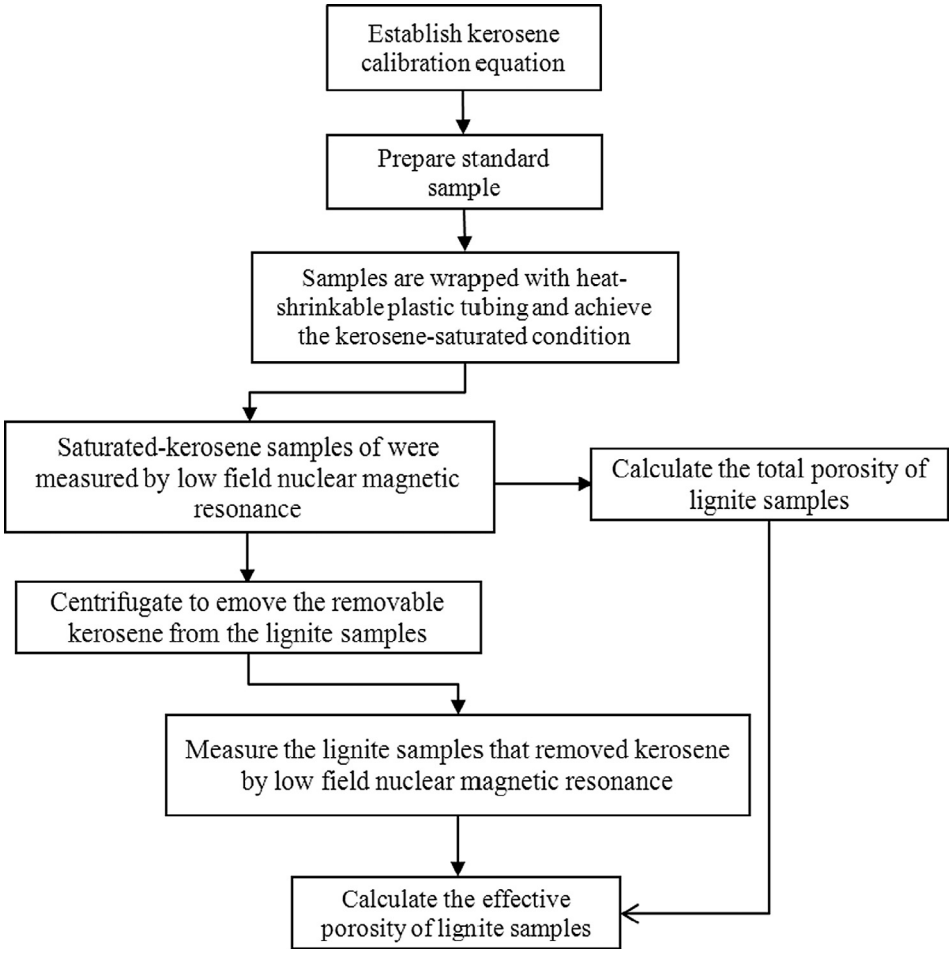

Fig. 1. Workflow used to improve measurement for lignite effective porosity by NMR.