Pore structure characterization of shale gas reservoirs, Blue Nile Basin, Sudan

Monera A. Shoieb, Nor Syazwani Zainal Abidin, Chow Weng Sum, Yassir Ibrahim and Ahmed A. H. Taha

Abstract_ The heterogeneity and complexity of shale gas have become clear as the development of unconventional resources has improved. It is important to characterize the pore structure of shale gas inorder to get an image about hydrocarbon storage and transport. Nitrogen adsorption method (N₂) was performed on a set of shale reservoir samples from the rift basin in Sudan, namely, the Blue Nile Basin using Surface Area Analyzer and Porosimetry System (SAP). The amount of gas adsorbed is proportional to the surface area of the sample. Inorder to get an idea about the nature of the pore structure including, pore size distribution and pore volume had to be characterized in details. The result of N₂ adsorption analysis of the shale samples showed that the pressure adsorption revealed significant differences in surface area and pore volumes for the sample suite. The pore size distribution suggested multi-modal system with a broad peak between 2 nm and 25 nm, and the pore volume is predominantly occupied by meso-pores (2~50 nm) and the main specific surface area is dominated by the micro-pores (<2 nm) and meso-pores (<50 nm). The porosity of shales proved to be mainly dependant on the degree of pore volume development in pores less than 10nm.

Keywords: Blue Nile Basin, Dinder Formation, Shale gas, Pore structure,Pore Size.

* Please underline the name of the presenter.
1. Introduction

The development of gas and oil in unconventional plays in the United State and Northern Europe has affected the finances and the energy of these areas as well as the whole world [1].

The storage, flow, and productivity of hydrocarbon gas are closely related to the pore structures of unconventional shale gas reservoirs, which are characterized as low porosity and low permeability [2]. Shale gas occurs commonly in the forms of free gas and sorbed gas, with only a tiny amount of dissolved gas present in the pores of shale [3,4]. Knowledge of pore size distribution is critical for understanding both fluid flow mechanisms and storage [5]. Nitrogen adsorption has been used for the characterization of porous materials, and as key parameters, such as surface area, pore volume and pore size distribution [6 and 7]. Characterization of the pore structure of the shale gas is important for the knowledge of the mode of occurrence of natural gas. These information on a detailed manner seems to be lacking for the study area. There is a need to characterization of meso-pore (2~50 nm) and macro-pore (>50 nm). (JSCP) Very few literatures is available in the study area, and focuses on the shale gas potentiality using organic geochemical techniques [1].

The objective of this paper is to investigate the pore structure of the shale samples of the rift basin and to calculate the surface area, pore volume and pore size distribution.

2. Materials and methods

A total of five cutting samples were used in this study, three samples were from F-1 well (F-1, F-8, F-9) and two samples were from T-1 well (T-1, T-2) were selected for
the nitrogen adsorption analysis, to get an idea into the nature of the pore structure including pore size distribution and pore volume.

Specific surface area from Nitrogen BET is based on forming a monolayer around measured surfaces. The method normally uses nitrogen, therefore, is referred to as Nitrogen BET. The concept using BET is that the amount of adsorbed gases on solid surfaces can provide a measure of the area of that surface. Isotherm of this adsorption can be computed by many methods. Much information can be adsorbed from surface area method including physical adsorption of molecules. For studying sedimentary rocks, information on surface area, pore size, and pore volume can be obtained. The N$_2$ data collected on crushed samples were interpreted using multi-point Brunauer–Emmett–Teller (BET) and Langmuir analysis for surface area and Barrett–Joyner–Halenda (BJH) analysis for pore size distributions. The samples were collected from shale layers within the rift basin, obtained from the Ministry of Petroleum in Sudan.

3. Results

3.1 Adsorption isotherms.

Nitrogen adsorption/desorption isotherms at 196°C may provide useful information about the pore structure characteristics of the shales [8]. N$_2$ adsorption isotherms (Fig.1) demonstrate a wide range in adsorption for all samples. In general, according to the Brunauer, Deming, Deming and Teller classification [9]. The N$_2$ adsorption isotherms belong to Type II, indicative of multilayer adsorption.

At low relative pressure (p/p$_0$=0~0.2), the volume of the gas adsorption has been increases, and it forms the monolayer adsorption. At relative pressure below 0.9, the monolayer adsorption begins to shift to multilayer adsorption. As relative pressure increases above 0.9, the gas adsorption volume increases. It is worthwhile to note that a significant portion of gas adsorption at relative pressure below 0.05 for all five shale samples is indicative of micro-pores of nanometers range.
3.2 Surface area and pore volume.

The pore size distribution is often plotted with a logarithmic diameter axis [10], as the area under the curve of a plot of \( dV/d\log(D) \) versus \( D \) is visually proportional to pore volume.
volumes [11]. Plots of cumulative pore volume versus pore size for nitrogen Adsorption (Figure 2) which illustrates the distribution of pore volumes for the samples.

The sample T-1 has surface area (9.8 m$^2$/g) and pore volume (0.0185 m$^3$/g), TW-2 has surface area (2.5 m$^2$/g), pore volume (0.0175 cm$^3$/g), while the surface area for F-1 sample is (4.9 m$^2$/g), pore volume (0.0183 m$^3$/g), F-8 the surface area is (2.6 m$^2$/g), pore volume (0.0142 m$^3$/g) and for F-9 sample, the surface area is (3.1 m$^2$/g) and pore volume is (0.0098 m$^3$/g). The T-1 sample has the highest surface area and pore volume 9.8 m$^2$/g and 0.0185 m$^3$/g, respectively.

Figure 2. Surface area and pore volume of shale samples showing variations in pore size ranging from 0.0175 cm$^3$/g to 9.8 cm$^3$/g. Labels A through D refer to samples 1 through sample 4 respectively.
3.3 Pore size distribution.
In general shale gas exhibits low porosity and low permeability. According to Barrett Joyner Halenda (BJH) Theory, the N₂ adsorption data were used to obtain the pore size distribution plot (Figure 3). The Figure shows that N₂ pore volume distributions reveal that the shale pore structure may be unimodal or multi-modal. N₂ pore size distribution plots display a smooth transition at 1 nm, thus providing the more comprehensive pore size distribution of shale samples.

![Figure 3](image)

Figure 3 Pore size distribution plots from adsorption data of F-1 samples showing a unimodal pore size distribution.

4 Discussion
All methods applied showed that the shale samples varies in their properties, including surface area, pore size, and pore volume as shown from the adsorption isotherm and Nitrogen BET. The Figure showing pore size distribution showed fluctuating pattern in the sizes upto 100 Å, indicating that there is a dominance of some grain sizes and
absence of other sizes. The sizes greater than 100 Å showed gradual increase, indicating that there is a gradual change in the grain sizes.

Surface area is also a function of grain size which increases with smaller grain size, i.e. is inversely proportional; therefore, it implies that variations in surface area is logically expected. Adsorption of nitrogen (which is an indication of the amount of shale gas content) will vary accordingly as the grain size and surface area vary.

5 Conclusions

N2 adsorption and high-pressure mercury intrusion techniques were combined to characterize the pore structure of the rift basin shale samples, providing the more comprehensive pore size distribution of shale samples.

According to the results, the pore size distribution suggested multi-modal with a broad peak between 2 nm and 25 nm, and the pore volume is predominantly occupied by meso-pores and the main specific surface area is dominated by the micro-pores and meso-pores.

References


