Petroleum 2 (2016) 138–147

Contents lists available at ScienceDirect

Petroleum

journal homepage: www.keaipublishing.com/en/journals/petlm

Original article

Shale characteristics impact on Nuclear Magnetic Resonance (NMR) fluid typing methods and correlations

Mohamed Mehana [a, *], Ilham El-monier [b]

[a] University of Oklahoma, Suez University, USA
[b] University of Oklahoma, USA

ARTICLE INFO

Article history:
Received 26 October 2015
Received in revised form
25 January 2016
Accepted 3 February 2016

Keywords:
Shale
Fluid typing
Fluid properties
Heterogeneity
Nuclear Magnetic Resonance

ABSTRACT

The development of shale reservoirs has brought a paradigm shift in the worldwide energy equation. This entails developing robust techniques to properly evaluate and unlock the potential of those reservoirs. The application of Nuclear Magnetic Resonance techniques in fluid typing and properties estimation is well-developed in conventional reservoirs. However, Shale reservoirs characteristics like pore size, organic matter, clay content, wettability, adsorption, and mineralogy would limit the applicability of the used interpretation methods and correlation. Some of these limitations include the inapplicability of the controlling equations that were derived assuming fast relaxation regime, the overlap of different fluids peaks and the lack of robust correlation to estimate fluid properties in shale. This study presents a state-of-the-art review of the main contributions presented on fluid typing methods and correlations in both experimental and theoretical side. The study involves Dual T_w, Dual T_e, and doping agent's application, T_1-T_2, D-T_2 and T_{2sec} vs. T_1/T_2 methods. In addition, fluid properties estimation such as density, viscosity and the gas-oil ratio is discussed. This study investigates the applicability of these methods along with a study of the current fluid properties correlations and their limitations. Moreover, it recommends the appropriate method and correlation which are capable of tackling shale heterogeneity.

1. Introduction

Since the introduction of Nuclear Magnetic resonance technology in petroleum industry, its applications answered a lot of questions in reservoir engineering and provided unambiguous techniques to evaluate rock, rock-fluid and fluid properties. NMR applications started with a tool to calculate the total porosity independently from rock matrix effects by calculating the intensity of hydrogen protons in formation. Then, the differentiation between the bound and free fraction of fluid in porous medium became obtainable. Further improvements were performed to extend its applicability to determine capillary pressure [1], wettability [2], and relative permeability [3] from NMR measurements. Consequently, NMR became a reliable instrument to diagnose fluid types, properties, and rock properties as well for both conventional and unconventional reservoirs [4–8].

Counting on NMR methods used in conventional reservoir to determine rock and fluid properties as a guide to analyze shale reservoirs response is misleading and will yield unreliable data [9]. In terms of composition, shale is a heterogeneous rock with various clay contents [10]. The clay distribution affects both NMR response and interpretation [11]. Apart from clay content, the presence of the organic matter will add more complexity to the system. Considering the pore size, shale has a wide spectrum of pore sizes ranging from nanometer pores, conventional pores to natural fractures along with the dependence of the organic pores on the maturity of the rock. Moreover, shale has different wettabilities and most of them

* Corresponding author. Tel.: +1 4058873536.
E-mail address: M.Mehana@ou.edu (M. Mehana).
Peer review under responsibility of Southwest Petroleum University.

Production and Hosting by Elsevier on behalf of KeAi

http://dx.doi.org/10.1016/j.petlm.2016.02.002

are mixed [10]. Due to the complexity of the shale system, an extensive study of rock and fluid characteristics impact is required to successfully interpret the NMR response.

2. Theory

NMR measurements procedure starts with exciting the sample by a magnetic field, which will polarize the hydrogen protons in one direction. Then, measuring the longitudinal relaxation time (T_1) or use Carr Purcell Meiboom Gill (CPMG) sequence and measure the transverse relaxation time (T_2) or use pulsed-field gradient sequence and measure the diffusion coefficient (D) [12]. After that, an inversion method will be adopted to obtain the decay exponents distribution [13]. This distribution will be the base of all succeeding interpretation methods.

The relaxation of fluids in a bulk state is bulk relaxation and tends to be longer as the relaxation will be due the interactions among fluid protons only. On the other hand, fluids relaxation in porous media will be promoted by the interactions among the fluids and the confining surface protons. Besides, the transverse relaxation time will be more affected by the molecules diffusion. The diffusion relaxation will not affect T_1 measurement, but it influences T_2 where there are spin dephasing and refocusing [14]. The relaxation governing equations in porous media is developed in fast diffusion regime as a weighted average between bulk and surface relaxation rate. Therefore, they will be

$$\frac{1}{T_1} = \frac{1}{T_{1,Bulk}} + \rho_1 \frac{S}{V} \tag{1}$$

$$\frac{1}{T_2} = \frac{1}{T_{2Bulk}} + \rho_2 \frac{S}{V} + \frac{D\gamma^2 G^2 T_E^2}{12} \tag{2}$$

The validity of fast diffusion regime assumption in shale will determine the applicability of those equations. In addition, the impact of the diffusion coupling, homonuclear dipole coupling, heteronuclear dipole coupling, residual dipole coupling and magnetization transfer as relaxation mechanisms should be considered [15].

3. Shale characteristics impact on the NMR signals

Shale is a clay-rich rock which contains variable content of clay minerals and organic matter. This rock contains different pore sizes which have fractional wettability and host different kinds of fluids. In addition, the Nano-scale pores and adsorption will add more ambiguity to the nature of these rocks. This section will discuss the main characteristics of Shale and their impact on NMR response.

3.1. Pore size

The behavior of fluids in confined porous media diverges from their behavior in bulk state [16]. These deviances will be more significant in Nano-scale pores (Fig. 1). Therefore, this entails a study of these deviances effects on relaxation mechanisms.

In most conventional pores studies, it is assumed that the main relaxation mechanism is the surface relaxation. Therefore, the position of the fluid peak will be directly proportional to the size of the pore-containing that fluid. With this in mind, many

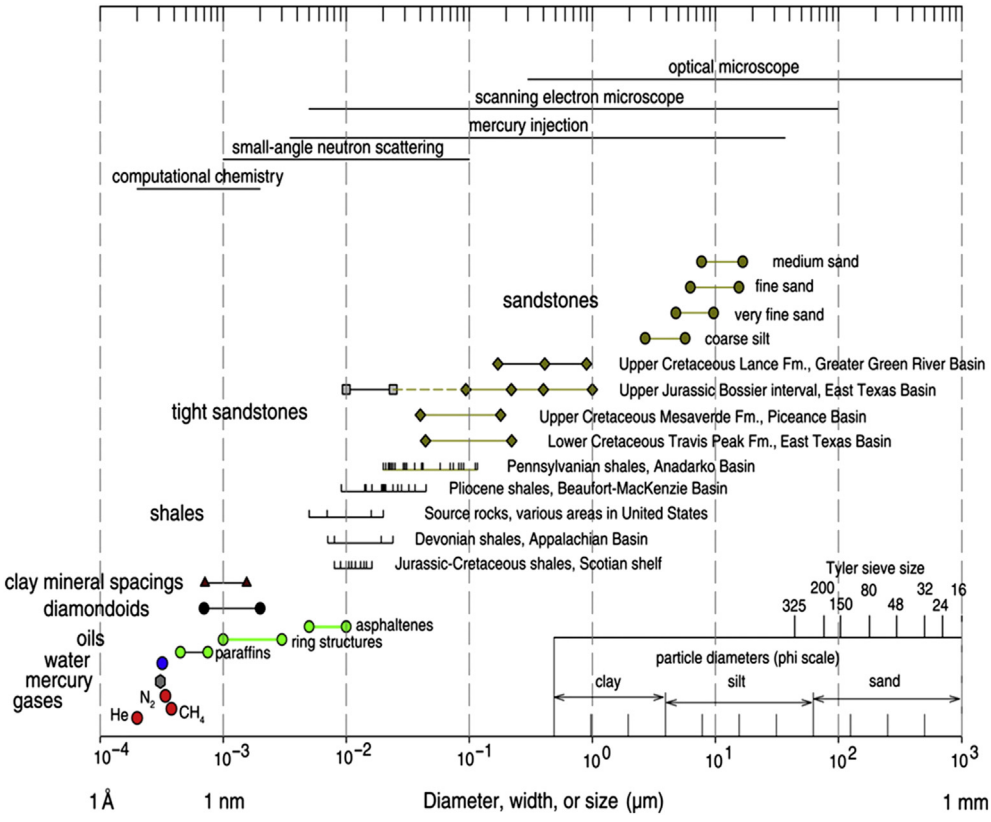

Fig. 1. Sizes of molecules and pore throats in siliciclastic rocks on a logarithmic scale. Measurement techniques are shown at the top of the graph [15].