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Heavy oil component characterization with multi-dimensional unilateral NMR

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Abstract: Heavy oil is a complicated mixture and a potential resource and has attracted much attention since the end of last century. It is important to characterize the composition of heavy oil to enhance its recovery efficiency. A designed unilateral Nuclear Magnetic Resonance (NMR) sensor with a Larmor frequency of 20 MHz and a well-defined constant gradient of 23.25 T/m was employed to acquire three-dimensional (3D) data for three heavy oil samples. The highly-constant gradient is advantageous for diffusion coefficient measurement of heavy oil. A fast data-implementation procedure including specially designed 3D pulse sequence and Inversion Laplace Transform (ILT) algorithm was adopted to process the data and extract 3D T_1-D-T_2 probability function. It indicates that NMR relaxometry and diffusometry are useful to characterize the components of heavy oil samples. NMR results were compared with independent measurements of fractionation and gas chromatography analysis.

Key words: Heavy oil, multi-dimensional NMR, unilateral sensor

1 Introduction

Heavy oil has high viscosity and density (API gravity in the range of 10°-20°, viscosity between 100 and 10,000 cp). The heavy oil reserves in the world are about 6 trillion barrels in situ (Galford and Marschall, 2000). With the continuous decline of conventional oil reservoirs, the commercial potential of heavy oil has attracted great attention. However, its high viscosity restricts heavy oil production flows. The major method applied in oil fields is to inject steam into the heavy oil reservoirs to reduce its viscosity, which needs careful manipulation due to the complex properties of heavy oil (Mullins et al, 2007; Zheng and Hirasaki, 2008; Hirasaki et al, 2002). Therefore, it is critical to know more about the components of heavy oil so as to optimize the recovery, upgrading, refining and transportation procedures (Mullins, 2005; Latorraca et al, 1998; Pena and Hirasaki, 2003).

A number of analytical techniques have been used to provide information about the components of complex fluids. These include gas chromatography, optical and NMR spectroscopy. In the context of this article, gas chromatography cannot detect the complete components of heavy oils because large molecules with more than 36 carbon atoms are difficult to transfer into the gas phase. However, those large molecules hold dominant ratios in heavy oil samples. Optical spectroscopy is unsuitable as heavy oils are largely opaque. NMR spectroscopy becomes inefficient due to the overlap of spectra from individual molecules. Compared to that, NMR relaxometry and diffusometry are robust enough to detect complete components of heavy oil because of the relationship between chain length and dynamic characteristics (T_1, T_2, and D) of its molecules (Freed et al, 2005; Freed, 2007).

A high-enough magnetic field gradient should be applied to encode slow diffusion characterization of heavy oil. In this paper, a designed NMR unilateral sensor with a highly-constant magnetic field gradient of 23.25 T/m was used to provide information about the complicated components of heavy oil. A multi-dimensional NMR technique and a fast data-implementation procedure were developed to measure, process and analyze components of heavy oil samples. 3D NMR distribution and 2D projection of oil samples were presented and discussed.

2 Spin-dynamics of heavy oils

Spin dynamics of a fluid are characterized by the longitudinal relaxation time T_1, transverse relaxation time T_2 of spin system and diffusion coefficient D of the entire molecule (Blümich, 2005; Dunn et al, 2002; Wong, 1999; Cowan, 1997). In a complicated hydrocarbon mixture, small molecules generally diffuse faster than large ones. Thus, the diffusion coefficient of a specific hydrocarbon molecule is related to its size, or chain length. The integral fluid environment influences molecular diffusion as well (Lisitza et al, 2009). The general scaling relationship between diffusion

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