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A novel NMR instrument for real time drilling fluid analysis

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ABSTRACT

We present here a novel instrument for real time drilling fluid NMR analysis at well site. The quantitative detection of oil and gas in drilling fluid while drilling helps to characterize reservoir quality and evaluate reservoir productivity. There is a big demand to detect oil content in drilling fluid in real time at well site in the petroleum industry. To meet the requirement for continuous and quantitative analysis, the new designed integrate NMR system comprises several subsystems: drilling fluid auto-sampling device, small-sized NMR sensor, spectrometer, main controller and wireless data communication. Auto-sampling device takes drilling fluids samples continuously and quantitatively from the flow line returning from the well and removes debris with diameter greater than 1 mm to reduce interference in measurement process. The small-sized NMR sensor is implemented based on Halbach magnets with 20 kg weight and about 20 MHz operating frequency. The integrated system is capable of performing remote control and data acquisition at harsh environment. The instrument has been fully tested at a number of wells, and successful discovered oil- and gas-bearing formations.

1. Introduction

During oil well drilling process, the drilling fluid may carry oil or/and gas released from the reservoir and return to the surface. The most economical method to find oil and gas formations is directly analyzing the drilling fluids. In practice, it shows that quantitative detection of the oil and gas contents in drilling fluids helps characterizing reservoir quality and evaluating reservoir productivity [1,2]. Although gas content and composition in drilling fluids can be detected by mud logging gas analysis, there is no effective way so far for oil detection in real time. Thus, important and valuable oil information in drilling fluid is missed. On the other hand, drilling fluid is usually mixed with crude oil, fluorescent additives and other chemical substances for sake of drilling safety. The high grade fluorescence of additives in drilling fluid masked the original fluorescence indicator of porous cuttings from drilling. To decrease the additive fluorescence strength will significantly increase drilling costs. Therefore an effective technique is required to solve the above mentioned problems. It is proved that low-field NMR techniques capable of detecting oil and water saturation and total quantity in pore media [3], and it's also a reliable method to determine the oil and water compositions of oil-water emulsions [4,5]. We started to design and build a novel NMR device at well site to analyze drilling fluid and successfully quantify oil content. This paper introduces our design and summarizes field results.

2. Methodology

As long as low-field NMR analysis can distinguish the oil and water cutoff value in transverse relaxation time (T_2) spectrum, the oil/water content of the oil-water mixture can be calculated by using the ratio of the sum of oil/water T_2 relaxation time signal and the total T_2 relaxation time signal. These methods have been applied to Canadian oil fields on commercial. The accuracy of oil content or water cut results has excellence correlation with conventional water cut [6–8]. In the detection of oil-water mixture, the relative oil content (Oil_c) of mixture can be expressed as follows,

$$Oil_c = \frac{A_{Oil}}{A_{sum}}. \quad (1)$$

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In formula (1), the sum of oil peak with cut off value in T_2 spectrum signal (A_{oil}) and the total T_2 spectrum signal (A_{sum}) are:

$$A_{sum} = \sum_{T_{2,min}}^{T_{2,\ max}} a_i, \tag{2}$$

$$A_{oil} = \sum_{T_{2,oil\ mincut\ off}}^{T_{2,oil\ max\ cut\ off}} a_i. \tag{3}$$

In fact, drilling fluid is also the mixture of water, oil, gas, cuttings and some other chemical substances via drilling, and therefore drilling fluid becomes the mixture of oil and water after filtering the cuttings and other solid materials. The study of drilling fluid NMR analysis demonstrates that it is able to quantitatively detect the oil content of water-based drilling fluids by using the difference T_2 relaxation time of drilling fluids and crude oil [9,10]. Although the drilling fluid also contains oil-based drilling fluid, mixed oil drilling fluid, and drilling fluid with fluorescent additives, in laboratory, the experimental result show that the solid additives have no NMR signal, and they cannot affect oil discovery during drilling. If the drilling fluid was added liquid additives such as sulphonated bitumen, the oil and drilling fluid signal in T_2 spectrum can be separated by adding $MnCl_2$ relaxation reagent. Moreover, the oil peak and drilling fluid peak of some oil-based drilling fluids may overlap. In this case, the drilling fluids should be analyzed by the 2D-NMR method a relaxation reagent employed to discriminate the oil and drilling fluid signals. Overall, when the oil and drilling fluid signals are separated by 1D NMR or 2D NMR technique, the oil content can be calculated by the ratio of oil signal area and the total signal area [11–13].

In one well, especially the onshore well, the type of drilling fluid commonly remain same. Therefore, oil peak and drilling fluid peak in T_2 spectrum should have about the same cut-off time. Fig. 1 shows NMR results of drilling fluid samples collected from well S903H in Xinjiang oil field of China. The samples of different depth with oil shows in mud logging were obtained from drilling fluid outlet, and all samples were analyzed directly without being pre-treated. It can be seen that the cut-off value of oil and the cut-off value of drilling fluid are different. The cut-off point is about 3 ms.

However, laboratory NMR instruments are cumbersome and therefore limit their use in drilling sites. Moreover, analysis of a single sample data source does not represent the actual reservoir oil data due to time lapse between the collection of the drilling fluids samples and the analysis result obtained during which characteristics of samples changed a lot. We need a new type of drilling fluid NMR analyzer which can be applied at well sites and detect oil content in the drilling fluid in real time.

3. Design and implementation

Fig. 2 shows the design of real time drilling fluid NMR analyzer. It mainly consists of auto sampling system, small-sized NMR sensor, NMR spectrometer, data acquisition and transmission, power supply, power control and remote computer. The first stage objective of the drilling fluid NMR analyzer is to continuously detect oil content in water based drilling fluids or in drilling fluids with solid fluorescence additives.

Auto-sampling device takes samples of drilling fluids continuously and quantitatively from the flow line. The sampling probe, whose injection holes diameter is 1 mm, can remove cuttings and other debris with diameter greater than 1 mm and some gas in drilling fluid to reduce the interference in measurement process. Drilling fluid samples are pumped into the quantitative sample tube in the NMR sensor for analysis. The sampling inlet pipeline uses the “U” structure so that the sample tube has always been filled with drilling fluid. After each sampling, the software of NMR analyzer controls the system to keep the drilling fluid stationary for 10s, and ensuring drilling fluid is completely polarized to improve the accuracy of the measurement. The Small-sized NMR sensor is implemented based on Halbach magnets structure [14–17]. The inner magnetic field is homogenous and the outer magnetic field is zero. Fig. 3 shows the picture of small-sized NMR sensor and the magnetic field distribution cloud map. The magnetic resonance frequency of NMR sensor for protonis about 20 MHz and the static magnetic field strength is about 0.5 T according to the laboratory measurement. The NMR sensor O.D. is 228 mm, I.D. is 90 mm, and

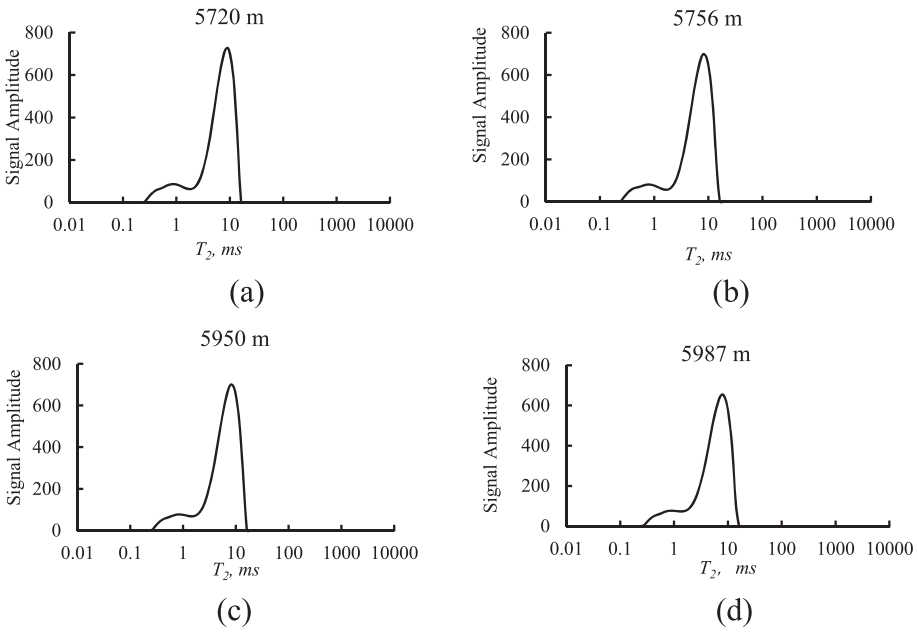

Fig. 1. NMR T_2 spectra of drilling fluid with oil shown in mud logging of different depth from a well in China (a, b, c, d).

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