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Laboratory analysis to assess shale stability for the Zubair Formation, Southern Iraq

Ahmed K. Abbas[a,b,*], Ralph E. Flori[b], Ahmed AL-Anssari[c], Mortadha Alsaba[d]

[a] Iraqi Drilling Company, Basrah, 61004, Iraq
[b] Department of Geoscience and Geological and Petroleum Engineering, Missouri University of Science and Technology, Rolla, MO 65401, United States
[c] Weatherford, Basrah, 61004, Iraq
[d] Australian College of Kuwait, Safat, 13015, Kuwait

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ABSTRACT

The Zubair Formation consists of approximately 55% shale, which causes almost 70% of wellbore problems due to incompatibilities between drilling fluids and shale formations. The most common and effective solution to shale instability is through the design and selection of appropriate drilling fluids. Understanding the interaction between drilling fluids and shale has been a challenge due to the complexity of both the physical and chemical variations in shale formations. This paper presents some of the primary laboratory and wellsite testing techniques that are often used by mud engineers to characterize and remediate drilling fluids and shale interactions. Well-preserved core samples retrieved from the Zubair shale formation in Southern Iraq were run through extensive testing to describe the special characterization of the Zubair shale. These characteristics were measured and described, including the structure, texture, mineralogy, and reactivity, using a scanning electron microscope (SEM), a thin-section photograph, X-ray diffraction analysis (XRD) imaging, and cation exchange capacity (CEC) analysis. Moreover, a capillary suction timer (CST), hot rolling dispersion test, bulk hardness test, linear swell meter (LSM), and fracture development test were used to evaluate the stability of shale in the presence of test fluids. The test fluids included fresh water, 20 wt% NaCl brine, 7 wt% KCl brine, and a combination of 7 wt% KCl and 3 vol% glycol. The results illustrated that the Zubair shale is composed mainly (average content of 51.46%) of brittle minerals (i.e., quartz and calcite), along with 43.54% of clay minerals. The predominant clay minerals were kaolinite and illite, with an average content of 48.06% and 34.71%, respectively. In addition, the cation exchange capacity analysis and capillary suction time test indicated that Zubair shale has a low-to-moderate reactivity with drilling fluids. Furthermore, among the fluid systems tested, the best shale inhibition was achieved when the 7 wt% KCl and 3 vol% glycol solution was used. Shale sample analyses methods were used to understand the geologic features of the Zubair shale formations and to achieve a better perspective on the potential interactions of shale formations with drilling fluids. Understanding the properties and responses of shale formations to fluids is a significant step in achieving the chemical clay stabilization objectives. Proper design of drilling fluids, with appropriate mud weight and suitable additives, can lead to substantial cost reduction in drilling operations.

1. Introduction

Wellbore instability is frequently reported as one of the most serious obstructions during drilling in the Zubair shale formation in several oil and natural gas fields in Southern Iraq (Abbas et al., 2018a). Wellbore instability problems (e.g., wellbore collapse, tight hole, stuck pipe and logging tools, poor log quality, wellbore enlargement, and poor primary cement jobs) result in excessive operational costs and delays in drilling time (Mohiuddin et al., 2007; Ferreira et al., 2016). These problems are generally caused by the imbalance created between the wellbore stress and rock strength (Lal, 1999). This usually happens when the wellbore stress exceeds the strength of weaker rocks, such as shale. In addition, drilling fluids can cause shale instability by altering the pore pressure or effective stress state and the shale strength through fluid/shale interactions (Xu et al., 2018). The mud density and chemistry invariably play major roles in solving wellbore instability problems. The minimum required mud weights to drill a stable well are often selected based on geomechanical wellbore stability modeling studies, while the mud type and chemistry are selected based on a laboratory evaluation of the drilling fluids performance (Jain and Mahto, 2017). Addressing the

* Corresponding author. Iraqi Drilling Company, Basrah, 61004, Iraq.
E-mail address: akayr4@mst.edu (A.K. Abbas).

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optimum drilling fluids chemistry and formulations requires a set of laboratory tests that evaluate the shale/fluid interaction and shale stability (Temraz and Hassanien, 2016; Li et al., 2017). Nevertheless, the behavior and responses of shale to the drilling and completion fluids are complex and were not well understood for many years because of the various and complex chemical and physical variations present in these type of formations (Van Oort, 2003). A complicating factor that distinguishes shale from other rocks is its sensitivity to fluids, particularly water, because of its large surface area and consequential strong adsorption capacity (Tang et al., 2014). Shale stability is strongly affected by shale characterizations (e.g., wettability, mineralogy, structure, texture, and reactivity with fluids) and the properties of the drilling fluid it contacts (e.g., density, salinity, and ionic concentration) (Shen et al., 2016; Villabona-Estupiñán et al., 2017). For these reasons, the interaction of shale with drilling fluid is not entirely understood, and drilling optimization is often approached on a trial-and-error basis. Therefore, shale characterization can help to understand the different responses of the shale to fluids and improve the selection of chemical additives to minimize or delay the shale/fluid interaction (Huang and Zhao, 2017).

Obtaining the representative preserved core samples is a critical step in deciding on the proper drilling and completion fluids. Shale formations are not the main target of hydrocarbon exploration; therefore, shale samples from deep boreholes are almost never available for testing due to the extra cost related to coring operations in deep wellbores. Even if core samples are taken from depths of interest, shale cores may be further damaged by the action of the drill bit during coring operations and by subsequent improper preservation and sample preparation. This may affect shale properties significantly and make core samples useless for fluid/shale interaction analysis (Al-Bazali, 2011). It is well known that the use of well-preserved shale core samples will provide highly accurate and reliable laboratory test results, which can help to assess shale reactivity with drilling fluids. In addition, the preserved shale core samples tend to maintain their natural wettability, so that the fracture network is conserved and less likely to be altered by the natural drying process.

Due to the severity of shale instability while drilling in the Zubair shale section, field owners and operator companies were motivated to core and test shale core samples to understand the petrologic and deformation features of the Zubair shale formation. In the present work, well-preserved core samples retrieved from the Zubair shale formation in Southern Iraq were fully characterized in terms of structure, mineralogy, and shale reactivity in relation to the drilling fluids. A thin-section photograph and X-ray diffraction (XRD) analysis were applied to understand the mineralogy, texture, grain distribution, and consolidation of the Zubair shale. Scanning electron microscope (SEM) imaging was used to observe the substructure morphology of the shale. The cation exchange capacity (CEC) analysis was applied to assess the shale reactivity in relation to various drilling fluids. Moreover, shale interaction tests were performed by exposing core fragments to four conventional types of fluids. The capillary suction time test, hot rolling dispersion test, bulk hardness test, linear swelling test, and fracture development test were then used to evaluate the applicability of these fluids. This holistic approach is very effective not only because the actual shale formation can be used for the experiments but also because it can integrate and cover many geological characteristics of the rock samples, including the type of clay, amount of clay, and reactivity.

2. Methodology

2.1. Shale samples

Shales are fine-grained sedimentary rocks that contain a significant amount of clay minerals. In practice, this means that their clay content needs to be higher than about 40% (Fjær et al., 2008). Shale's extremely low permeability, clay content, and sensitivity to fluids make it a very special rock material to study (Chenevert and Sharma, 1993; Zhang et al., 2015). Shale is very sensitive to wetting fluids, such as water, or to a loss of fluid from its pores (Lyu et al., 2015). Van Oort et al. (2016) further clarified these concerns, describing that the natural pore fluid of a poorly preserved shale evaporates from the pore space, which then fills with air. As the shale sample is no longer 100% saturated when it is exposed to atmospheric conditions, special procedures should be applied to prevent the loss of the natural pore fluid. Otherwise, the laboratory testing will not give an accurate reflection of the actual behaviors of the shale samples in fluids. Therefore, the shale samples that were used in this study were all well-preserved in a metal casing at the point of recovery, and the two ends were sealed with rubber caps to prevent the native pore fluid from being lost after the coring operations. The preserved cores were obtained from three wells, covering a wide range of the Zubair shale formation interval.

2.2. Shale characterizations methods

2.2.1. CT scanning technique

X-ray computed tomography (CT) is a technique that allows visualization of the internal structure of a scanned object without cutting it. CT operates by using an X-ray generator that rotates around the central axis of the scanned sample. Each of the specimens was scanned at 1-degree increments about the vertical axis for a full 360°. The X-ray detectors are positioned on the opposite side of the circle from the X-ray source. CT images record differences in the degree of attenuation of the X-rays, which is both material and energy-dependent (Choo et al., 2014). CT produces data that can be manipulated to demonstrate various bodily structures based on their ability to absorb the X-ray beam. The CT images generated were in the axial or transverse planes, perpendicular to the long axis of the body sample. The degree of digital image resolution depends mainly on the distance between the camera positioned within the scanning device and the scanned object. In this study, one recovered full diameter core section (~1 m) was scanned by a 2-D computed tomography (CT) scanner to examine the initial sample conditions and evaluate the presence of any preexisting (i.e., natural) fractures and/or mechanical damage caused by drilling and the coring processes. The CT scan was performed in two main parts: longitudinal (i.e., vertical) and axial. Five axial images (slices) were selected (at 20-cm intervals) to cover the internal features of the shale core samples.

2.2.2. Scanning electron microscope (SEM)

A shale sample from the Zubair Formation was imaged using an SEM to determine the integrity of the rock and measure the degree of cementing and compaction, using a clean sample mounted on the specimen stage and placed into the instrument. SEM photographs allow for better 3-D observations of micro-cracks and micro-laminations in the specimen that are not easily seen using transmitted light or transmitted electron microscope techniques. The texture and orientation of the shale, its degree of compaction, and the presence of embedded minerals and pores can be observed (Stephens et al., 2009). SEM images of a specimen were produced by scanning the surface with a focused beam of electrons. These electrons interact with atoms in the specimen, producing various signals that contain data about the specimen's surface topography and composition. For SEM, a specimen needs to be completely dry and large enough to withstand the vacuum conditions and high-energy beam of electrons. Magnification in a scanning electron microscope can be controlled over a range of about six orders of magnitude from about 10 to 1,000,000 times. The magnification ranges that were used for shale analyses ranged from 100 to 500x.

2.2.3. Thin-section analysis

A petrographic analysis was carried out to provide a detailed description of the texture (i.e., grain size, sorting, and grain contacts), sedimentary structures (i.e., laminations and bioturbation), framework grain composition, authigenic minerals, and types and distribution of