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Geomechanical characteristics of common reservoir caprock in Iran (Gachsaran Formation), experimental and statistical analysis

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ABSTRACT

The evaporitic Gachsaran Formation consists of seven members with sequence of anhydrite, marl and salt layers. The first member (the lowest one) which is made up of anhydrite is known as the caprock of the Asmari carbonate reservoir, the most famous hydrocarbon reservoir in Iran. The geomechanical behavior of the Gachsaran Formation is the main concern of drilling and development operations in Iranian oil and gas fields. However, the chief problem is lack of deep core samples from Gachsaran sequences due to the challenging and costly coring process in the non-reservoir Gachsaran formation. In a practical approach of obtaining samples for essential geomechanical laboratory tests, caprock (anhydrite) core samples of Gachsaran Formation have been taken from depths of 80–300 m, at three dam sites. The rock physical and geomechanical properties were examined by analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) tests. The results from analysis of the properties of samples collected from Ghotvand and Chamshir dam sites showed no significant differences, but some of the characteristics of samples of Khersan dam site were considerably different from those of the other samples. Moreover, the physical properties of anhydrite samples were compared with the properties inferred from the petrophysical well logs from a depth of about 2000 m. It was demonstrated that the observed discrepancies between the measured values from Ghotvand and Chamshir samples and those from deep logs are not significant at the 95% confidence level. The investigation results illustrated that anhydrite samples taken from shallow depths can be used for evaluating the geomechanical properties of deeper anhydrites.

1. Introduction

The Gachsaran Formation is an evaporitic formation which draws the attention of much E&P activity in Iranian hydrocarbon development. This formation generally consists of alternating layers of anhydrite, marl and salt, each reveals a particular physical and geomechanical behavior. The first member of the Gachsaran Formation is the famous caprock of the Asmari carbonate reservoir and the presence of this formation can be a good marker for oil and gas traps. However, drilling through the Gachsaran layers is always associated with problems such as lost circulation, kicks and stuck pipe. Casing collapse and casing shear are the other frequent events reported by some operating companies with respect to the Gachsaran Formation. These issues impose expenditures on operational and production companies (Rolf et al., 2006; Gorjian et al., 2013).

Regardless of the drilling and stability concerns in the Gachsaran Formation, its significant role as a caprock in enhanced oil recovery (EOR) treatments such as gas injection is undeniable. In fact, not only is the presence of an integrated and resistant caprock as an impermeable cap one of the major factors to hydrocarbon accumulation, but preservation of the caprock integrity during EOR treatments (e.g. gas injection), natural gas storage or CO_2 sequestration is important (Shukla et al., 2010; Soltanzadeh and Hawkes, 2012). Recently, attention has been devoted to the diagnosis of caprock behavior as the result of such activities (Khan et al., 2011;

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Orlic et al., 2011).

In this regard, investigating the geomechanical characteristics of the Gachsaran Formation in Iranian hydrocarbon fields is important from two aspects:

- First, due to the low hydrocarbon recovery status in Iran (10 percent lower than the world average), the need for increased production and higher recovery using EOR (e.g. gas injection) or stimulation methods is indispensable (Zoveidavianpoor et al., 2012); To maintain caprock integrity during and after a gas injection process, for example, a comprehensive study of the geomechanical response of caprock is vital.
- Second, operational reports illustrate that many wells in several Iranian hydrocarbon fields regularly encounter drilling problems, casing shear and collapse through the Gachsaran Formation (especially at the interfaces of the rigid and ductile members, e.g. anhydrite and salt). Recommending any solution to overcome these types of issues strongly depends upon recognizing the geomechanical characteristics of this problematic formation (Dusseault et al., 2001; Rolf et al., 2006; Gorjian et al., 2013).

Despite the vital role of geomechanical investigations on future risk management in Iranian field development, lack of core samples and well log information for the Gachsaran Formation remain major obstacles for any studies of this formation. A low coring efficiency (poor recovery) and severe core damage, making samples worthless from a reservoir property point of view, are the main causes for the lack of suitable core samples in this formation. Important geomechanical properties are achieved from destructive tests on core samples; hence, it is necessary to propose a proper procedure to deal with the lack of suitable cores from Gachsaran Formation in Iranian oil and gas fields. A practical approach which is presented in this research is using shallower (80–300 m depth) core samples of Gachsaran Formation instead of deeper caprock (about 2000–2300 m depth) taken from hydrocarbon fields. In this study, the shallower core samples have been taken from several geotechnical boreholes in three dam sites where the Gachsaran Formation is near the surface.

Although shallower core samples are appropriate alternatives and provide valuable information, it is essential to evaluate and validate the achieved results of these representatives, which are taken from different sources. There are various methods to evaluate and compare several data sets to indicate the significant differences or similarities. Statistical methods provide different type of multiple comparison procedures to compare and evaluate the equivalency of several groups, quantitatively (Hsu, 1996; Weiss, 2011; Gao et al., 2014).

In this study, anhydrite samples of caprock member of Gachsaran Formation have been taken from three different dam site locations, including Ghotvand, Chamshir and Khersan dams. In these dam sites, the depth of Gachsaran members varies from 80 to 300 m. Different types of rock physical and geomechanical tests have been carried out on these samples. Comparisons among the results of tested samples, which were from different locations, have been performed by means of analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) tests. In fact, the goal of this study is to propose an approach to compensate the lack of core samples from non-reservoir formations along with presenting the geomechanical characteristics of caprock of Asmari carbonate reservoir.

2. Field overview and sample preparation

The Zagros sedimentary basin which is made of a thick sequence of Paleozoic to Pliocene sedimentary rocks holds lots of giant oil traps in Middle East region. At the late Cenozoic, Gachsaran Formation was formed on top of the Asmari formation (one of the main reservoir rocks). Due to the rheological and mechanical characteristics of the Gachsaran formation, which come from the thick intervals of salt and marl components, there is no complete surface type section and disconformity can be observed in the deposited layers. According to what have been seen in the Iranian oil fields, the Gachsaran Formation is consisted of seven members, the lowest part is the cap rock of the Asmari reservoir.

Member 1, which is often called the cap rock, consists of somewhat platy, dark grey to white anhydrites, grey to bluish grey marls, bituminous shale, and some thin beds of limestone. More than 75% of this member is made up of anhydrite. A thick salt bed which was located above the cap rock is considered as member 2 of the Gachsaran formation. In this member, thin beds of anhydrite and marls interbeds with thick layers of salts. More than 70% of this member is made up of salt. Member 3 includes interbedded anhydrite and grey marl with occasionally thin salt beds. Top of the member 4 has been placed at the highest thick salt bed. The sequence for this bed is anhydrites, salts, grey and red marls with some limestones. Member 5 mostly includes grey marls and anhydrites with some beds of red marls. The color of this member varies from grey to greenish grey from top to bottom. Top of member 6 consists of prominent red marl. The sequence of this member is anhydrite, grey marls, red marls and limestone. Member 7 is mainly composed of anhydrite, grey marl and sometimes cross-bedded carbonates (Ghazban et al., 2007; Motiei, 1995). Fig. 1 illustrates the simplified geological section of Gachsaran members in one of the Iranian hydrocarbon field. It is noteworthy that the Gachsaran Formation has outcrop at some locations such as Gotwand-E-Olya, Chamshir and Khersan dam sites (Mahab Ghods Consulting Engineering, 2007).

Regarding to the lack of core samples in oil and gas wells, especially caprock samples, the required samples for geomechanical analysis have been taken from three dam sites in which Gachsaran Formation is near the surfaces and its depth varies between 80 and 300 m Fig. 2 shows the geographical locations of the above mentioned dam sites. More than 20 samples of the member 1 (caprock) anhydrite have been prepared for different geomechanical analysis. All selected sample were visually intact and homogeneous with no macroscopic trace of laminations. Prepared cylindrical samples (108 mm × 54 mm) were pure with less than 10% of impurities. Moreover, after coring all samples were preserved to avoid any alteration. Some of the prepared samples are presented in Fig. 3.

3. Principals of statistical analysis

Practical and scientific activities which deal with information or experimental data try to make scientific judgments about the uncertainty and variation along with data gathering (Walpole et al., 2012). Generally, Statistical methods have been developed to help in understanding data and to assist in making decisions or judgments. Inferential statistical methods have received lots of attention by different researchers in different fields of study, such as manufacturing, food products, energy, clinical and medical sciences, earth sciences, etc. (Cummins, 2013; Walpole et al., 2012; Dunn, 2009; Webster, 2007; Bluman, 2009).

Activities in earth sciences, including geology and engineering, generate data from different sources or measurements (chemical and physical analysis, ore mineral determination, etc.) for specific purposes. In such cases, inferential statistical methods may be applied, such as multivariate estimation of rock properties, multiple comparisons among collected datasets from different locations,