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Characterization and Testing of Saudi Barite for Potential Use in Drilling Operations

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Abstract. There are huge drilling operations in most areas of the Kingdom of Saudi Arabia nowadays searching for potential hydrocarbon reservoirs. While drilling for oil and gas, formations of high pore fluid pressure may be encountered (up to 20 ppg equivalent). Normal drilling fluid can control formation pressure up to 10 to 12 ppg. Therefore, it is necessary to increase mud pressure to correct this imbalance, otherwise a blowout may occurs. Barite is preferred upon the other weighting materials for its low price, purity, availability and its non-toxicity. Barite expenditure is estimated to be one half of the total mud cost. The expenses of importing barite from outside the area, necessitate the testing of local sources of barite which are cheap to utilize and are abundantly available. Therefore, samples of barite deposits were collected from Rabiqh area in the Western Province of Saudi Arabia. The collected samples were investigated for mineralogy, chemical analysis, physical properties, water requirement and its effect on common water-based drilling mud properties. For comparison, commercial barite was as well tested for the same properties. Based on the analysis performed in this study, it was found that the local barite is identical to commercially available one. Therefore, it is recommended to perform an economical feasibility study for the utilization of this local mineral.

Introduction

Generally speaking, drilling fluid may be defined as a suspension of solids in a liquid phase. Drilling fluid is a vital element of the drilling process. In fact, the success or failure of the mud program will largely determine whether a well can ultimately be drilled to the operator's specifications in a safe and economical manner or not. The drilling fluid engineer's task in designing a drilling fluid program is to derive from the variety of available mud-making materials the precise combination of physical and chemical properties needed to meet the demands of the well. This aspect of drilling cannot be underestimated, the slightest miscalculation can result in huge, unnecessary costs in time, money and safety. Drilling fluid was introduced simply as a way to circulate rock cuttings out of the wellbore. But today, as deeper and more hazardous wells are being attempted to meet the demand of oil, drilling fluid becomes an increasingly important and complex part of the rotary drilling process [1-8]. To fulfill the above functions, drilling mud properties such as density, viscosity, yield point, gel strength, filtration and pH must be adjusted to the desired level while drilling process is going on. When the formation pore fluid pressure is greater than the mud hydrostatic pressure, formation fluids will flow from the formation into the wellbore. The reasons of this pressure imbalance could be due to insufficient mud weight, improper hole fill-up during tripping, or swabbing pressure caused by fast pulling the drillstring. While drilling, properties of the drilling mud may depart from those initially designed due to contamination by drilled cuttings and formation fluids. On the other hand, special additives may be needed to overcome unexpected problems such as shale swelling, salt beds, stuck pipe, lost circulation, overpreussred formations, etc. [4]. Common drilling fluid additives as well as its functions are summarized in Table 1. This paper focuses on the possibility of the utilization of local barite as a weighting material to control high-pressure formations.

Table 1. Common drilling fluid additives [4]

Drilling fluid additive type	Functions
Alkalinity, pH control	Control the degree of acidity or alkalinity
Bactericides	Reduce bacteria count.
Calcium removers	Prevent and overcome the contaminating effect of anhydrite and gypsum.
Corrosion inhibitors	Minimize corrosion.
Defoamers	Reduce foaming action.
Emulsifiers	Creating a hetrogenouse mixtures.
Filtrate reducers	Reduce filtration.
Flocculants	Rise gel strength.
Foaming agents	Foam the mixture.
Lost circulation materials	Plug thief zones.
Lubricants	Reduce torque.
Pipe-freeing agents	Reduce friction.
Shale inhibitors	Control caving and shale swelling.
Surface active agents	Reduce interfacial tension between contacted surfaces.
Thinners, Dispersants	Modify viscosity of high solids fluids.
Viscosifiers	Improve mud viscosity.
Weighting materials	Control over-pressured formations.

Weighting materials used in drilling fluids

When high-pressure formations are encountered, it is necessary to increase the drilling fluid density to overcome any kicks. The pressure exerted on the formation being drilled (P_m, psi) is a function of the drilling fluid density (ρ_m, ppg) and well depth (h, ft) as shown in the following equation:

$$P_m = 0.052 * \rho_m * h \quad ...(1)$$

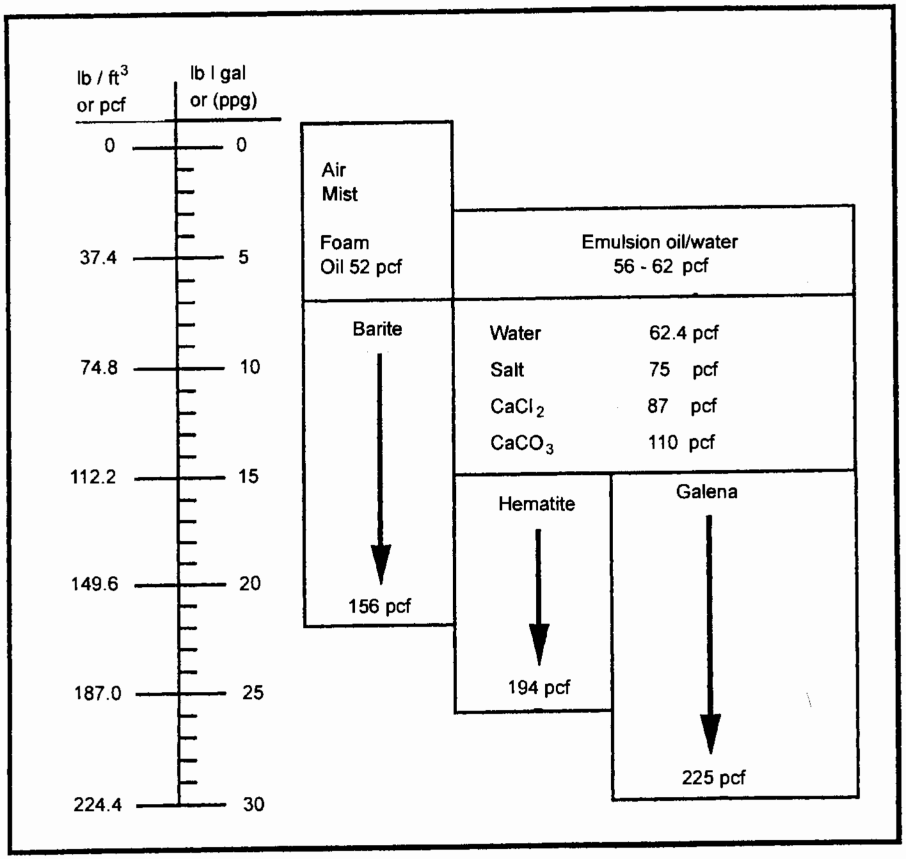

Fig. 1. Density ranges of drilling fluids weighting materials [13].

Originally reactive solids (such as bentonite) or polymers are added to the drilling mud to enhance its rheological properties. The drilled solids have a specific gravity ranging from 2.1 to 2.3, therefore, high weight non-reactive solids must be added to the drilling mud to increase its density to control any high-pressure formations that might be encountered. Several weighting materials have been used in the past to increase mud density (Fig. 1). The properties of these weighting materials are discussed below [1-9]:

i) **Dissolved salts.** Dissolved salts such as sodium chloride (NaCl), calcium chloride ($CaCl_2$) and calcium bromide (CaBr) are used to formulate solid free drilling or workover fluids. These are: NaCl- up to 10 ppg, $CaCl_2$- up to 11.6 ppg, and CaBr- up to 15 ppg. The corrosive aspect of dissolved salt solutions is the main disadvantage of the utilization of these types of additives.

ii) **Calcium carbonate.** Limestone ($CaCO_3$) has a specific gravity of 2.7 and a hardness index of 3.0. It is primarily used for obtaining mud weights up to 14.8 ppg in oil-base drilling or work over fluids. It is available in fine, medium and coarse grades. Being acid soluble, it can be used as a lost-circulation material when completing or working over zones that could suffer productivity damage from conventional lost-circulation materials.

iii) **Barite.** Barite ($BaSo_4$) is a widespread naturally occurring high gravity mineral with a specific gravity ranging from 4.2 to 4.6 and a hardness index of 3.0. It is a non-reactive solid used to increase mud weight up to 22 ppg. Barite was formed under low to moderate temperatures in hydrothermal veins. Barite is also found in sedimentary rocks as replacements, veins and cavity fillings. The API requirements for barite are shown in Table 2. Other physical properties of barite are summarized in Table 3. Barite is routinely used to increase drilling mud density because it is less expensive and does not contain any toxic materials, non-erosive and easy to handle, water wet and insoluble in water, does not react with clays or drilled solids, and normally pure and low in cost.

Table 2. Barite API physical and chemical requirements [6, 11, 12]

Requirement	Numerical value
Specific gravity	4.2 minimum
Soluble alkaline earth metal	250 ppm maximum
Wet sieving analysis	
Residue on U.S. sieve no. 200	3% maximum
Residue on U.S. sieve no. 325	5% minimum
Particles less than 6 micrometers	3% maximum
pH	7.0 maximum
Moisture content	1% maximum
Oil adsorption	9% maximum
Barium Sulfate	90% minimum
Water soluble Alkaline earth metals	250 mg/kg maximum

Table 3. Physical properties of barite ($BaSO_4$) [11, 12]

Chemical formula	**$BaSO_4$**
Variable formula	$(Ba, Sr)SO_4$
Composition	Barium sulfate, sometimes small amounts of strontium.
Color	Colorless, white, yellow, red, brown, blue, gray, multicolored or banded.
Hardness	3.0 to 3.5
Crystal forms	Orthorhombic
Specific gravity	4.2 to 4.6
Uses	It is important in the manufacture of paper, glass and as a drilling fluid additive
Commonly occurs with	Calcite, Gypsum, Quartz, Dolomite and sulfur

iv) **Hematite.** Hematite or iron oxide (Fe_2O_3) has a specific gravity ranging from 4.9 to 5.3 and a hardness index of 7.0 and it can increase mud density up to 26 ppg. Its color vary from brown to nearly black. Hematite is rarely used at the present time due to its serious discoloration of skin and clothes as well as its erosion effect.

v) **Galena.** Galena or lead sulfide (PbS) has a specific gravity ranging from 6.8 to 6.9 and a hardness index of 2.5. It is a gray to black crystalline substance, rarely used as a weighting material except in emergency situations requiring mud weights up to 30 ppg. It should be noticed that, the higher gravity solids require a very fine-grained or a more viscous base for colloidal suspension.

Thus, the objective of this study is to experimentally investigate the potential use of Saudi barite as a drilling fluid weighting constituent. This goal can be achieved by performing several tests including: physical properties, mineralogy, specific gravity, flame test, wettability, chemical analysis, and effect of barite addition on the properties of common drilling fluids used for drilling oil and gas wells. In all previously mentioned tests, commercial barite will be used as a reference for comparison.

Experimental Results and Discussion

Raw materials

The Kingdom of Saudi Arabia has a large variety of metallic and non-metallic mineral resources large enough to sustain profitable exploration and utilization. Most of these minerals are located in the proterozoic rocks of the Arabian Shield exposed in the Western Province of Saudi Arabia. Barite is deposited in several parts of the world as shown in Table 4. In Saudi Arabia, barite is deposited in commercial stocks in the Western Province in the Umm Gerad prospect near Rabigh, and an occurrence 20 km south of Al-Aqiq is estimated to contain 100,000 metric tons and 40,000 metric tons of barite, respectively. Thirty-two other occurrences are recorded but have not been investigated in detail [10]. These locations are shown in Fig. 2. This local barite reserve is enough to establish profitable barite mining projects if compared to the world barite stocks. In this study, raw barite was obtained from Rabigh in the Western Province of Saudi Arabia. In this location pure barite is deposited in long layers (one to two meters deep) of about one meter thickness covered by shallow unconsolidated soils.

Table 4. World mine production and reserve base of barite [11, 12]

Country	Mine production, 1000 metric tons	Reserve base, 1000 metric tons
United States	692	60,000
Canada	103	14,600
China	3,500	150,000
France	76	2,500
Germany	120	1,500
India	400	32,000
Iran	150	NA
Kazakhstan	250	NA
Mexico	237	8,500
Morocco	270	11,000
Thailand	55	15,000
Turkey	160	20,000
United Kingdom	100	600
Other Countries	820	161,000
World Total	6,930	480,000

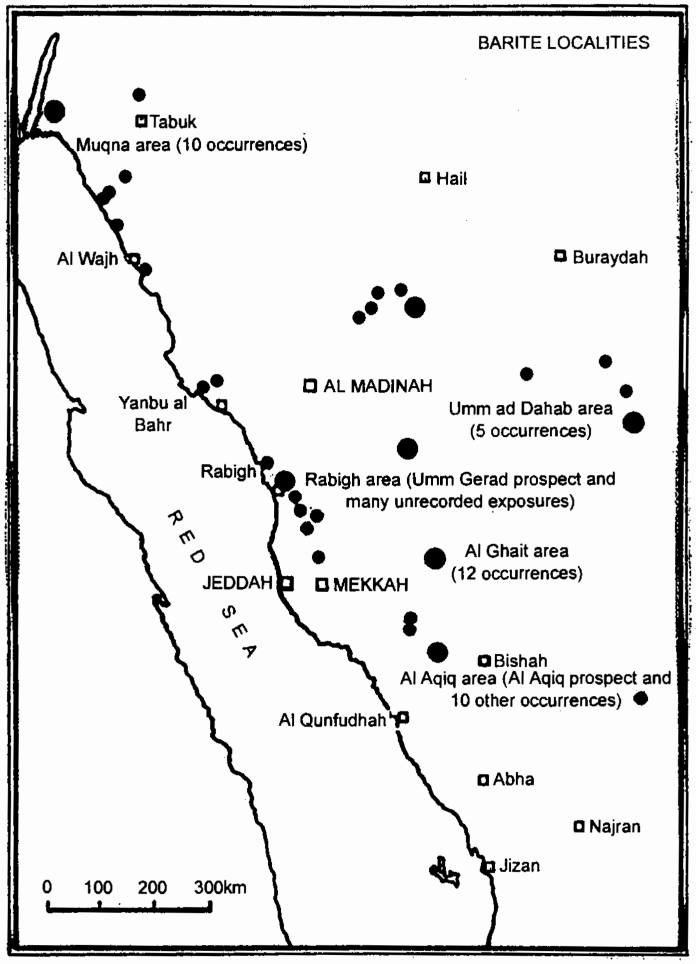

Fig. 2. Barite deposits locations in Saudi Arabia [14].

Flame test and mineralogical analysis

One test for barite identification is the flame test. A tiny chip, splinter, or bit of powder could be put in a gas flame and watched carefully. If the flame turns a yellowish green, then barite (barium) should be present. If powder is used, the color change may be very brief. The yellow present in most flames is caused by sodium, which is almost always present, makes most flames yellow. A specific gravity test would determine if barite is the mineral, but this is possible only if the specimen is pure barite or close to 100 percent barite. Since several minerals have similar specific gravity, flame test can be used to verify the mineral type. The tested Saudi barite has a specific gravity equal to 4.4

and produced a yellowish green flame, which indicates that the tested raw material is mainly composed of pure barite. X-ray analysis (XRD) of both the commercial and the local barites have shown that their composition is identical as shown in Fig. 3. XRD analysis (Table 5) indicated that the tested barite raw material is composed mainly from barite and quartz in addition to traces of some other minerals. This result is supported by the flame test and the measured specific gravity [11, 12].

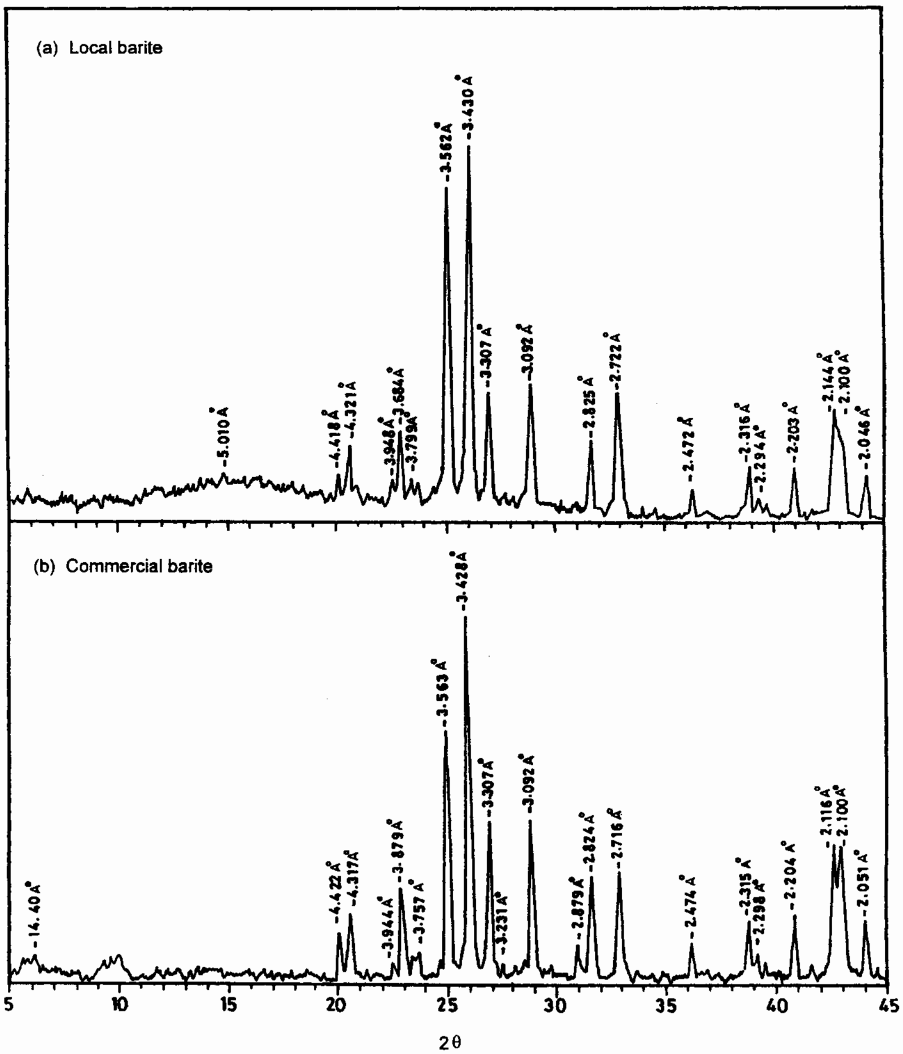

Fig. 3. XRD patterns of the local and commercial barites.

Table 5. XRD identification data

2θ	Spacing (d), Å	Mineral type
6.131	14.4045	Vermiculite
20.062	4.4222	Halloysite
20.556	4.3171	$CaCO_3$
22.907	3.9791	Barite ($BaSO_4$)
23.662	3.7569	Quartz (SiO_2)
24.968	3.5633	$CaBa_2Si_2O_8$
25.970	3.4281	Barite ($BaSO_4$)
26.934	3.3075	Barite ($BaSO_4$)
28.852	3.0919	Barite ($BaSO_4$)
31.042	2.8786	Vermiculite
31.657	2.8241	Barite ($BaSO_4$)
32.947	2.7164	Barite ($BaSO_4$)
36.283	2.4739	Hematite (Fe_2O_3)
38.864	2.3153	Quartz (SiO_2)
40.915	2.2039	Quartz (SiO_2)
42.698	2.1159	Barite ($BaSO_4$)
43.036	2.1000	Barite ($BaSO_4$)
44.123	2.0508	Bauxite Al_2O_3

Physical properties and chemical analysis

The tested Saudi barite crystals are white in color and mainly composed of barium sulfate ($BaSO_4$) as indicated by XRD and chemical analysis. Using water displacement technique, local barite specific gravity was found to be 4.4 while the pH of water-barite mixture was found to be in the range of 8.0. The tested Saudi barite contains traces of impurities such as calcite, gypsum, dolomite and sulfur. The chemical analysis of the tested barite indicated that it is composed of: 94% $BaSO_4$, 4% SiO_2, 0.4% $SrSO_4$, 0.2% Fe_2O_3, 0.05% MgO, 0.2% CaO and 0.3% Al_2O_3. The amount of barium sulfate indicated by the chemical analysis shows that the tested local barite is in accordance with the API requirements for barite [7,11,12] as shown in Table 2.

Crushing, powdering and sieving analysis

Bulk barite samples were collected from the site under investigation. In laboratory, these samples were washed with fresh water to remove any dust they may contain on their external surfaces. The washed samples were dried in an oven at a temperature of 50 °C for a week. Dry barite bulk samples were crushed with clean hammer and then poured into a crushing machine to convert them to the required powder grade (similar to the commercially available barite). Few grams of powder sample were taken for XRD and wet sieving analysis (Fig. 4). The remaining powder was stored in an airtight containers for use as drilling fluids weighting material.

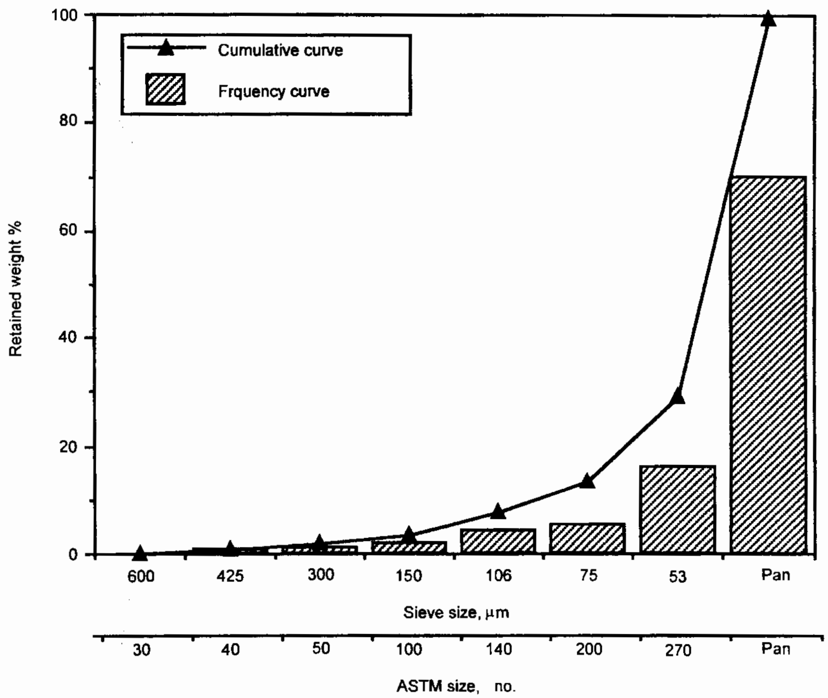

Fig. 4. Granulometric analysis of local and commercially available barite.

Water requirement for barite

Because barite is water wet, water molecules are adsorbed on the crystals free surfaces. Therefore, excess water must be added to the drilling fluid to be weighted before barite is added to avoid any reduction in the water that is originally associated in the drilling mud. To measure the amount of water required to moisten barite crystals, a known weight of the local barite powder is placed in a container then water is added gradually using a syringe and the contents are mixed thoroughly. This process is repeated until a slurry of barite is formed with no free water. Water required to moisten local barite crystals was found to be 0.18 cc/g which is in agreement with the literature cited water requirement for commercial barite used in oil well cementing which is estimated to be 2.4 gal/100 lb of barite (0.20 cc/g) [13]. This quantity of water is necessary to moisten barite crystal surfaces in case of water-base mud and to provide encapsulation of barite in case of oil-base mud.

Effect of barite addition on drilling fluid properties

API procedures for drilling fluids testing were used to investigate the effect of barite addition on the properties of water-base mud [1-6]. The measured properties are: density, pH, yield point, gel strength, viscosity, and filtration. Fresh water-polymer mud was prepared as a base mud for barite characterization. Properties of the formulated drilling mud before and after the addition of commercial or local barites are tabulated in Table 6. Fig. 5 shows the relationship between weight of barite added and density increase for a water-polymer drilling fluid. It can be seen that both the local and the commercial barites increased the density of the tested drilling fluid to similar levels, indicating good quality of the tested local barite. Similar conclusions can be made for other properties including pH, plastic viscosity, yield point, gel strength, filtration and mud cake thickness.

Table 6. Effect of barite addition on the properties of a water-base drilling mud

Property		Barite added, g							
		0	150	300	450	600	750	900	1050
		Laboratory measured properties of water-base mud composed from: 0.10% HV-CMC + 0.20% XC-Polymer + 350 cc Fresh water after the addition of commercial or local barite							
Density, ppg	C	8.33	11.00	13.10	14.80	16.20	17.40	18.60	19.50
	L	8.33	11.20	14.60	15.00	16.45	17.85	17.00	20.10
pH	C	7.60	08.30	8.30	08.20	08.10	08.10	08.10	08.10
	L	7.60	08.45	8.17	08.10	08.00	08.00	08.10	07.90
Plastic viscosity, cp	C	2.00	04.00	8.50	13.00	18.50	23.50	30.00	46.00
	L	2.00	04.25	8.60	13.20	18.80	24.00	31.00	46.70
Yield point, lb/ 100 ft^2	C	5.00	10.50	10.00	12.00	14.00	27.50	32.00	49.00
	L	5.00	10.75	10.20	12.00	14.20	28.00	32.85	50.10
30 min. API filtration, cc	C	---	24.30	38.70	38.87	47.00	80.50	103.0	104.0
	L	---	23.45	35.80	37.56	46.50	80.00	103.5	103.6
10 sec gel strength, lb/ 100 ft^2	C	2.50	02.50	02.90	03.20	03.50	05.50	07.00	14.00
	L	2.50	02.60	03.10	03.30	03.56	05.60	07.50	14.55
10 min. gel strength, lb/ 100 ft^2	C	2.50	03.00	03.00	03.30	03.50	04.30	06.50	11.50
	L	2.50	03.10	03.30	03.35	03.65	05.10	06.85	12.00
Mud cake thickness, 32^{nd} in.	C	0.00	01.45	04.00	06.00	06.10	18.13	26.40	32.10
	L	0.00	01.45	03.95	05.85	06.00	17.85	25.00	31.50
Particles less than 75 micrometer	C	< 5%							
	L	< 5%							
Water soluble Alkaline earth metals (Ca and Mg), mg/kg	C	---							
	L	25							
Specific gravity	C	04.20							
	L	04.40							
Color	C	Gray							
	L	Pure white							
Flame test color	C	Yellowish green							
	L	Yellowish green							

C: Commercial barite L: Local (Saudi) barite

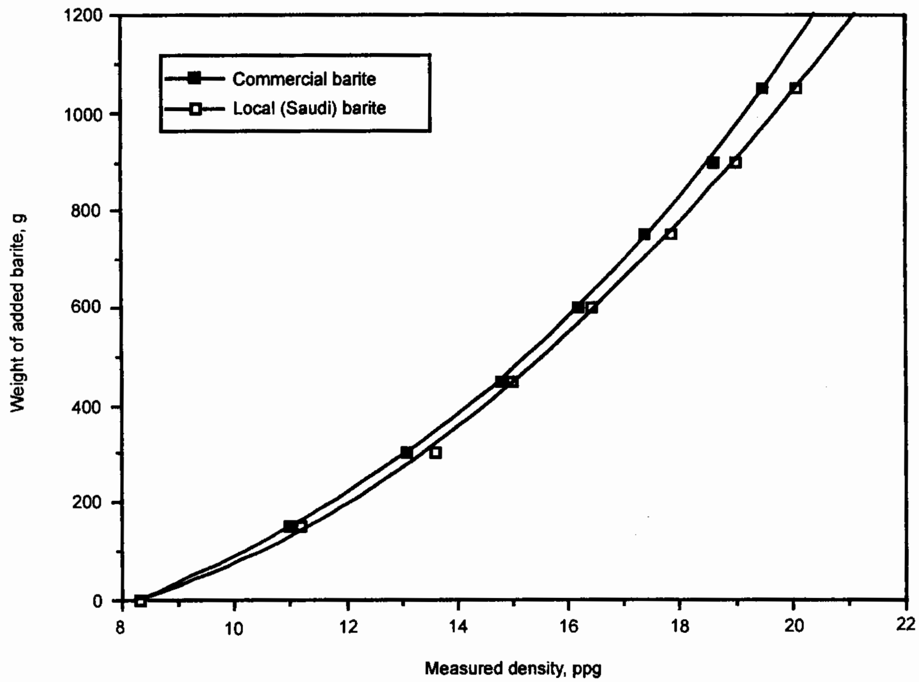

Fig. 5. Effect of barite aqddition on the properties of water-polymer mud formulated using 0.10% HV-CMC + 0.20% XC-Polymer + 350 cc fresh water.

Conclusions and Recommendations

- The tested Saudi barite is free of contaminants and pure white in color.
- The tested Saudi barite is identical to the commercially available barite as indicated by XRD, chemical analysis, flame test and specific gravity evaluation.
- The tested Saudi barite satisfied the API requirement for weighting materials.
- The effect of Saudi barite addition on the properties of water-polymer mud is similar to the effect of commercial barite addition.
- The commercial utilization of Saudi barite is recommended after performing an economical feasibility study.

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تقويم إمكانية استخدام البارايت السعودي واختبارها في عمليات الحفر

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ملخص البحث. تجري في الوقت الحاضر العديد من عمليات الحفر في المملكة العربية السعودية بحثا عن مكامن نفطية أو غازية جديدة. و يتم خلال عمليات الحفر تلك اختراق طبقات ذوات ضغط مسامي عالي (يكافئ ٢٠ باوند/جالون). ويمكن لسوائل الحفر الاعتيادية أن تتحكم في الضغوط المسامية بما يكافئ من ١٠ إلى ١٢ باوند/جالون. لذلك من الضروري أن يتم رفع ضغط سائل الحفر باستخدام بعض المواد المثقلة حتى يتم مواجهة الضغوط المسامية العالية حين مواجهتها خلال عمليات الحفر وإلا سيواجه خطر تفجر أجهزة الحفر. ويعتبر البارايت من أفضل المواد المثقلة لرخصه ونقاوته وعدم سُمِّيته ولتوافره بكثرة في العديد من بقاع العالم.

تقدر كلفة البارايت المستخدم في عمليات الحفر بنصف قيمة كلفة سوائل الحفر ككل. لذلك يحتم علينا هذا الوضع البحث عن مصدر محلي يوفر الكميات والنوعيات المطلوبة من البارايت لتقليل تكلفة عمليات الحفر. لذلك تم تجميع عينات من البارايت المترسب في منطقة رابغ الواقعة في المنطقة الغربية من المملكة العربية السعودية. وتم اختبار التركيب المعدني و الكيميائي، والخواص الفيزيائية والادمصاص المائي لتلك العينات من البارايت المحلي. كما تم دراسة تأثيرها على خواص سوائل الحفر بعد الإضافة معمليا. و للمقارنه تم اختبار عينة من البارايت التجاري ولنفس الخواص.

واعتمادا على نتائج هذه الدراسة وجد أن البارايت المحلي المترسب في منطقة رابغ الواقعة في المنطقة الغربية من المملكة العربية السعودية يماثل تماما البارايت التجاري المستخدم حاليا في عمليات الحفر. وعلى ذلك نوصي بإجراء دراسة جدوى اقتصادية تمهيدا لاستغلال تلك الترسبات من البارايت.