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# Improving Local Bentonite Performance for Drilling Fluids Applications

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**Abstract.** Drilling fluid is a vital element of the drilling process. Any drilling fluid must have common properties that facilitate safe and satisfactory completion of the well.

The main component of water base mud is clay (mostly bentonite). The present consumption of bentonite clay in the drilling operations in Saudi Arabia alone can reach over 100,000 tons a year and all of it is imported from USA. This trend is expected to continue as drilling activity increases. The large consumption and the high importation cost of this material lead to an attempt to find a local substitute.

Clays in Saudi Arabia are represented by numerous commercial stocks. The use of these local clays in the drilling activities can save a huge amount of hard currency that otherwise would be spent on importing it from abroad.

Several attempts were made to investigate shale outcrop precipitates in the kingdom. This work focuses on the possibility of the utilization of local bentonite clay minerals as a basic material for drilling fluids used to drill oil and gas wells. The only known bentonite outcrop in the kingdom is in Khulays area, 70 km north Jeddah adjacent to Makkah-Madinah road.

API specifications for acceptable drilling mud was the base for evaluating the local bentonite. The properties of the local mud can be improved economically by adding some cheep materials to the prepared mud to enhance its viscosity and filtration loss (such as CMC, Drispac polymer, and bentonite extenders). Also, shearing speed can be used as an enhancement method to improve the dispersion rate of the clay suspension, and hence increase viscosity and decrease filtration loss. But, the used shearing speed should be limited to a practical and economical speed.

The bentonite extender can be either a salt or a polymer, it enhances viscosity buildup by slightly flocculating the bentonite suspension. Sodium carbonate is an example of a salt that can be added as an extender. Soaking raw bentonite with a solution of sodium salt resulted, through ion exchange, in a higher sodium bentonite content. More effective extenders than inorganic salts are the high molecular weight linear polymers.

## Introduction

Drilling fluids are a vital factor in drilling a successful well. Any drilling fluid must have common properties, which facilitate safe and satisfactory completion of the well such as:

- Bottom hole cleaning and removal of cuttings to the surface.
- Controlling high pressure zones.
- Cooling and lubricating down hole drilling equipment.
- Forming bore hole wall supporting filter cake.
- Supporting the drill string and casing weight.
- Allowing the interpretation of electric logs.

These functions are controlled by the reheological and filtration properties of mud. The main component of water base mud is clay (mostly bentonite). One definition of a clay is that it will break upon dispersion into particles smaller than 2 microns when placed in water. Bentonite is a geological term for a rock which contains montmorillonite as its major component.

A good bentonite for a drilling fluid requires montmorillonite with sodium and calcium as the minor-cations associated with its exchange sites. A drilling grade bentonite must readily disperse in water to produce a thixotropic or shear thinning fluid which possesses gel strength and a low fluid loss to the formation (Mud School, 1996).

**Raw bentonite**

Commercial grades of bentonite occur as relatively thin beds of altered volcanic ash very close to the surface. Consequently, bentonite is almost exclusively recovered by a strip mining method. An integral part of mining bentonite is preliminary core drilling to determine the thickness and extent of the deposit and to provide samples for the estimation of the physical properties and ore grades within the deposit.

To meet these product requirements, the bentonite ores are fed as is to the plant processing facility. Most bentonite products require that the ore should be dried in a rotary drier to less than 15% moisture content. Additional drying occurs during further processing. Products required to be granular in nature are recovered by sieving the drier discharge.

Finely ground products are typically produced by milling dried ore through a roller mill which grinds to less than 200 mesh or finer particle sizing. Soda ash is added in concentrations up to 20 pounds per ton to lower grade bentonite ores which contain an excess of divalent cations at the montmorillonite exchange sites, improving the viscosity properties of the final product.

**Raw bentonite processing**

If the mineral composition of a bentonite is such that its viscosifying power is insufficient, an extender can be added. The extender can be either a salt or a polymer, and it enhances viscosity buildup by slightly flocculating the bentonite suspension.

There are only two simple methods available for increasing bentonite quality:

1. Ion exchange.
2. Extender addition.

The first method has no drawbacks if the bentonite is properly washed after the treatment. The addition of an extender, however, can give rise to an unexpected bentonite performance, in particular when polymeric extenders have been added.

The tendency to hydrate, which is greater in some clay than in others, determines whether chemical treatment is needed to achieve the properties desired for a particular drilling situation.

Sodium carbonate is an example of a salt that can be added as an extender. In some cases, it is already present in the bentonite because it can also be used for pretreatment. Soaking raw bentonite with a solution of sodium salt results, through ion exchange, in higher sodium montmorillonite content.

Anionic polymers, such as a Polyacrylate (Cypan), are used to increase the yield per ton of a bentonite blend. In concentrations as low as 0.1 pound per ton of bentonite, these polymers can increase the viscosity of 6% dispersions of the bentonite to produce an over 90-barrel yield per ton product. The current API specifications ensure that bentonite is not over treated with the polymer.

Non-dispersable particles of 75 micrometers or larger must be maintained below 4.0 wt%. These non-dispersable particles are from quartz, feldspar, mica and other minerals in the natural deposits. Their particle size is controlled in processing by grinding to less than 200 mesh (75 microns).

**Bentonite quality**

Bentonite quality is determined mainly by four parameters:

1. The content of material other than montmorillonite.
2. The type of counter-ions presents on the montmorillonite platelets.
3. The presence or absence of a small amount of extending polymer.
4. The size and charge of the montmorillonite platelets.

Pure bentonite should contain only montmorillonite. In practice, because of the declining reserves of high-quality bentonite, other material such as illites, kaolinites, chlorites (all clays), quartz, and feldspar are usually present. Because montmorillonitic clays have the highest swelling capacity (which is responsible for viscosity buildup and the formation of a low-permeability filter cake), the presence of the other materials will have an adverse effect on bentonite quality.

**Bentonite hydration**

When exposed to water, bentonite adsorb water and swell. The degree of swelling is controlled by the cation associated with the clay structure. For sodium bentonite, clay interlayer swelling can be twice the swelling of the calcium bentonite. In drilling fluids, the degree of clay swelling or the viscosity of the hydrated clay is the measure of its quality. The degree of calcium presence in clay is reflected on its viscosity.

**Bentonite quality evaluation**

Bol carried out several tests to prove that commercial bentonites were extended by using polymers so that it can perform better properties when used in preparing drilling fluids and to satisfy the API and the OCMA standards (Koninkijka, 1986).

Also, the variation in charge and size of the bentonite platelets will affect the swelling characteristics of the material and thus the quality.

General quality standards for bentonite are laid down in OCMA and API specifications (Table 1). Both methods include only tests at room temperature on suspension in distilled water.

**Table 1. API and OCMA specifications**

| Property | API Requirements | OCMA Requirements |
|---|---|---|
| Fann-600 reading (7% wt bentonite) | > 30 | ---- |
| Yield point | < 3 | ---- |
| API filtrate | < 15 mL | ---- |
| Wet sieving residue on sieve No. 200 | < 4 wt % | < 2.5 wt % |
| Wet sieving residue on 100 mesh screen | ---- | < 2 wt % |

Bol tested various commercially available bentonites for the presence of polymer extenders, including a non-oil field product which is a high purity grade bentonite. This non-oil field bentonite, in practice, is not intended to be used for viscosity development and thus, most probably, does not contain any extending chemicals. Neither of the specifications of the other tested bentonites mentioned the presence of any extending chemical (Koninkijka, 1986).

The results of his work show that only two products are not extended. They are the same two products that fail to meet OCMA requirements. He concluded that the fact that the pure non-oil field bentonite fails to meet the OCMA requirements lead to the conclusion that the OCMA and the API standards are very high. And, the fact that the other less purity bentonite fulfill the API and OCMA specifications more than the pure bentonite would lead to the conclusion that extenders were added to these bentonites.

He recommended that the API and OCMA standards should be lowered. This would exclude the addition of polymer extenders to bentonite by the producers as their product would fulfill the standards of the API and OCMA without adding polymer extenders (Koninkijka, 1986).

**Bentonite in Saudi Arabia**

Bentonite is imported from USA, which makes it an expensive material. Drilling operations consume a large quantity of bentonite. The large consumption and the high cost of this material lead to trying to find a local substitute.

Several attempts were made to investigate shale outcrop precipitates in the kingdom. First attempt was made by Dahab *et al*. to investigate Um Raduma shale outcrop 200 km east of Riyadh. It was attapuligite, which is a salt resistance clay usually used to prepare salt water base drilling fluids. They concluded that this local attapuligite is a good substitute for the imported attapuligite, which is called Zeogel (Dahab, 1987).

The attempt was continued to find a substitute for the imported bentonite. Musad *et al*. investigated many other locations. They collected clay samples from different locations in the kingdom. The tested clay samples were mostly kaolinite, which is a low swelling clay usually not used in drilling fluid formulation (Al-Awad, 1998).

There are several locations for clay outcrops in the kingdom. But, the only known bentonite outcrop is in the Khulays area, 70 km north Jeddah adjacent to the Makkah-Madinah road. Khulays bentonite deposit has proven reserves ranging from 420 thousand tones (proven) to 28.9 million tones (indicated) and 38.9 million tones (possible) (Spencer, 1986). Bulk samples were taken from this location and tested for their suitability to be used in drilling fluids.

## Experimental Work and Results

**Sample preparation**

Bulk samples of raw bentonite were obtained from Khulays area. The raw bentonite was crushed to a very small size, then it was milled by a ball-mill machine to a very fine size. The resulting powder was sieved by using a 45-micron openings mesh.

**Clay identification**

The X-ray diffraction and the SEM methods are considered as the most reliable methods to identify clay minerals. They are easy and fast identification methods. The result of the X-ray method is an oscillating curves with several high peaks. The peaks are the identity of the tested clay. Each clay type can give a certain distinctive and one or more peaks that are used to distinguish it from other clay types.

The X-ray diffractometer tests of the imported bentonite and Khulays clay show a very good agreement between the resulted peaks, which verify that Khulays clay is bentonite.

The difference between the two results is indicated at the peaks of the local bentonite d = 3.34 and d = 7.096. The first one indicates the presence of quartz in high concentration, while the second indicated the presence of small concentration of kaolinite (Fig. 1).

The SEM results show a clear image of the clay particles of the local bentonite (Fig. 2), while the SEM results of the imported bentonite show clay particles covered with a smooth material, which is believed to be an extending polymer (Fig. 3). The results of the SEM give a good boost to the conclusions of Bol that imported bentonites are extended by using polymers, so that it can perform better properties when used in preparing drilling fluids and to satisfy the API and the OCMA standards.

Also, particle size analyses were carried out for the less than 45 micron powder of the local bentonite. These analyses were done by using Malvern Laser Sizer instrument. The results show that the size range of the bentonite particles is between 0.03–20 micron with a mean size of 3.1 micron, and 90% of the particles are less than 10 micron (Fig. 4).

As clay particles are less than 4 micron in size, this result is a reflection of the presence of quartz as silt particles, which would affect the clay suspension properties. These particles should be removed to get better performance of the local bentonite.

**Testing local bentonite**

A drilling mud consisting of 5-15% by weight of local bentonite was prepared and an equivalent mud

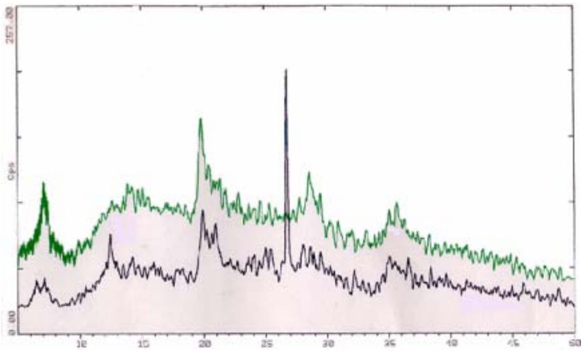

**Fig. 1. X-ray-diffraction results for the local and the imported bentonite.**

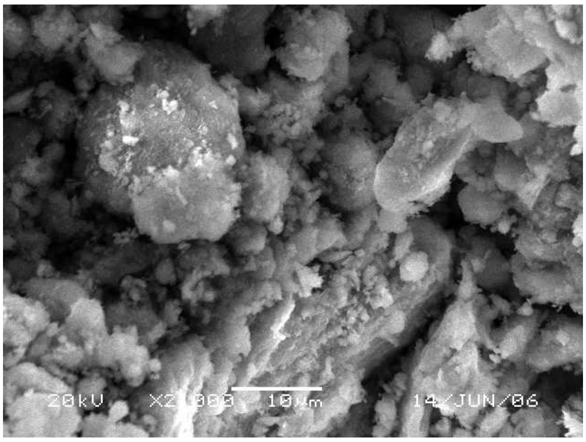


**Fig. 2. The SEM image of the local bentonite.**

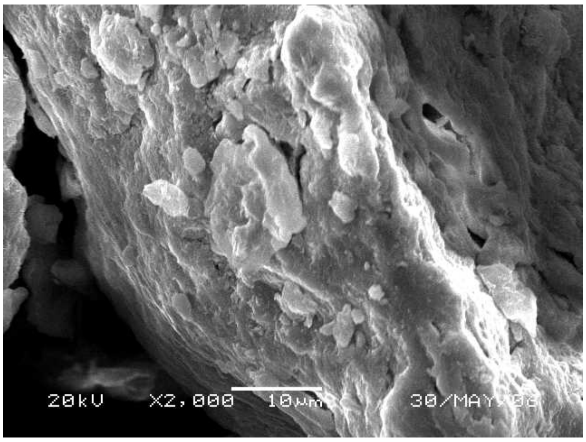


**Fig. 3. The SEM image of the imported bentonite.**

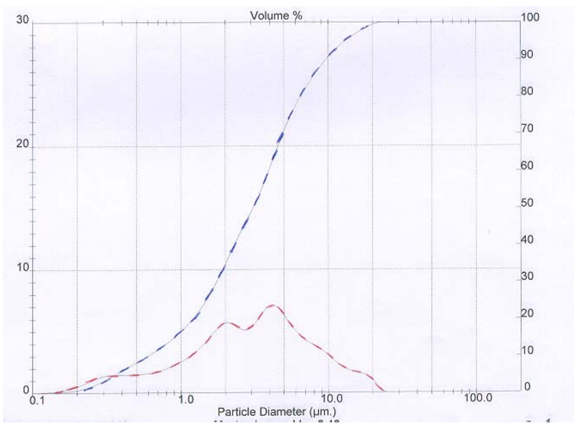


**Fig. 4. Particle size distribution of the tested local bentonite particles.**

consisting of imported bentonite (Macogel or Aquagel) was also prepared. The resulted muds were tested for viscosity, filtration loss and pH. Then, a comparison was performed between these types of muds.

Figure 5 shows the apparent viscosity of muds prepared from imported and local bentonite. This figure shows a big difference in the viscosity between the two muds especially at high concentration. But, the viscosity of local mud is still higher than that of high yield drilling clay (Baroco) muds.

Figure 6 shows the filtration loss at 30 min for the two clays. Filtration results again show a big difference in filtration loss between the two muds.

Figure 7 shows the pH of the mud prepared from the two clays. The pH of the local bentonite mud is lower than that of the imported bentonite mud by nearly 0.6.

### Improving local clay performance

Local bentonite should satisfy the API specifications to compete with the imported bentonite. This can be done economically by adding some cheap materials to the prepared mud to enhance its viscosity and filtration loss. Also, shearing speed can be used as an enhancement method to improve the dispersion state of the clay suspension, and hence increase viscosity and decrease filtration loss. But, the speed used should not exceed practical and economical shearing speed limit. In all following tests, the local bentonite concentration was kept at 7%.

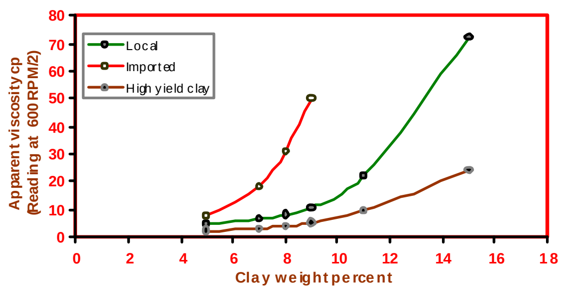


**Fig. 5. Effects of clay wt% on apparent viscosity of drilling mud.**

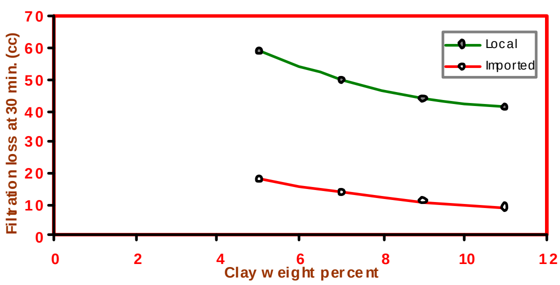


**Fig. 6. Effect of clay wt% on filtration loss of drilling mud.**

## Results

### Effect of increasing shearing or mixing speed

Increasing shearing speed from 6000 to 15000 rpm causes a great improvement in viscosity and filtration loss of the local bentonite mud (Figs. 8 and 9). There was 200% increase in viscosity and 35% reduction in filtration loss. It seems that this method of improving local clay mud properties is an effective method, but it has some economical and equipment limitations. Economical limitations are due to the high energy needed to reach high shearing speed. Equipment limitations are related and determined by the mixing equipments at the rig site. Thus, this method of improving mud properties can be used if these limitations are satisfied at the rig site.

### Effect of adding CMC (sodium carboxymethyl cellulose)

The CMC is a long chain of molecules, which is used to reduce filtration loss and increase mud viscosity at a temperature less than 250°F and for salts concentration less than 50000 ppm. The addition of CMC to the mud prepared from the local bentonite

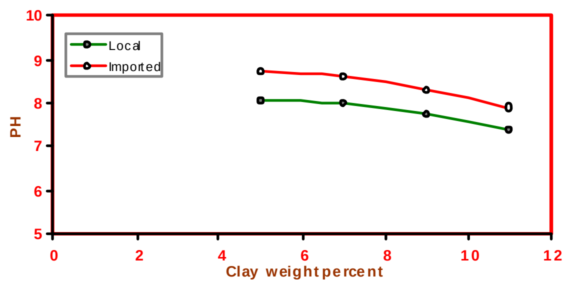


**Fig. 7. Effect of clay wt% on the pH of the drilling mud.**

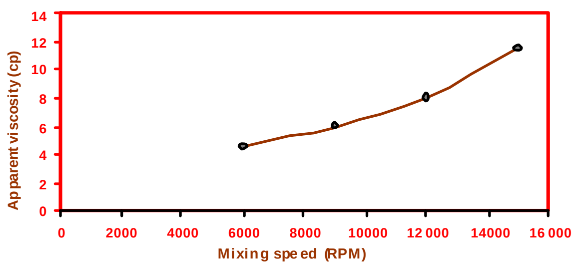


**Fig. 8. Effect of drilling mud mixing speed on apparent viscosity.**

causes an increase in viscosity to double at a concentration of 6 gm/l of mud (Fig. 10), but this concentration is relatively high. At a concentration of 1 gm/l, there was a sharp reduction in filtration loss from 50 to only 21 ml (Fig. 11).

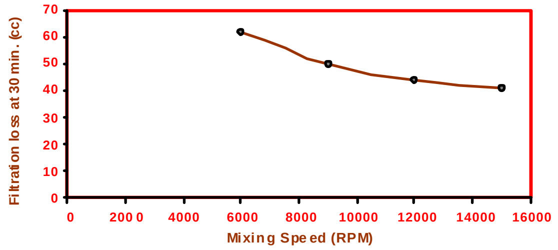


**Fig. 9. Effect of drilling mud mixing speeed on filtration loss.**

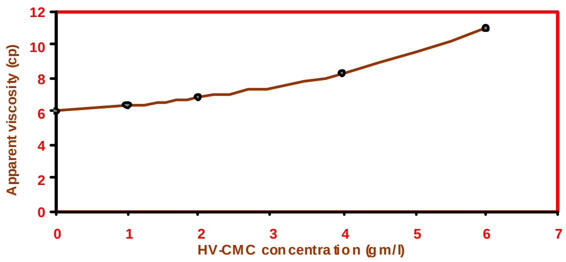


**Fig. 10. Effect of adding HV-CMC on the viscosity of drilling mud.**

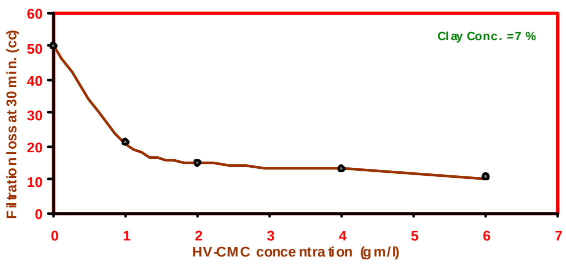


**Fig. 11. Effect of adding HV-CMC on the filtration loss of drilling mud.**

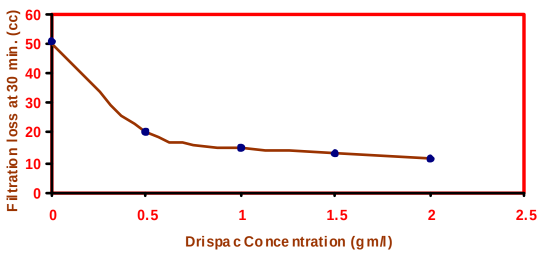


**Fig. 12. Effect of adding Drispae on the filtration loss of drilling mud.**

## Effect of adding Drispac (polyanionic cellulose polymer)

Drispac is a long chain polymer of high molecular weight. Small amount of this additive can both improve viscosity and reduce water loss even at a high salt concentration and high down-hole temperature. The addition of Drispac to the mud prepared from the local bentonite causes a huge reduction in filtration loss. At a concentration of 1 gm/l, this reduction reaches the API requirements (Fig. 12). To reach the API requirements concerning the viscosity, 2 mg/l should be added to the local bentonite mud (Fig. 13).

## Effect of adding NaOH

The effect of adding NaOH must take in consideration not only the effect of sodium ions, but also the effect of hydroxyl ions. Adding sodium into the mud system causes the viscosity to increase possibly as a result of base exchange. This is more obvious in Ca-base clays, as some sodium ions would replace calcium ions, which improves clay dispersion and resulted in higher viscosity.

As the addition of NaOH to the mud would increase the pH, its concentration should be limited to a certain value that would keep the pH around 9. In

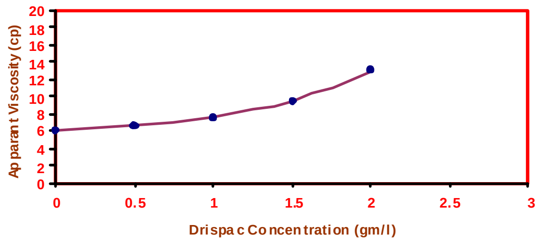


**Fig. 13. Effect of adding Drispac on the viscosity of drilling mud.**

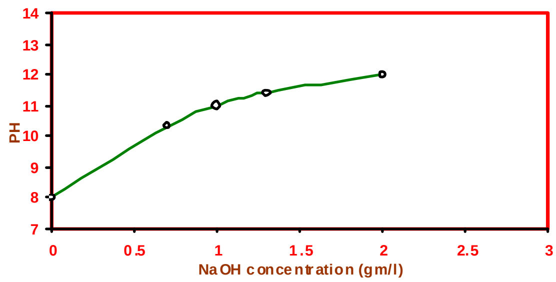


**Fig. 14. Effect of adding caustic soda on the pH of the drilling mud.**

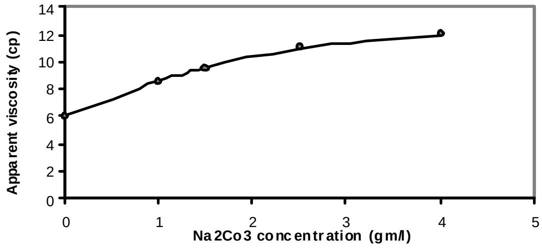


**Fig. 15. Effect of adding $Na_2Co_3$ on the viscosity of drilling mud.**

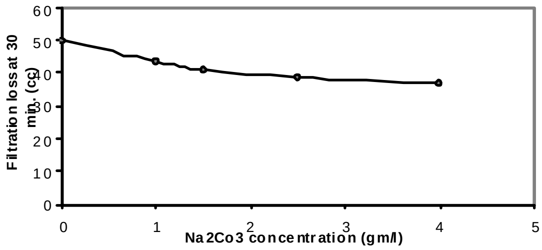


**Fig. 16. Effect of adding $Na_2Co_3$ on the filtration loss of drilling mud.**

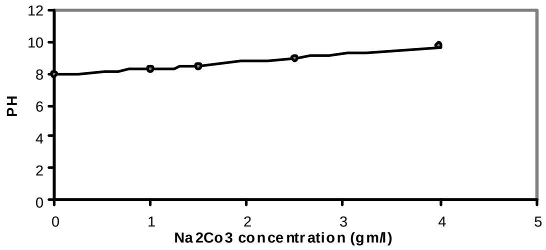


**Fig. 17. Effect of adding $Na_2Co_3$ on the pH of the drilling mud.**

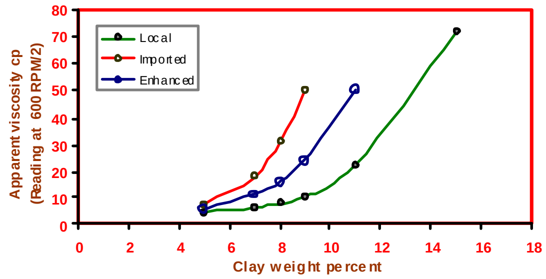


**Fig. 18. Enhanced local bentonite viscosity versus imported bentonite.**

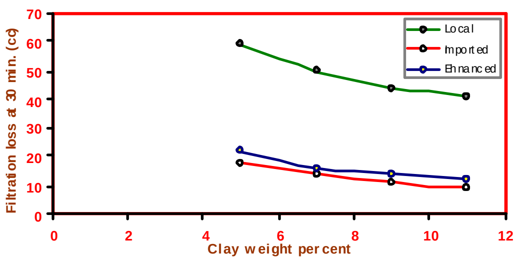


**Fig. 19. Enhanced local bentonite filtration loss versus imported bentonite.**

the present case, to get a good enhancement in the viscosity, the concentration of NaOH should be higher than 1 gm/l. But, this concentration will result in a pH higher than 11 (Fig. 14), which is an unacceptable level of pH. Thus, the use of NaOH to enhance local clay performance is not recommended.

**Effect of adding bentonite extender**

The extender can be either a salt or a polymer, and it enhances viscosity buildup by slightly flocculating the bentonite suspension. Sodium carbonate is an example of a salt that can be added as an extender. Soaking raw bentonite with a solution of sodium salt resulted, through ion exchange, in a higher sodium bentonite content. More effective extenders than inorganic salts are the high molecular weight linear polymers.

**Adding sodium carbonate salt (soda ash)**

One of the factors affecting the tendency of ion exchange in clay is the relative concentration of sodium cations. By adding $Na_2CO_3$, an enhancement of properties was expected as some of the Na-cations could occupy some surface locations and increasing the swelling tendency of clay.

Figure 15 shows the effect of adding $Na_2CO_3$ (soda ash) at different concentrations on local bentonite mud viscosity, as bentonite concentration in the mud was kept at 7%. At a concentration of 4 gm/l of mud, the mud viscosity was double.

Figure 16 shows the effect of $Na_2CO_3$ (soda ash) on mud filtration loss at 30 minutes. At 4 mg/l filtration loss decreases by 25% only, which necessitates adding another additive to reduce it to below 15 cc.

The addition of $Na_2CO_3$ will increase the pH of the mud to 9, which is an acceptable value (Fig. 17).

**Comparing enhanced local bentonit with imported bentonite**

Figure 18 shows mud viscosity of local bentonite after enhancement by adding soda ash and Drispac compared with imported bentonite. The performance of local bentonite was competing with the imported one.

Figure 19 shows mud filtration loss of enhanced local bentonite compared with the imported one. The two filtration losses are nearly identical.

The calculated yield for the imported bentonite was 95 bbl/ton, and that of the enhanced local bentonite was 85 bbl/ton. This yield can be increased over 90 bbl/ton by introducing an additional 0.5% Drispac.

## Conclusion

1. Based on the above results and in order to produce a product which can compete with the imported bentonite and to meet the API standards, the following product formulation is suggested: Enhance the performance of the local bentonite by adding salt extender (soda ash) at a concentration of 5% and by adding cheap polymer such as Drispac at a very low concentration of 0.5% of the added bentonite. These are necessary because the imported bentonite is not a raw bentonite. It was already extended by adding polymers, as it was proven in the literature and in this study.
2. The viscosity and the filtration loss of the 7% wt imported bentonite mud is nearly identical with the viscosity of the 8% wt enhanced local bentonite mud.
3. Depending on the published Baroid drilling fluid additives prices, the cost of the enhanced local bentonite, with a yield higher than 90 bbl/ton, is less than 46% of the imported bentonite cost. This estimation needs further investigations concerning local bentonite mining cost, processing, packing and transportation.

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# س أداء البنتونايت ا لي للاستعمال سوائل ا فر

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(قدم للنشر في ١٢/٠٧/٢٠٠٦م؛ وقبل للنشر في ٣١/١٠/٢٠٠٧م)

**ملخص البحث.** إن سوائل الحفر تعتبر عنصرًا أساسيًا في عملية الحفر. يجب أن يكون لسائل الحفر خواص تساعد على إكمال البئر بكفاءة وأمان. إن المكون الرئيسي في سوائل الحفر هو طفلة البنتونايت. إن استهلاك طفلة البنتونايت في عمليات الحفر في المملكة يفوق السبعين ألف طن في السنة، وجميع هذا البنتونايت يستورد من الولايات المتحدة. إن الكلفة العالية لهذه الكميات من البنتونايت أدى إلى محاولة البحث عن بدائل محلية.

جرى العديد من المحاولات لإيجاد بديل باستكشاف المتكشفات الطينية في المملكة. إن هذه الدراسة تركز على إمكانية توظيف البنتونايت المحلي كمادة أساسية في سوائل الحفر. إن المتكشف الوحيد في المملكة والمحتوي على البنتونايت يقع في منطقة خليص ٧٠ كم شمال جدة بمحاذاة طريق مكة -المدينة.

إن الأساسيات المستخدمة في هذا البحث في تقييم البنتونايت المحلي للاستخدام في سوائل الحفر هي مواصفات المعهد الأمريكي للبترول. وبالإمكان تحسين خواص البنتونايت المحلي بإضافة بعض المواد الرخيصة مثل CMC أو Drispac أو Bentonite extenders. كذلك يمكن تحسين عملية انتشار جزيئات الطفلة في السائل المعلق بزيادة سرعة الخلط.

إن تغطيس البنتونايت في محلول أملاح الصوديوم يؤدي وبواسطة التبادل الأيوني إلى إنتاج بنتونايت ذو محتوى أعلى من الصوديوم، حيث أن قيمة البنتونايت تزيد مع زيادة كمية أيونات الصوديوم الداخلة في تركيبته، أما الطريقة الأكثر فاعلية في تحسين البنتونايت هو إضافة البولمير ذو الوزن الذري العالي.