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Formulation of Drilling Fluids for High Temperature Well Application Using Sabah Bentonite

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ABSTRACT

The objective of this work was to investigate the rheological performance of a locally-sourced bentonite from Sabah for use as drilling fluid and compare it to a commercial bentonite from India. The rheological properties of the drilling fluids were obtained using standard testing apparatus such as mud balance, viscometer and filter press. It was observed that the Sabah bentonite has lower values of density, gel strength (GS), plastic viscosity (PV), yield point (YP) and filtration loss as compared to the Indian bentonite. The Malaysian bentonite did not meet the API required viscometer reading of 600 rpm. However, it was found that adding 1.0 ppb of NaOH as an additive to the mud improves the rheological performances of the mud significantly to meet the API standard. Economic analysis indicates that the treated Sabah bentonite mud is cheaper than the Indian bentonite by as much as 39%. The results of this work showed that the locally-sourced treated bentonite is technically and economically feasible for use as a drilling fluid.

1. INTRODUCTION

Drilling mud, which is a type of drilling fluid also known as spud mud, is used during operations to drill boreholes into the earth. The mud is often used for drilling exploration and production wells for hydrocarbons. Bentonite is an impure clay composed mostly of montmorillonite and an adsorbent aluminium phyllosilicate. Its main function is to improve the viscosity and filtration control. Bentonite, when added to freshwater mud, makes the mud gel and causes it to stiffen when circulation stops. This stiffening effect holds the cuttings in place within the mud instead of allowing them to fall to the bottom of the hole. When the mud starts moving again, it reliquefies and flows normally (H.C.H Darley, G.R Gray, 1998). Bentonite from India is widely used because it meets API Standards. This bentonite is capable of absorbing up to 7 to 10 times its own weight in water and swells up to 18 times its dry volume. The objective of this study was to investigate the rheological properties of the Sabah bentonite and compare it with Indian bentonite to determine the feasibility of using Sabah Bentonite for drilling fluid application.

2. EXPERIMENTAL WORKS

There were three stages in the laboratory testing as outlined in Table 1.

Table 1: Laboratory Work Stages

Stage	Objectives
Stage I	To determine the rheological properties of Indian Bentonite.
Stage II	To determine the rheological properties of Sabah Bentonite.
Stage III	To investigate the effect of NaOH on the rheological performance for Sabah Bentonite.

The experimental procedures for all three stages of the laboratory work were similar, and the steps are shown in Figure 1.

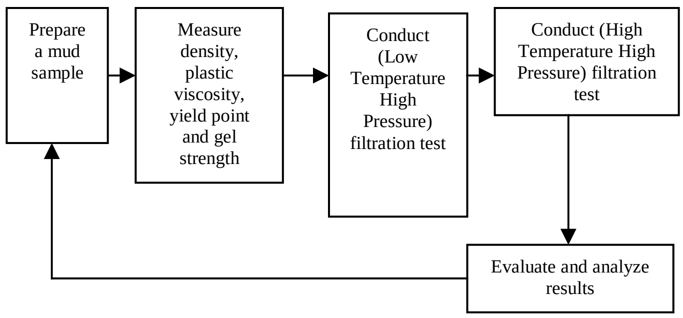

Figure 1: Flow sheet of experimental procedures

The standard drilling mud samples were prepared according to API 13, where 22.5 g of bentonite powder were mixed with 350 ml of distilled water. Each sample was mixed thoroughly using a Fann Multimixer.

3. RHEOLOGICAL PERFORMANCE OF SABAH AND INDIAN BENTONITE

The rheology tests were conducted at room temperature to determine the density, viscosity, yield point and filtaration loss of both the Sabah and Indian Bentonite. The results of the experiments are as follow:

Table 2: Comparison of Rheological Properties of Sabah And Indian Bentonite at Room Temperature

Rheological Properties	Types of Drilling Fluid		
	API Standard	Sabah	Indian
Density (lb/gal)	n/a	8.47	8.60
Viscometer Reading at 600 rpm / min	Minimum 30	3	30
Plastic Viscosity (cp)	n/a	2	9
Yield Point (lb / 100 ft^2)	n/a	1	12
YP/PV	Maximum 3	0.50	1.33
Filtration properties (ml)	Maximum 15	9.80	4.00

Table 3: Comparison of Rheological Properties at High Temperature

Rheological Properties	Indian			Sabah		
	75°C	120°C	150°C	75°C	120°C	150°C
Viscometer Reading at 600 rpm / min	77	79	85	3	2	2
Plastic Viscosity (PV)	25	26	29	2	1	0.5
Yield Point (YP) (lb / 100 ft^2)	27	27	27	1	1	1
YP/PV	1.08	1.03	0.93	0.5	0.5	2
Gel Strength (10 s)	56	67	49	2	2	1
Gel Strength (10 m)	54	73	65	2	2	2
Density	8.3	8.75	8.7	8.4	8.4	8.3
Filtration properties (ml)	8.60	9.50	13.80	12	14	16

As shown in Tables 2 and 3, the Indian bentonite was found to have a higher density, and density did not change with temperature for either bentonite. This is due to the fact that Indian bentonite has a higher content of montmorillonite, which is a very soft phyllosilicate mineral that typically forms in microscopic crystals. The function of the montmorillonite is to make the mud slurry viscous, which helps in keeping the drill bit cool and also in removing broken rock fragments in the drill hole.

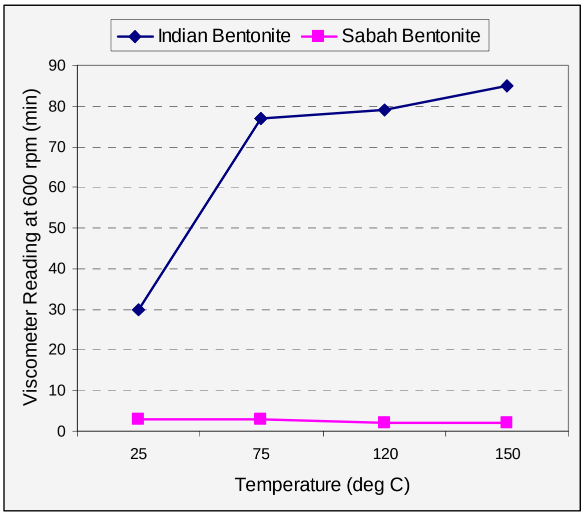

Figure 1: Viscometer Reading at 600 rpm/min

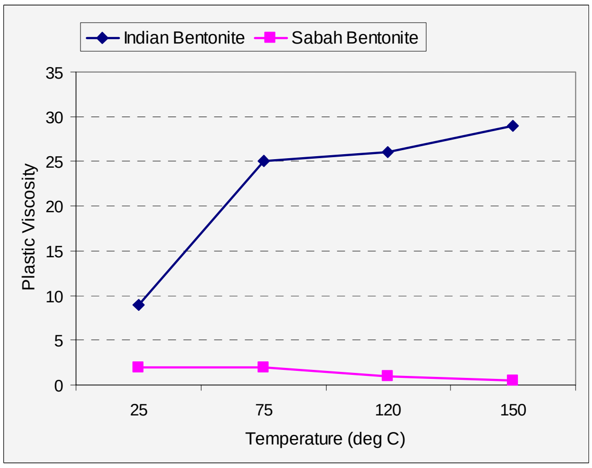

Figure 2: Plastic Viscosity

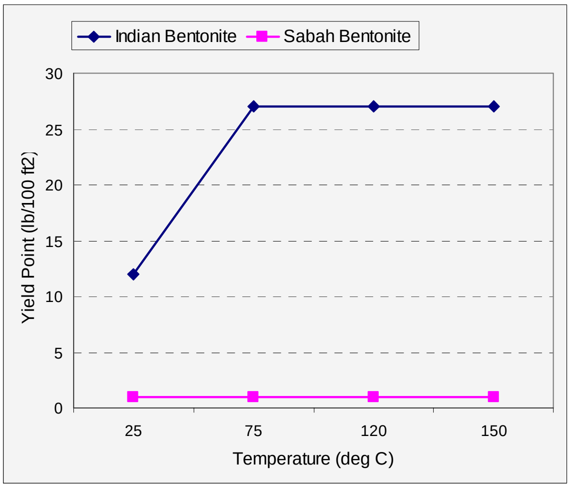

Figure 3: Yield Point

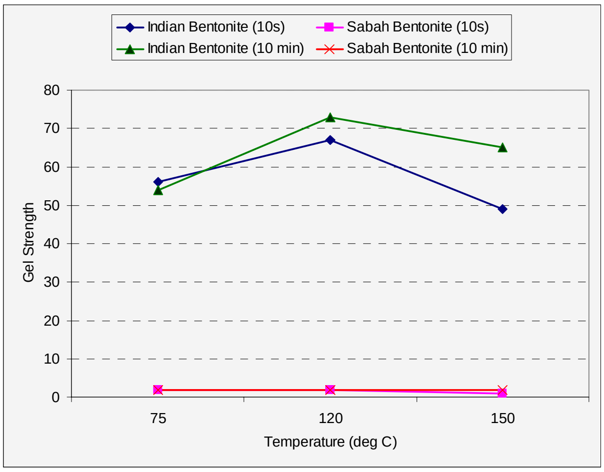

Figure 4: Gel Strength

As shown in Figure 1, the Sabah Bentonite did not meet the standard API viscometer reading of 600 rpm / min. It also had a much lower plastic viscosity and yield point compared to the Indian Bentonite as shown in Figures 3 and 4, respectively. The low plastic viscosity of the Sabah Bentonite may result in its failure to control the magnitude of shear stress of fluids and this may lead to fluid failure during the operation. The low yield point may also cause the failure of the Sabah Bentonite to develop and retain its structure during operations.

The Sabah bentonite also showed a decrease in the viscometer readings as the temperature went up, as shown in Figure 1. This is because as the temperature increases, the clay swelling decreases, and thus the viscosity of the mud decreases. The Indian bentonite showed a different pattern, as displayed in Figure 3. The plastic viscosity increased with temperature due to shear thickening effect, and it resulted in the bentonite becoming more dispersed, thus increasing the number of individual platelets in the suspension. The plastic viscosity (PV) is a measure of the internal resistance to fluid flow attributable to the amount, type, and size of solids present in a given fluid.

The yield point (YP) of the Sabah bentonite was found to be constant with respect to temperature as shown in Figure 4. On the other hand, the YP of Indian bentonite increased with temperature until it peaked at 75°C. The YP is the resistance to initial flow and it represents the stress required to start fluid movement. This resistance is believed to be due to electrical charges located on or near the surfaces of the particles. The values of the yield point and thixotropy are measurements of the same fluid properties under dynamic and static states, respectively. Thus readings from the rolled bentonite indicated the same result for dynamic conditions.

As shown in Figure 4, the gel strength of the Sabah bentonite was found to be constant with respect to temperature. The Indian bentonite, however, showed an increase in gel strength with temperature until a temperature of 120°C was reached, after which the gel strength decreased. The exposure of the Indian bentonite to high temperatures for long periods of time caused it to become more dispersed, increasing the number of individual platelets in the suspension and increasing the viscosity at low shear rates.

4. EFFECT OF SODIUM HYDROXIDE ON SABAH BENTONITE

Darley and Gray (1988) stated that the interaction between sodium (monovalent) and montmorillonite determines the swelling of the particles. High sodium content results in high swelling, and thus high density and viscosity of the fluid. The content of Sodium in the Sabah bentonite is only 0.56% as compared to that of the Indian bentonite, which is 2.70%. The sodium content in the Sabah bnetonite may be raised with the addition of NaOH.

Table 4: XRF Results for Indian and Sabah Bentonite

No	Compound	Indian (%)	Sabah (%)
1	Titanium (TiO_2)	1.03	0.83
2	Sodium (Na_2O)	2.70	0.56
3	Potassium (K_2O)	0.17	3.03
4	Magnesium (MgO)	3.14	2.30
5	Calcium (CaO)	2.51	0.26
6	Ferric Oxide (Fe_2O_3)	10.4	5.63
7	Alumina (Al_2O_3)	21.6	21.3
8	Silica (SiO_2)	57.6	65.6
9	Loss of ignition	0.85	0.49

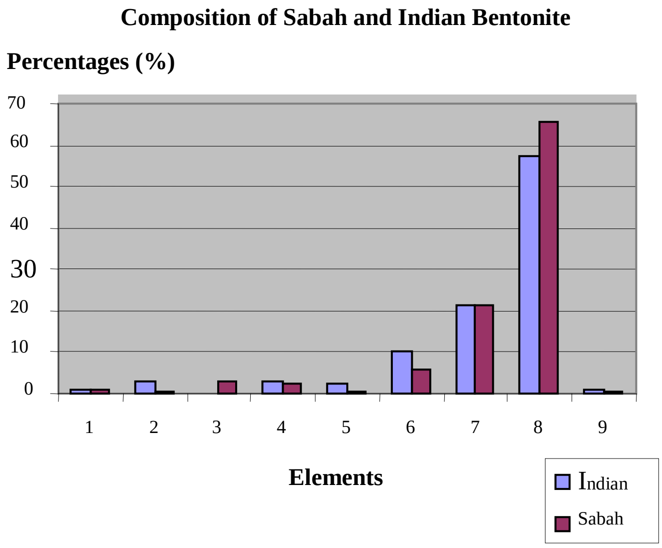

Figure 5: XRF Result for Composition of Indian and Sabah Bentonite

The results of the rheological performance tests on the modified Sabah Bentonite are shown in the following Table 5.

Table 5: Rheology Properties

Rheological Properties	Indian Bentonite	Sabah Bentonite with NaOH additive (ppb NaOH)							
		0.5	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
Viscometer Reading at 600 rpm / min	30	32	32	38	39	32	39	35	35
Plastic Viscosity (cp)	9	4	8	7	6	7	7	6	6
Yield Point (lb / 100 ft^2)	12	24	16	24	27	18	25	23	23
YP/PV	1.33	6.00	2.00	3.42	4.50	2.57	3.57	3.83	3.83
Gel Strength (10 s)	27	29	25	30	32	43	30	28	28
Gel Strength (10 m)	28	29	22	28	29	42	28	25	25
Density (lb / gal)	8.60	8.70	8.70	8.70	8.70	8.70	8.70	8.65	8.50
Filtration properties (ml)	4.00	12.00	15.00	16.00	63.80	66.50	68.40	69.30	69.60

Based on the results shown in Table 5, the addition of sodium hydroxide (NaOH) improved the rheological and filtration propetries of the Sabah bentonite. Addition of sodium hydroxide and other monovalent cations to an aqueous suspension of dispersed hydrated clay increases the ionic atmospheric charge from the sodium and chloride ions. The hydroxide ions increase the negative charge of the solution and the positive charge of the sodium ions. The increased number of sodium ions causes some to approach the planar surface of the clay more closely than the cation previously associated with it, thereby tending to decrease the sheet negative charge and the repulsive charge between sheets.

The repulsive force between the ionic atmosphere and reduced planar charge will remain high, however, because of the increased atmospheric negative charge. The reduced repulsive charge between sheets, the attractive edge valencies, and the high repulsive charge of the ionic atmospheric negative charges force the clay sheets to form openings, causing fluid loss to increase. If the result of flocculation is a regrouping of the sheets in stacked parallel layers (aggregated), then viscosity and gel strength decrease and fluid loss increases. Since such a regrouping is a matter of statistical chance, it is seldom that the randomly oriented sheets will completely restack themselves. In all probability, some restacking occurs, with the remaining plates interlocked at random angles (W.F Rogers, 1968).

Flocculate or cluster in lumps. These lumps are more difficult to move than the individual clay sheets, as manifested by an increase in viscosity and gel strength. In addition, once the sheets are not available in individual

Increasing the sodium hydroxide (NaOH) concentration also increases the pH of the mud. Under high pH conditions, the mud viscosity is unduly high because of the effect of the hydroxyl radical. A condition where NaOH is present and conducive to the development of sodium clays is when shales are drilled that have great hydration and dispersion effects which add viscosity to the mud. This may be highly undesirable and should be kept at a minimum pH of 8.0 to 9.0.

5. ECONOMIC ANALYSIS

In Malaysia, the bentonite found in Sabah is of the calcium variety (Radzuan Junin *et al.*, 1992). This study has provided an alternative way to beneficiate and activate this bentonite to provide a better product, which is the sodium-based bentonite. The bentonite deposit in Sabah has a mass of about 5.1 million tons with an average thickness varying from 1 meter to 2.5 meters. This study has shown that the Sabah bentonite can be upgraded to meet the API specifications with the addition of NaOH.

In order to drill a well, it is estimated that about of 270 tons of bentonite are needed to prepare the required drilling mud. A comparison of the cost per well using beneficiated bentonite mud to that using commercial bentonite is shown in Table 6. As shown, the beneficiated mud is about 39% cheaper than the commercial bentonite. Based on the forecasting of 50 development and 10 exploration wells to be drilled per year, about 16,000 tons of the bentonite are required annually. If the treated Sabah bentonite samples can be produced and used commercially, a total cost of about RM 2.4 million can be saved per year.

6. CONCLUSIONS

The results have shown that an optimum dosage of 0.5 to 1.00 ppb of NaOH added to the Sabah bentonite upgrade it to meet API standards for use on drilling fluid. It is estimated that about RM 2.4 million can be saved annually by using this mud.

Table 6: Comparison of Cost between Commercial Bentonite And Beneficiated Sabah Bentonite Sample

Cost	Commercial Bentonite	Beneficiated Sabah Bentonite
Price of NaOH to activate1 ton bentonite (US$)		6*
Processing cost per ton of bentonite (US$)	-	10*
Total Price per ton (US$)	42*	16
Total Cost (RM)	146.58	1396
Total Cost per well (US$)	11340	4 455*
Total Cost per well (RM)	39576.6	15547.95

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