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POTENTIAL OF AN ANDRASSY AND MANSULI BENTONITE AS A DRILLING MUD MATERIAL

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Abstract

This paper presents the results of laboratory treatment works on upgrading the bentonite from two areas of Sabah, Malaysia, namely Andrassy and Mansuli for the uses in petroleum industry. Bentonite, as a common material used in water based drilling mud is the sodium bentonite. Since the Malaysian bentonite is proved to be calcium base, certain treatment is needed to convert this bentonite to sodium variety. The successfully treated bentonite will be used as a material in drilling mud, which is cheaper as compared to the Wyoming and standard bentonite. This study included two treatment processes; wet treatment and electrolysis to upgrade the non-sodium based bentonite to sodium based variety. Several sodium sources have been studied but only the sodium carbonate can successfully be used to upgrade the bentonite. The result obtained after these two treatment processes showed improvement in cation exchange capacity (CEC), which is about 27% increment for electrolysis treatment and 22% to 29% for wet treatment, respectively. However, the treated bentonite failed to meet the API 13A Specification (American Petroleum Institute) requirements for rheological properties when used as a material in drilling mud. Thereafter, certain polymer extender had been added to improve rheological of the upgraded bentonite slurry so that it can be used as a drilling mud material. In general the treated bentonite from Malaysia can be used as a replacement for the more expensive imported bentonite especially for local petroleum industry. In addition, the methods developed can also be used to convert the similar type of bentonite from other locations, since the deposits of calcium based bentonite in Malaysia are far more than the sodium based bentonite.

Introduction

In order to reduce the overall cost of bentonite used in local oil and gas industry, the feasibility study of Mansuli and Andrassy bentonite application had been initiated. Before these bentonite can be used, their physical and chemical properties and their performance as compared with the standard bentonite must be determined. If their performances are not as good of standard bentonite, treatment ought to be applied to convert the counter ion that placed between the unit clay surfaces. The type of counter ions has a great effect on the swelling capacity of the montmorilonite mineral and by far the best performance is obtained with sodium-based montmorillonite mineral, which has sodium as counter ions. If the montmorilonite mineral in bentonite contains counter ions other than sodium, the swelling properties, viscosity build-up and filter cake permeability will be adversely affected.

Three sources of samples that were used in this study, two sources namely SA5-1 and SA5-4 from Andrassy of Tawau area and the other namely M4 from Mansuli of Lahad Datu in Sabah. These bentonite are proved to be non-sodium based, which are different from the commercial sodium based bentonite according to the chemical and physical properties such as Atterberg limits, moisture content, moisture adsorption, ignition loss, specific surface and cation exchange capacity. From the chemical composition also, with the higher content of calcium compound and lower content of sodium compound compared to standard bentonite, the Andrassy and Mansuli bentonite can be categorized as non-sodium based bentonite.

Experimental Works

a) Bentonite Sample Preparation

Bentonite samples from the field will be dried in the oven at 55 °C for four hours until reach moisture content less than 10%. Then the sample will be crushed using grinding machine till it become powder. Selection of bentonite grain size is very important to obtain optimum cation exchange. Based on literature (API specification 13A, 1993), showed that sand grain size is bigger than 74 μm, so the bentonite samples used for this treatment should be less than 74 μm, which can be achieved by using wire cloth sieve.

b) Mineral Composition

The first phase of experiment works for this study is bentonite mineral composition determination. X-Ray

Diffraction (XRD) analysis had been used and the test was done by using Siemens D-5000 fully automatic diffractometer. The mineralogical constituents within the bentonite sample can be directly characterized giving critical information as to the geological evolution of rock samples.

c) Physical Properties

Second phase are the physical properties of bentonite. These properties including Atterberg limits determination and also the moisture content (MC), moisture absorption (MA) and ignition loss (IL).

The physical study values are used to obtain information on the nature and quality of the mineral by using Atterberg Limits Test, such as plastic limit (PL), liquid limit (LL) and plasticity index (PI). The standard testing method for liquid and plastic limit are according to ASTM specification is ASTM 4318-84. Liquid limit and plastic limit also refer as Atterberg limit, which depending on the moisture content of bentonite sample. The liquid limit provides the moisture content at which the clay changes from plastic to the liquid state. While the plastic limit was simply the moisture content at which a ball of clay when rolled to a diameter of 1/8 inch. On the other hand, plasticity index is the difference between liquid limit and plastic limit.

In addition, the moisture adsorption (MA), moisture content (MC) and ignition loss (IL) of bentonite will also be determined since the qualitative mineral content of bentonite can be studied. Moisture adsorption (MA) is defined as the percentage of water lost when clay from a saturated atmosphere (around 20°C) is dried in an oven at 105°C. The moisture adsorption value can be used to predict the mineralogy nature for clay. Moisture content (MC) is the percentage of water lost when clay from normal room temperature atmosphere (at around 20°C) is dried at 105°C. While the ignition loss is the percentage of weight lost when a dried clay (at 105°C) is fired to 1000°C in furnace.

d) Chemical Properties

The chemical properties of bentonite, which will be determined in this study, included chemical composition, cation exchange capacity and specific surface of bentonite.

Methylene Blue Test (MBT) is used to estimate the CEC. A sodium-based bentonite should have a CEC value same as that of montmorillonite (80-150 meq/100 grams). Approximately 1 gram of bentonite sample will be tested in 50 ml of distilled with about 0.5 ml of 5 N sulfuric acid added. The bentonite solution will than boiled gently for 10 minutes. The CEC is measured by conductomercial titration after cation exchange, meq/100grams. In addition, the chemical composition of bentonite will be tested by EDAX Philip Series-40 instrument. This equipment can calculated quantitatively of bentonite element based on the emission of electron in it's orbital. For specific surface determination, Methylene Blue Spot Test is used and this method is similar to the MBT, the only difference is the bentonite sample solution will not be boiled and the addition of acid is unneccesarry.

e) Performance as Drilling Mud Material

After that, the bentonite will underwent a series of testings based on API (American Petroleum Institute) specification 13A, and OCMA (Oil Companies Materials Association) specification. Comparison will be made between the Andrassy and Mansuli bentonite and standard bentonite.

f) Wet Treatment Process

There are many attempts that had been done by previous researchers (Khairuddin *et.al.*, 1992) to fully utilize the Malaysian bentonite in the industries other than petroleum industry such as decolorizing agent for palm oil industry. In order to widen the uses of these bentonite, certain treatments must be applied to these non-sodium based bentonite to convert them into sodium variety, so that can be used as material in drilling mud.

In the industry, the most sophisticated method to convert the non-sodium based bentonite to sodium based is the treatment process involved the use of sodium carbonate. In order to have a better quality of bentonite that produced, the entire treatment process is done under wet condition. This treatment process commonly known as wet treatment process and the additive that been used is sodium carbonate (soda ash).

The most common wet treatment process is mixing the non-sodium based bentonite directly with the solution that contains sodium ions as the exchange medium. The entire treatment process needs to be run under the wet condition that is either in solution form or in high moisture condition. This method is more complicated than dry treatment process but the bentonite that produced can have a CEC much higher than that produced by dry process.

g) Electrolysis Treatment

Electrolysis treatment processes were prepared firstly by making the electrolyte solutions. In this study Na_2CO_3 electrolyte solutions will be vary from 0.5% to 7.5%. DC power supply was used as power source. Both the areas of the Aluminum cathode and anode were 15 cm^2 (1 cm x 15 cm).

Firstly, 5 grams bentonite were mixed by electrolyte solutions till homogenous. Then the electrode was inserted into the container by clipping the electrode and connected with DC power supply. The operating conditions for electrolysis were applied by ranging electrical potential 6V, 9V, 12V.

Results and Discussions

Mineral Composition

Generally, the Andrassy bentonite samples (SA5-1and SA5-4) before wet treatment are seem to have montmorillonite mineral as theirs major component. However, if compared with the standard bentonite, the montmorillonite composition is still less than desired. Besides, these bentonite samples contain kaolinite, illite in small amount, which are identical to the standard one. However, the Andrassy bentonite consist the feldspar in a very small quantity, which is different from the standard bentonite. There is only trace of feldspar mineral in standard bentonite. So, it is believed that the occurrence of bentonite in Andrassy area of Tawau consist of the some feldspar mineral with amount that can be detected by XRD.

For M4 sample from Mansuli, the situation is even worse because the predominant mineral for this sample is quartz instead of montmorillonite mineral. The montmorillonite is just appears as minor mineral with the presence of kaolinite, illite and feldspar in small quantity.

After wet treatment, the whole mineral composition of the Andrassy and Mansuli bentonite remains unchanged (see Table 1). This is what we expected because the treatment process will only affect the chemical component in the structure of the bentonite unit layers or surfaces and not changing the mineral content of the entire sample. As for the bentonite samples after electrolysos treatment, the results are almost the same as the wet treatment except for the montmorillonite content of treated M4 sample, which less than the untreated and wet treated one. This may be caused by the inhomogeneous sample while preparing the sample.

Physical Properties

a) Atterberg Limits

Commonly, the range of liquid limit for montmorillonite is around 100 % to 800 %. None of the untreated Andrassy and Mansuli bentonite meets this requirement except for SA5-4 sample (see Table 2). For untreated SA5-1and M4 sample, the liquid limit values are below the range of montmorillonite. In fact, the liquid limit of bentonite mainly depends on the moisture of the bentonite itself or the water absorption ability. For M4 sample which rich in quartz mineral, for sure the liquid limit is very low.

SA5-4 sample has the highest plastic limit followed by SA5-1and lastly M4 sample. From the sequence, it is known that the plastic limit has direct relationship with the plasticity of bentonite. SA5-4 sample has the highest plastic limit value because of its better water absorption and swelling capability compared the SA5-1 sample. Again, M4 sample which has the lowest plastic limit value due to its high quartz content.

As an integration of liquid limit and plastic limit, plasticity index means that the bentonite can absorb larger amounts of water without changing physical states. As for low plasticity index (less than 100 %) of the untreated Andrassy and Mansuli bentonite, only small amount of water can be absorbed.

In general, the Andrassy bentonite samples show good agreement in the liquid limit and plastic limit after wet treatment (see Table 2). It is noted that SA5-1and SA5-4 show better improvement in liquid limit with increment more than 100 % of the original values. In addition, these bentonite samples also show improvement in plastic limits. This again proven that the mineral content of bentonite plays an important part that influences the plasticity of a sample especially the type of montmorillonite. Bentonite sample that contains sodium montmorillonite will have a better plasticity properties than those contains calcium one.

On the other hand, when eletrolysis treated M4 is tested for Atterberg Limit, the Plasticity Index (PI) decreased into 31.72 from original value of 51.34. For treated SA51 and SA54, the situation are slightly different which are 156.92 from original value of 36.79 for SA51 and 268.05 from original value of 81.22 for SA54. These PI values for Mansuli and Adrassy bentonite failed to meet standard bentonite, which is 590.53, as shown in Table 2. It means that Mansuli and Andrassy bentonites are not the sodium montmorillonite (sodium bentonite) type since PI for the standard bentonite is sodium montmorillonite, with the ordered as followed: M4-T < SA5-1 < SA5-4 < Standard Bentonite.

b) MC, MA and IL

From Table 3, it is clearly shows that the MC, MA and IL results of untreated and treated Andrassy and Mansuli bentonite samples. For a bentonite that have a MA value near or greater than 23 % indicated that the sample contains mostly montmorillonite mineral while less than 3 % means the clay consist kaolinite as the main mineral. Among the untreated bentonite samples, SA5-4 is the only sample that has a MA value nearest to 23 %. For the MA value that lies between 3 % and 23 % showed that the bentonite sample may contains kaolinite and montmorillonite in certain proportional and other minerals as impurities. The lower the MA value, by means the content of montmorillonite mineral is decreased with the increment of kaolinite minerals. Among the untreated bentonite samples, M4 sample has the lowest content of montmorillonite with a MA value less than 10 %. For ignition loss, there is no much difference between the bentonite samples, including the standard one. This represent that the amount unwanted impurities (fired at 1000°C in furnace) for all the bentonite samples are almost identical to one another.

From Table 3, it is clearly seen that there is only a slightly increased in MA value for SA5-4 and M4 after wet treatment. For SA5-1 sample, the MA has been increased from 11.91 % to 17.25 %. Improvement in MA value for SA5-1 sample means that the content of montmorillonite mineral in the sample also increased. As already been discussed, there is no much difference for IL values between the treated and untreated bentonite samples, including the standard one.

After eletrolysis treatment, the moisture content (MC) for treated M4 and treated SA5-1, SA5-4 bentonite is around 10%, as shown in Table 3. Moisture absorption for treated M4 is 7.69%, treated SA5-1 is 17.03%, treated SA5-4 is 20.22%. These moisture absorption values fail to meet standard bentonite, which is 30.31 %, as shown in Table 3. This moisture absorption value shows the ability of bentonite to absorb a number of water. Ignition loss for treated M4, SA5-1 and SA5-4 ranges from 7.7% to 11.2%, as shown in the table. This is due to crystal bound water and CO_2 were driven off from the samples when heated at 1000 °C for an hour.

Chemical Properties

a) Cation Exchange Capacity

From Table 4, we can see that all the CEC values of untreated Andrassy bentonite (SA5-1 and SA5-4) are much higher than Mansuli bentonite, M4. However, it is still not as good as the standard bentonite due to the high content of calcium montmorillonite.

The CEC of the wet treated Andrassy and Mansuli bentonite are also as shown in Table 4. From the table, we can see that the CEC of Andrassy bentonite samples (SA5-1and SA5-4) had been improved. The percentage of improvement is 29 % for SA5-1 sample (53 meq/100 grams) and 22 % for SA5-4 sample (66 meq/100 grams). This improvement indicates that the calcium ions on the Andrassy bentonite unit layers had been replaced by sodium ions. For M4 sample from Mansuli, no change of CEC value was indicated because of its high content of quartz mineral.

After electrolysis treatment process, CEC for M4 becomes 25 meq/100 grams, 52 meq/100 grams for SA5-1 and 66 meq/100 grams for SA5-4. When these untreated and treated M4, SA5-1, SA5-4 CEC values were compared with standard bentonite (79 meq/100 grams) failed to reach the standard minimum requirement.

b) Specific Surface

From Table 5, in is indicated that SA5-4 sample exhibits better result than other Andrassy and Mansuli bentonite samples in specific surface because of its mineral content. , it is believed that untreated SA5-4 sample contains more sodium montmorillonite than SA5-1 sample. It is known that sodium montmorillonite has larger face or planar surface of negatively charged compared to calcium montmorilonite. For sure this surface will attracts more methylene blue cationic dye, with a formula $C_{16}H_{18}N_3S^+$ than those calcium montmorillonite and causes the specific surface that determined is higher. For M4 sample from Mansuli, only minor amount of montmorillonite is detected and the specific surface is absolutely lower than other samples.

As expected, the Andrassy bentonite shows better improvement in specific surface after wet treatment (see Table 5); that is around 62.26 % for SA5-1 sample and 46.48 % for SA5-4 sample respectively if compared to M4 sample from Mansuli, with an improvement of specific surface of only 34.68 %. Meanwhile, after electrolysis treatment process yields similar results in which the specific surface area increased significantly for SA51 and SA54. This increment is appropriate when correlated with mineralogy composition, physical properties and chemical properties. However, the specific surface of these treated bentonite samples are still not as good as the standard bentonite, with a specific surface of around 819.62 m^2/g.

c) Chemical Composition

From Table 6, the silicon (Si) composition of standard bentonite seem do not satisfy the theoretical formula, so are the untreated Andrassy and Mansuli bentonite samples, which has a lower amount of silicon than suggested by Grim (1962). The aluminium (Al) of standard bentonite is 15.84 %, which is much lower than the theoretical formula and can be concluded that the aluminium had been substituted by ferum (Fe) in octahedral sheet (as high as 13.98 %). M4 sample also has the similar situation, with Al of 16.36 % and Fe of 13.39 %. As for the Andrassy bentonite, the amount of Al is ranges from 24.18 % to 29.64 %, which are higher than standard and M4 bentonite samples and seen have almost fulfill the theoretical formula. For untreated Andrassy and Mansuli bentonite samples, the calcium is the main exchangeable cation instead of sodium. M4 sample only had 0.71 % of Ca while the Andrassy bentonite samples have higher contents of Ca, which ranges from 1.71 % to 4.95 %.

After wet treatment the Si composition of treated Andrassy and Mansuli bentonite seen almost remained at the same value, which is lower than the theoretical formula due to the substitutions within the lattice in tetrahedral and octahedral coordinations. This is happened also on the Al composition of treated Mansuli and standard bentonite, which has an Al composition of 18.83 % and 15.84 %, respectively. It is believed that the Si and Al of these bentonite samples had been substituted by Fe. This kind of phenomenon is generally known as "isomorphous substitution". In addition, it is also indicated that the Na compound after wet treatment had been increased for the bentonite samples of SA5-1, SA5-4 and M4. SA5-4 sample has the highest content of Na among the bentonite samples followed by M4 and SA5-1 sample. In addition, sodium content of Andrassy and Mansuli benotnite also increased after eletrolysis treatment process, which was 3.85% to 4.99% respectively. This increment of sodium means that there is ion exchange within the bentonite interlayers, which had already been discussed before this. In addition, the exchangeable cation calcium (Ca) and sodium (Na) in the standard bentonite is considered reasonable since the amount of sodium is higher than calcium.

Performance as a Drilling Mud Material

After being treated with sodium carbonate, the Andrassy and Mansuli bentonite also had been tested for their rheological properties with refer to the required specifications. However, because of the treated bentonite samples did not satisfying the standard requirements, polymer extender had been added to the bentonite suspension. This generally caused by the limitation in montmorillonite content for the Malaysian bentonite samples, especially the Mansuli bentonite. The polymer extender had been used for this study are partially hydrolyzed poly-acrylamide (PHPA) and carboxyl methyl cellulose high viscosity (CMC HV).

a) Viscometer 600 rpm Dial Reading

The results showed in Table 7 indicated that the suspension properties of all the untreated Andrassy and Mansuli bentonite almost failed to meet the requirements that had been set by API and OCMA except for the moisture content. It can be seen that the untreated Andrassy and Mansuli bentonite sample failed to meet the viscometer 600 rpm dial reading requirement of API and OCMA specifications.

Ater wet treatment, only SA5-4 sample with the additional of 3 % of PHPA by weight can produce a promising result, which successfully meets the API and OCMA specifications. For the bentonite samples that underwent the electrolysis treatment, the specific requirement can only be achieved by SA5-4 sample with 4 % of CMC added.

b) YP/PV ratio

Although the yield point to plastic viscosity ratio for untreated bentonite is fulfill the requirements, but the viscosity for untreated local bentonite is very low. From physical indication, there are almost no gelling effects for the drilling mud prepared using untreated bentonite. This is caused by the calcium montmorillonite of Andrassy bentonite and quartz mineral of Mansuli bentonite. As we known, calcium montmorillonite have lower swelling and absorbency capacities than sodium variety and quartz is a non swelling mineral.

After treatment (wet and elecrolysis treatments), the situation is remained the same. Almost all the bentonite samples fulfill the requirement of YP/PV ratio except for the electrolysis treated M4 sample with 1 % of CMC added.

c) Fluid Loss Control

From the results, it is indicated that the fluid loss control capability of the untreated Andrassy and Mansuli bentonite are very poor and failed to meet the standard requirements. This is mainly caused by the poorer wall sealing property by the calcium montmorillonite, which is the main component of the untreated bentonite samples.

After wet treatment, it can be seen that the SA5-4 sample has a better fluid loss control capability with only a small amount of polymer was added compared to others. 0.5 % of PHPA is seemed to be enough to reduce the fluid loss of this sample. In general, if the CMC was used, a higher amount of this polymer is required for these bentonite samples to meet the specfifcations. For the bentonite samples after electrolysis, a similar situation was obtained. So, It can be concluded that the PHPA has a better abiliby to reduce the fluid loss when used as polymer extender for bentonite.

Conclusions

Based on the mineralogy, chemical and physical properties determinations, the non-sodium based Andrassy and Mansuli bentonite had been successfully upgraded to sodium variety. However, because of the limitation in montmorillonite mineral, these bentonite failed to meet the API 13A and OCMA specifications. Among the samples, SA5-4 sample is the most potential bentonite that can be used as a drilling mud material with the addition of some polymer extender.

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Table 1: Semi-quantitative analysis of untreated and treated Andrassy and Mansuli as compared to the standard bentonite

Mineral	Standard Bentonite	Untreated			Wet treatment			Electrolysis treatment		
		SA5-1	SA5-4	M4	SA5-1	SA5-4	M4	SA5-1	SA5-4	M4
Montmorillonite	****	***	***	**	***	***	**	***	***	*
Quartz	*	*	*	***	*	*	***	*	*	***
Kaolinite	*	*	*	tr	*	*	*	*	*	tr
illite	*	**	**	*	**	**	*	**	**	*
Others	tr Feldspar	* feldspar	* feldspar	* feldspar	* feldspar	* feldspar	* feldspar	* feldspas	* feldspar	* feldspar

Table 2: Comparison of the Atterberg limit between the Andrassy and Mansuli bentonite samples as compared to standard bentonite

Sample	Untreated			Wet treatment			Electrolysis treatment		
	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)
Standard Bentonite	583.12	57.64	524.48	-	-	-	-	-	-
SA5-1	68.32	32.21	36.11	219.50	50.21	169.30	192.49	35.57	156.92
SA5-4	122.84	42.36	80.48	248.50	45.83	202.70	306.95	38.90	268.05
M4	79.69	29.79	49.90	65.80	30.66	35.20	66.53	34.81	51.34

Table 3: MC, MA and IL values of untreated and treated Andrassy and Mansuli bentonite as compared to standard bentonite

Sample	Untreated			Wet treatment			Electrolysis treatment		
	Moisture Content (%)	Moisture Adsorption (%)	Ignition Loss (%)	Moisture Content (%)	Moisture Adsorption (%)	Ignition Loss (%)	Moisture Content (%)	Moisture Adsorption (%)	Ignition Loss (%)
Standard Bentonite	4.88	30.31	8.53	-	-	-	-	-	-
SA5-1	9.39	11.91	10.32	5.63	17.25	10.03	8.71	17.03	11.23
SA5-4	9.49	21.53	11.31	7.91	21.58	11.03	10.29	20.22	10.29
M4	7.39	9.51	9.31	1.69	10.85	7.51	4.9	7.69	7.69

Table 4: CEC of untreated and treated bentonite as compared to standard bentonite

Sample	Untreated	Wet treatment	Electrolysis treatment
	CEC (meq/100 g)	CEC (meq/100 g)	CEC (meq/100 g)
Standard bentonite	79	-	-
SA5-1	42	53	52
SA5-4	54	66	66
M4	24	24	25

Table 5: Specific surface of untreated and treated Andrassy and Mansuli bentonite as compared to standard bentonite

Sample	Untreated	Wet treatment	Electrolysis treatment
	Specific Surface (m^2/g)	Specific Surface (m^2/g)	Specific Surface (m^2/g)
Standard Bentonite	819.62	-	-
SA5-1	324.18	526.02	526.02
SA5-4	434.28	636.12	672.82
M4	151.69	204.29	140.68

Table 6: Chemical composition of untreated and treated Andrassy and Mansuli bentonite as compared to standard bentonite

Chemical compound	Chemical composition (% weight)									
	Standard bentonite	Untreated			Wet treatment			Electrolysis treatment		
		SA5-1	SA5-4	M4	SA5-1	SA5-4	M4	SA5-1	SA5-4	M4
Fe	13.98	7.00	3.66	13.39	6.03	3.44	12.17	6.45	11.83	9.09
Na	4.13	0.73	0.39	1.62	2.39	6.28	5.10	4.20	4.99	3.85
Mg	5.15	1.51	2.00	2.60	3.12	2.63	3.74	2.47	3.44	2.72
Al	15.84	29.64	24.18	16.36	24.41	21.41	18.83	24.54	21.72	9.82
Si	57.58	57.91	60.72	60.25	60.86	61.33	53.18	58.25	49.46	67.17
K	0.51	0.82	2.84	4.02	0.96	1.53	5.61	1.25	2.96	4.29
Ca	1.88	1.71	4.95	0.70	1.51	3.05	0.36	2.09	3.65	1.31
Mn	0.94	0.68	1.26	1.05	0.72	0.33	1.01	0.74	2.01	1.76
Total	100.01	100.00	100.00	99.99	100.00	100.00	100.00	99.99	100.06	100.01

Table 7: The suspension properties of untreated and treated Andrassy and Mansuli bentonite as compared to standard bentonite with refer to API 13A and OCMA specifications

Requirement	API 13A spec.	OCMA spec.	Std. Ben.	Untreated			Wet treatment			Electrolysis treatment		
				SA5-1	SA5-4	M4	SA5-1	SA5-4	M4	SA5-1	SA5-4	M4
Viscometer Dial Reading at 600 rpm	30, min	30, min	32	2.0	5.0	1.0	2.5	8.0	1.5	4.0	7.0	1.0
YP/PV Ratio	3, max	6, max	1.2	0.5	0.5	0.5	0.5	0.67	-0.5	0	1.3	-1
Fluid loss (cm^3)	15	16	14	64	52	114	20.5	19.5	49.0	18.0	16.0	57.0

Table 8: Suspension properties of Andrassy and Mansuli bentonite (wet treatment) with the addition of PHPA

Sample	Viscometer 600 rpm dial reading (cp)	30' Filtrate (cm^3)	PV (cp)	YP (lb/100 ft^2)	YP/PV Ratio
SA5-1 with 0.5% PHPA	6.0	18.0	3.0	0.0	0.000
SA5-1 with 1.0% PHPA	10.0	15.0	5.0	0.0	0.000
SA5-1 with 1.5% PHPA	13.0	14.5	5.0	3.0	0.600
SA5-1 with 2.0% PHPA	15.5	13.0	5.5	4.5	0.818
SA5-4 with 0.5% PHPA	9.0	14.0	3.0	3.0	1.000
SA5-4 with 1.0% PHPA	12.0	13.0	5.0	2.0	0.400
SA5-4 with 1.5% PHPA	20.0	11.5	7.0	6.0	0.857
SA5-4 with 2.0% PHPA	23.0	9.5	7.0	9.0	1.286
SA5-4 with 3.0%PHPA	30.0	9.0	10.0	10.0	1.000
M4 with 0.5% PHPA	3.0	21.0	1.0	1.0	1.000
M4 with 1.0% PHPA	4.0	14.0	2.0	0.0	0.000
M4 with 1.5% PHPA	5.5	12.0	2.5	0.5	0.200
M4 with 2.0% PHPA	8.0	11.5	4.0	0.0	0.000

Table 9: Suspension properties of Andrassy and Mansuli bentonite (wet treatment) with the addition of CMC

Sample	Viscometer 600 rpm dial reading (cp)	30' Filtrate (cm^3)	PV (cp)	YP (lb/100 ft^2)	YP/PV Ratio
SA5-1 with 0.5% CMC	4.0	19.0	2.0	0.0	0.000
SA5-1 with 1.0% CMC	7.5	17.5	3.5	0.5	0.143
SA5-1 with 1.5% CMC	10.5	17.0	3.5	3.5	1.000
SA5-1 with 2.0% CMC	13.0	15.5	5.0	3.0	0.600
SA5-4 with 0.5% CMC	10.0	18.0	4.0	2.0	0.500
SA5-4 with 1.0% CMC	13.0	16.5	5.0	3.0	0.600
SA5-4 with 1.5% CMC	15.0	15.0	6.0	3.0	0.500
SA5-4 with 2.0% CMC	21.0	12.5	8.0	5.0	0.625
M4 with 0.5% CMC	2.0	29.0	0.5	1.0	2.000
M4 with 1.0% CMC	3.0	21.5	1.0	1.0	1.000
M4 with 1.5% CMC	4.0	18.5	2.0	0.0	0.000
M4 with 2.0% CMC	5.0	17.0	2.8	-0.6	-0.214

Table 10: Suspension properties of Andrassy and Mansuli bentonite (electrolysis treatment) with the addition of PHPA

Sample	Viscometer 600 rpm Dial reading (cp)	30' Filtrate (cm^3)	PV (cp)	YP (lb/100 ft^2)	YP/PV Ratio
SA5-1 with 1.0% PHPA	8.0	13.5	4.0	0.0	0.000
SA5-1 with 2.0% PHPA	12.0	9.0	5.0	2.0	0.400
SA5-1 with 3.0% PHPA	18.0	8.0	7.0	4.0	0.571
SA5-1 with 4.0% PHPA	23.0	11.0.	8.0	7.0	0.875
SA5-4 with 1.0% PHPA	8.0	10.0	2.0	4.0	2.000
SA5-4 with 2.0% PHPA	12.0	8.5	5.0	2.0	0.400
SA5-4 with 3.0% PHPA	21.0	9.5	8.0	5.0	0.625
SA5-4 with 4.0% PHPA	26.0	8.0	8.0	10.0	1.250
M4 with 1.0% PHPA	7.0	9.0	3.0	1.0	0.333
M4 with 2.0% PHPA	10.0	9.0	4.0	2.0	0.500
M4 with 3.0% PHPA	15.0	9.0	6.0	3.0	0.500
M4 with 4.0% PHPA	19.0	9.5	7.0	5.0	0.714

Table 11: Suspension properties of Andrassy and Mansuli bentonite (electrolysis treatment) with the addition of CMC

Sample	Viscometer 600 rpm Dial reading (cp)	30' Filtrate (cm^3)	PV (cp)	YP (lb/100 ft^2)	YP/PV Ratio
SA5-1 with 1.0% CMC	7.0	14.5	5.5	3.5	0.636
SA5-1 with 2.0% CMC	8.0	12.0	3.0	-1.5	-0.500
SA5-1 with 3.0% CMC	21.0	11.5	4.0	1.0	0.250
SA5-1 with 4.0% CMC	23.0	12.5	8.0	9.0	1.125
SA5-4 with 1.0% CMC	10.0	11.0	8.0	7.0	0.875
SA5-4 with 2.0% CMC	16.0	10.5	4.0	-2.0	-0.500
SA5-4 with 3.0% CMC	24.0	10.0	6.0	6.0	1.000
SA5-4 with 4.0% CMC	33.0	9.0	8.0	10.0	1.250
M4 with 1.0% CMC	5.0	22.0	5.0	27.0	5.400
M4 with 2.0% CMC	8.0	13.0	2.0	-2.0	-1.000
M4 with 3.0% CMC	11.0	11.0	3.0	3.0	1.000
M4 with 4.0% CMC	14.0	10.0	5.0	3.0	0.600