Technical Paper 14:

DRILLING MUD MATERIAL COST SAVING THROUGH UTILIZATION OF TREATED MALAYSIAN LOCAL BENTONITE

SONNY IRAWAN[1] & ARIFFIN SAMSURI[2]

[1]Department of Geoscience and Petroleum Engineering,
Universiti Teknologi PETRONAS (UTP),
Bandar Seri Iskandar 31750, Tronoh – Perak, Malaysia

e-mail: drsonny_irawan@petronas.com.my

[2]Department of Petroleum Engineering,
Universiti Teknologi Malaysia (UTM)
Johor Bahru 81310 , Malaysia,

email: ariffin@utm.my

ABSTRACT

Based on the result of Geological Survey Department Malaysia investigation, the bentonite resources in Sabah is large. In order to reduce the overall cost in oilwell drilling and completion, the development of Sabah bentonite as drilling mud material has been initiated. Two groups of samples from the Andrassy and Mansuli area in Sabah were tested. Mineralogically the samples were characterized as low grade Ca-Mg smectite. The dominant gangue mineral is ferrous ion with small amounts of kaolinite, quartz, illite, muscovite and hematite. Iron is present as magnetite and as amorphous oxides and hydroxides. Characterization of these samples indicated that the bentonite response for Na-exchange was poor while their hydration, plastic and rheological properties were inferior to those of commercial bentonite (WY-BEN). The sample was processed by crushing followed by aero cyclone to give pre-concentrates which were extracted with diluted oxalic acid and activated with sodium carbonate. Application of such simple flow sheet effectively removed the majority of the associated ferrous ion. These concentrates were further refined by a series of organic acid and alkaline treatment prior to their evaluation as industrial bentonite. The mineralogy, chemical analysis and physical properties of final concentrates and their activated products successfully match the required specifications for drilling mud industrial processes. Utilization of these bentonite, after their extracting and activation, can represent a value added to the Sabah economy by minimizing the imported bentonite used by oil and gas industry.

ABSTRAK

Berasaskan kepada laporan Jabatan Penyiasatan Kajibumi Malaysia, negeri Sabah mempunyai sumber bentonit yang besar. Untuk mengurangkan kos penggerudian minyak, usaha untuk pembangunan sumber bentonit ini telah dimulakan. Dua kumpulan sampel daripada kawasan Andrassy dan Mansuli di Sabah telah diuji. Sampel telah dicirikan sebagai Ca-Mg Smektit bergred rendah. Mineral gang utama adalah ion ferum dengan sedikit kaolinit, kuarza, illit, muskovit dan hematit. Jenis besi adalah magnetit, oksida dan hidroksida yang amorfus. Pencirian sampel bentonit menunjukkan bahawa kapasiti penukaran natrium adalah rendah dan sifat penghidratan, plastik dan reologi nya kurang dibandingkan dengan bentonit komersial (WY-BEN). Sampel telah diproses melalui penghancuran diikuti dengan alat saiklon aero untuk mendapat prakonsentrat dan diekstrakan dengan asid oksalik cair dan natrium karbonat. Cara ini dapat mengurangkan kebanyakkan ion ferum. Konsentrat ditapiskan melalui satu siri rawatan dengan asid organik dan alkali sebelum dinilai sebagai bentonit untuk kegunaan industri. Sifat minerologi, kimia, dan fizikal konsentrat terakhir dan hasil pengaktifan adalah sama dengan spesifikasi untuk lempung penggerudian dan lempung kegunaan diproses industri. Kegunaan bentonit ini selepas diekstrakkan dan *diaktifkan boleh menambah nilai kepada ekonomi Sabah dan mengurangkan import bentonit oleh industri minyak dan gas.*

INTRODUCTION

Bentonite $(Al_{0.2693}\ Fe^{2+}_{0.7212}\ Mg_{0.1374})\ (Si_{3.5808}\ Al_{0.4192})\ X_{0.5855}\ nH_20$ is by far the most abundant of the smectite clay minerals. In drilling industry, bentonite is generally classified as sodium (Na) or calcium (Ca) types, depending on the dominant exchangeable ion. The major problems facing the utilization of Sabah bentonite is their low concentration of smectite, high level of iron contaminant and inconsistent composition. Previous studies on some Sabah bentonite suggested that, without upgrading, they were unsuitable for drilling mud material. Response of this bentonite to Na-exchange was poor and their hydration, plastic and rheological properties were inferior to that of reference bentonite [1]. Several attempts were made to upgrade to meet OCMA/API specification for drilling fluid and other industrial uses. [2,3,4]. This paper presents utilization of treated Malaysian local bentonite for drilling mud material cost saving. The tests were conducted on run-of-mine (ROM) and chemically activated samples. Chemical methods involve extracting of the mineral with organic acid and cation exchange capacity measurement.

EXPERIMENTAL WORK

BENTONITE SAMPLE

In this study, two groups of local bentonite samples were collected, namely SA5-1, SA5-3, SA5-4 and SA5-7 (N4^{0}18.97'- E 117^{0}57.37') from Andrassy area in Tawau district and M4 (N5^{0}7.35'- E118^0 12.03') from Mansuli area in Lahad Datu district. The SA5-1and SA5-3 sample were collected exactly at 0.5 m depths, SA5-4 and SA5-7 sample was collected at 1.0 – 1.5 m depths and M4 at 0.3 m depths. The field sampling from Mansuli area were taken mainly in area underlain by the Ayer Formation, which collectively form the Segama Group and is interpreted to be Miocene in age. The Andrassy area is underlain mainly by high level alluvium and volcanic rock, and occur in a bed underlying of Pleistocene to Holocene in age [1].

EXPERIMENTAL PROCEDURE

UTILIZATION PROCESS

Bentonite samples from the field were dried in the oven at 35°C for four hours until they reach a moisture content less than 10%. Then the samples were crushed using a Jaw crusher to 100% below 75 µm in size. This was followed by aero cyclone model EPC100P [5], to separate the smectite from its associating gangue minerals. Both the aero cyclone underflow (coarser than 75 µm) and the overflow fractions (finer than 75 µm) were filtered dried at 55°C and weighed. Underflow fractions, which were heavily contaminated with iron and free-silicon impurities, were discarded. Meanwhile, the overflow fractions were used as bentonite pre-concentrates. The latter products were further upgraded by extracting, their residual iron impurities, with 7.1 kg m^{-3} oxalic acid solutions for 2 hours at 80 °C temperature. The bentonite was beneficiated to improve its smectite content by removing the associated gangue minerals (mainly iron and free-silicon).

PHYSICAL AND CHEMICAL PROPERTIES DETERMINATION

Common chemical property of bentonite is pH, cation exchange capacity (CEC) and specific surface area (SSA). pH values were measured by pH meter Model Hanna H18424, following the BS1377:Part3: 1900:9 procedures. [6]. SSA was measured using methylene blue spot test [7]. In addition, the physical properties determinations include the Atterberg limit such as liquid limit (LL), plastic limit (PL) and plasticity index (PI), moisture absorption (MA), moisture content (MC) and ignition loss (IL). Methylene Blue Test (MBT) is used to estimate the CEC. A sodium-based bentonite should have a CEC value of 80 –10 meq/100 grams. Approximately 1 gram of bentonite sample was tested in 50 ml of distilled water with about 0.5 ml of 5 N sulfuric acid added. The bentonite solution was boiled gently for 10 minutes. The CEC is measured by conductomercial titration after cation exchange, in meq/100grams. The testing method for liquid and plastic limit is according to ASTM D4318-84 [8] standard. Liquid limit and plastic limit, also referred to as

Atterberg limit, depends on the moisture content of sample. The liquid limit provides the moisture content at which the clay changes from plastic to the liquid state. The plastic limit is the moisture content of a ball of clay when rolled to a diameter of 1/8 inch without crumbling. The 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 sample were also be determined since the qualitative mineral content of sample can be studied. Moisture adsorption (MA) is defined as the percentage of water lost when clay from saturated atmosphere (around 20°C) is dried in an oven at 105°C. The analysis of moisture adsorption followed the ASTM. Committee D4318-00 procedures. Moisture adsorption (MA) value can be used to predict the mineralogy of the 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. The ignition loss is the percentage of weight lost when a dried clay (at 105°C) is fired to 1000°C in a furnace.

MUD RHEOLOGICAL TESTS

In testing the rheological properties of the activated products, the suspension was re-agitated for 5 min, using a mixer, and then transferred to the viscometer at a rotor speed of 600 rpm. The readings of the viscometer were recorded at 5 min intervals until a stable reading was attained. This procedure was repeated at a rotor speed of 300 rpm. The reading of the viscometer at 600 rpm is taken as the apparent viscosity (A.V.) while the difference between the readings taken at 600 and 300 rpm represents the plastic viscosity (P.V.). The yield point (Y.P.) is calculated from the difference between the reading of viscometer at 300 rpm and plastic viscosity. Fig. 1 shows a simplified flow sheet for the beneficiation scheme. Testing of the samples as a raw material for drilling fluid was carried out according to Section 11 of the API specifications 13A. [10].

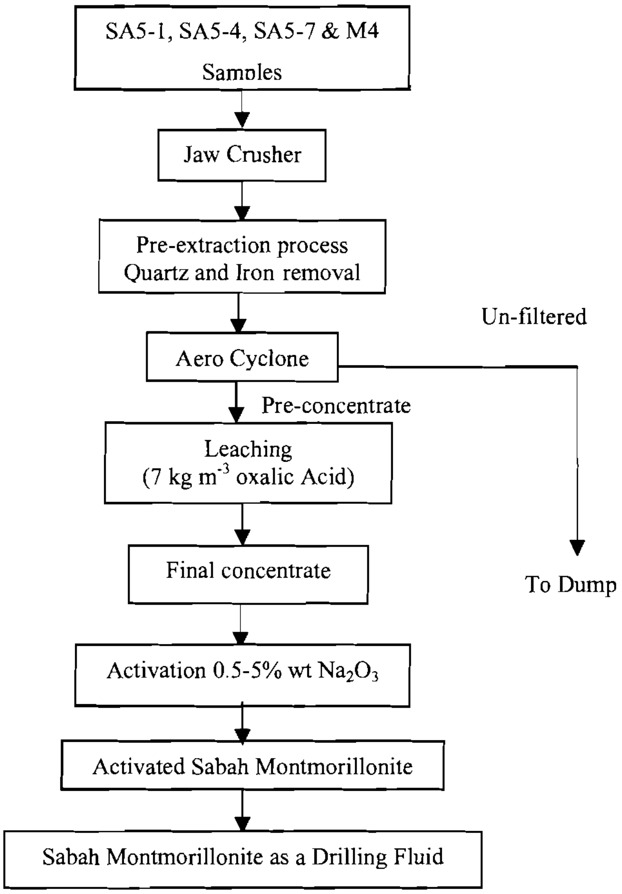

Figure 1: A flowsheet for the upgrading Sabah bentonite and its use in Drilling fluid

RESULTS AND DISCUSSION

THE MINERALOGY

From qualitative analysis (Table 1), after organic acid beneficiation, the mineral composition of the Andrassy samples changed with minor improvement (SA5-4 and SA5-7). From quantitative analysis (Table 2), the overall montmorillonite composition in the bentonite slightly changed. It is clear that the beneficiation by using oxalic acid had successfully removed iron impurities in the sample and the quantity of the montmorillonite in the samples have increased.

Table 1: Semi-quantitative analysis of beneficiated Andrassy and Mansuli samples

Mineral Composition	**Commercial Bentonite**	**Beneficiated Bentonite Samples**				
		SA5-1	**SA5-3**	**SA5-4**	**SA5-7**	**M4**
Montmorillonite	****	*	*	**	**	*
Quartz (SiO_2)	**	*	*	*	*	*
Kaolinite(($Al_2Si_2O_5(OH_4)$)	nd	*	*	*	*	tr
Illite ((K, H_3O) ($Al, Mg,Fe)_2$ $(Si,Al)_4O_{10}$)	*	*	*	*	*	*
Others	** Feldspar $KAlSi_3O_8$	* feldspar	tr feldspar	tr feldspar	nd	* feldspar

Keys: ****: dominant, ***: major, **: minor, *: appreciable; tr: trace; nd: not detect

Table 2: Quantitative analysis of beneficiated Andrassy and Mansuli samples

Montmorillonite content (%Volume)	**SA5-1**	**SA5-3**	**SA5-4**	**SA5-7**	**M4**
	43.78	47.74	53.76	53.89	44.83
Percentage of change after beneficiation process (%)	186	226	47	54	258

PHYSICAL PROPERTIES

MC, MA, IL

The MC, MA and IL results of beneficiated Andrassy and Mansuli are as shown in Table 3. It is observed that the MC for the beneficiated sample had been increased in the range of 9.92 % to 63.33 % of the original values. The beneficiated M4 sample from Mansuli area, had been dramatically increased i.e., 63.33 % of the original value because of reduced free-silicon content. It is indicated that the beneficiated SA5-3 sample has a very low MC as compared to other bentonite samples due to low water adsorption and cation exchange since its closer to plastic kaolin region. The water in the lattice of bentonite mineral is important as an agent of chemical reaction such as ion exchange and adsorption into the mineral. The mineral moisture distribution is important for the sorption characteristics because mineral with higher specific gravity are transported in solution. The reference bentonite sample shows higher moisture content and plasticity index compared to beneficiated Andrassy and Mansuli samples. The low moisture content in Andrassy and Mansuli samples was due to the low percentage of montmorillonite mineral as shown in Table 1 & Table 2. There are some improvements in MA values as shown in Table 3 due to reducing iron and free-silicon content in the samples, i.e. increment of 3.42 % to 79.26% which is still not as good as the reference bentonite. The IL values Andrassy and Mansuli samples are higher than raw bentonite sample, except for SA5-3 sample. Since the water molecules in SA5-3 sample is located within the tetrahedral and octahedral sheets of bentonite crystal structure.

ATTERBERG LIMIT

Generally, after beneficiation Andrassy samples show improvement in liquid limit with increment varying from 89.82 % to 229.63 % of the original values, as shown in Table 3. These samples also showed improvement in plastic limits, with increment varying from 0.40 % to 37.13 %. This again proved that the montmorillonite mineral plays an important role that influences the plasticity of a sample. These results show that the iron and free-silicon content as impurities in the raw bentonite decreased, but the improvement still not as good as reference bentonite. As shown in Table 3, after beneficiation, the plasticity index of beneficiated Andrassy and Mansuli sample had also been improved with increment varying from 181.78% and 582.57 %. This means that the water absorption capabilities of these samples are better than those raw one. The low percentage of bentonite mineral in the sample has resulted in lower moisture content and plasticity index.

Table 3: MC, MA and IL values and Atterberg Limit of beneficiated Andrassy and Mansuli samples

Bentonite Sample	MC		MA		IL		LL (%)		PL (%)		PI (%)	
	%	% of change	%	% of change	%	% of change	%	% of change	%	% of change	%	% of change
Reference Bentonite	16.732	-	24.51	-	5.43	-	700	-	65	-	635	-
SA5-1	12.58	33.97	21.35	79.26	11.45	10.95	259.8	165.62	55.75	6.17	204.05	266.01
SA5-3	11.99	0.42	17.62	0.46	11.25	-0.18	120.25	89.82	32.25	0.40	88	181.78
SA5-4	12.65	33.30	22.85	6.13	11.45	1.24	278.5	126.72	49.25	5.57	229.25	365.48
SA5-7	14.85	9.92	22.98	3.42	7.52	3.72	458.98	134.05	58.65	15	400.33	582.57
M4	12.07	63.33	16.4	72.45	10.287	10.49	267	229.63	40.85	37.13	226	341.32

CHEMICAL PROPERTIES

CATION EXCHANGE CAPACITY (CEC)

From the Table 4, we can see that the CEC of beneficiated Andrassy and Mansuli samples had been improved. This will have a positive impact to the hydration and swelling capability when used as a material in drilling mud. However, their CEC values still much less than the reference bentonite (CEC of 80 meq/100 g).

SPECIFIC SURFACE AREA

Specific surface area is shown in Table 4. It is clearly seen that the beneficiated Andrassy samples show some improvement in specific surface area. The treatment with oxalic acid had successfully removed iron in the sample therefore the specific surface area of all sample improved. This proved that the SA5-4 sample (640 m^2/g) is the most suitable sample as it has a specific surface area close to the reference bentonite (660.37 m^2/g). However, it is still has insufficient absorption capability since the specific surface area still not to compared to the reference bentonite due to its low content of montmorillonite mineral in the local sample. The SA5-1, SA5-7 and M4 samples also exhibit increment in specific surface area. Since there is only limited or small amount of montmorillonite mineral, these beneficiated samples still failed to reach the specific surface area of reference bentonite (660.37 m^2/g). As for SA5-3 sample, due to its low content of montmorillonite mineral an increment of specific surface area to 17 % is considered encouraging.

Table 4. CEC and Specific surface area of beneficiated bentonite sample

Bentonite Sample	CEC (meq / 100 g)			Specific Surface (m^2/g)		
	Original	beneficiated	% of change	Original	beneficiated	% of change
Reference Bentonite	80	-	-	660.37	-	-
SA5-1	30	65	54	160.11	540	70.35
SA5-3	39.5	60	34	282.20	340	17
SA5-4	27	72	64	338.40	640	47.13
SA5-7	41	68	40	253.92	400	36.52
M4	25.24	36.05	30	13.5	300	104.50

DRILLING MUD PERFORMANCE

As shown in Table 5, the beneficiated Andrassy and Mansuli sample still failed to meet the API specification 13A except for YP/PV ratio and moisture content. However, it is clearly seen that the beneficiated samples show improvement in two important parameters; viscometer 600 rpm dial reading and filtrate loss, i.e., around 380 % to 700 % of viscometer 600 rpm dial reading and, 60% to 85 % of fluid loss reduction. This generally caused by presence of impurities and low amount of montmorillonite content of the local bentonite samples, especially the SA5-3 sample. Hence, it is desirable to find a solution and the possible solution is to add some polymer extender that can improve the viscosity generated. There are two types of polymer dispersant had been used for this study; Tannathin (Ground Lignite) and high viscosity carboxymethyl cellulose (CMC). Tannathin normally used as a bentonite thinner, dispersant or as a filtration loss reducer. CMC is an example of polyelectrolyte and mainly depends on the degree of polymerization. The higher of the degree polymerization the molecular weight will be higher and can generate more viscosity. From Figure 2 and 3, the viscometer 600 rpm dial reading is directly proportional to the increment of the polymer dispersant concentration. The bentonite suspensions with Tannathin show higher value of the reading as compared to the one with CMC. This is generally because the Tannathin originally is the specific dispersant for bentonite and has a better association with the bentonite particles. From these samples, the order from the lower to higher value of viscometer 600 rpm dial reading is as followed; SA5-3, M4, SA5-7, SA5-1 and SA5-4. However, all treated bentonite samples still failed to meet the API specification 13A requirements with a maximum allowable polymer dispersant of 2 % by weight of bentonite (Ta, Dinh Vinh *et al.*, 1989). In order to determine the required dispersant concentration for the bentonite to achieve the specific requirement, the addition of more dispersant had been proceed to the bentonite sample that has the highest value of dial reading, SA5-4. From Figure 3, it is indicated that SA5-4 sample successfully reached the minimum requirement of viscometer 600 rpm dial reading (24 cp) that contributed by addition of 3 % by weight of Tannathin polymer. It is because the Tannathin have successfully hydrated and uncoiled in the suspension with the bentonite particles of SA5-4 sample.

Table 5: Suspension properties of beneficiated Andrassy and Mansuli samples

Suspension properties	API Spec. 13A, 1995 requirements	Reference Bentonite	SA5-1		SA5-3		SA5-4		SA5-7		M4	
				% of change		% of change		% of change		% of change		% of change
Viscometer Dial Reading at 600 rpm	30, min	28	14	600	10	400	24	380	22	389	20	700
Yield Point/Plastic Viscosity Ratio	3, max	1.2	1.00	203	0.525	0.00	1.10	120	1.10	340	1	100
Filtrate Volume (cm^3)	15, max	16	17	-73	20.5	-74	16	-69	16	-60	17	-85
Moisture content (% wt)	10, max	8.47	8.65	-8	8	-33	8.25	-13	8.25	-15	8	8

Table 6. Polymer used in beneficiated Andrassy and Mansuli samples

Polymer Dispersant		Viscometer dial reading		Gel (lb/100ft^2)		pH	Filtrate (ml)	PV (cP)	YP (lb/100ft^2)	YP/PV
		300 rpm	600 rpm	10sec.	10min.					
SA5-1										
Tannathin (% wt)	1.00%	4	7	0	0	8.5	18	3	1	0.3
	2.00%	6	11	0	0	8.5	15	5	1	0.2
	4.00%	10	15	0	0.5	8.5	14.5	5	5	1
CMC (% wt)	1.00%	3.5	6	1	17	8.5	32	2.5	1	0.4
	2.00%	7.5	12	0	0	8.5	24	4.5	3	0.7
	4.00%	10.5	16	0	0	8.5	20	5.5	5	0.9
SA5-3										
Tannathin (% wt)	1.00%	6	10	0	0	8.5	15	4	2	0.5
	2.00%	10	15	0	0	8.5	14	5	5	1
	4.00%	11	18	0	0	8.5	12	7	4	0.6
CMC (% wt)	1.00%	9.5	15	4	20	8.5	32	5.5	4	0.7
	2.00%	16.5	23	7	35	8.5	20	6.5	10	1.5
	4.00%	16	25	8	45	8.5	17	9	7	0.8
SA5-4										
Tannathin (% wt)	1.00%	7.5	12	0	8	8.5	14	4.5	3	0.7
	2.00%	16	23	3	12	8.5	12	7	9	1.3
	4.00%	9	14	2	10	8.5	10	5	4	0.8
CMC (% wt)	1.00%	14	19	8	36	8.5	28	5	9	1.8
	2.00%	21	28	12	38	8.5	14	7	14	2
	4.00%	19	30	15	40	8.5	15	11	8	0.7
SA5-7										
Tannathin (% wt)	1.00%	6	9	0	9	8.5	14	3	3	3
	2.00%	10	15	2	12	8.5	11	5	5	5
	4.00%	7	13	2	9	8.5	9	6	6	1
CMC (% wt)	1.00%	5.5	8	7	17	8.5	25	2.5	2.5	3
	2.00%	7.5	10	11	25	8.5	20	2.5	2.5	5
	4.00%	11	18	8	45	8.5	15	7	7	4
M4										
Tannathin (% wt)	1.00%	3	5.5	3	4	8.5	19	2.5	0.5	0.2
	2.00%	8	13	2	3	8.5	18	5	3	0.6
	4.00%	5	10	0	0	8.5	15	5	0	0
CMC (% wt)	1.00%	2	4	6.5	9	8.5	45	2	0	0
	2.00%	4	6	0	0	8.5	35	2	2	1
	4.00%	5	8	0	0	8.5	25	2	2	0.7

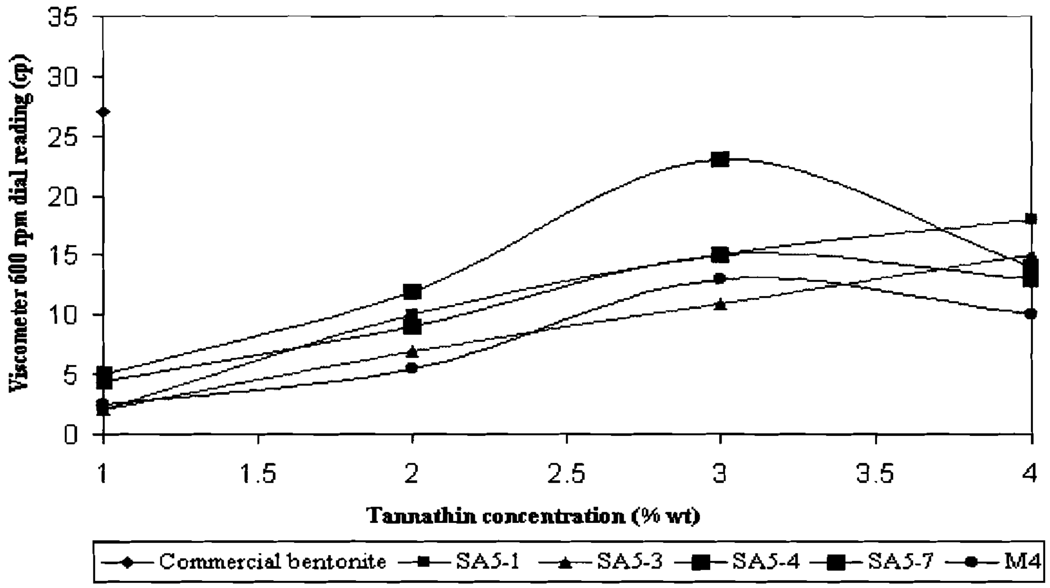

Figure 2: Viscometer 600 rpm dial reading of beneficiated bentonite suspension with addition of Tannathin

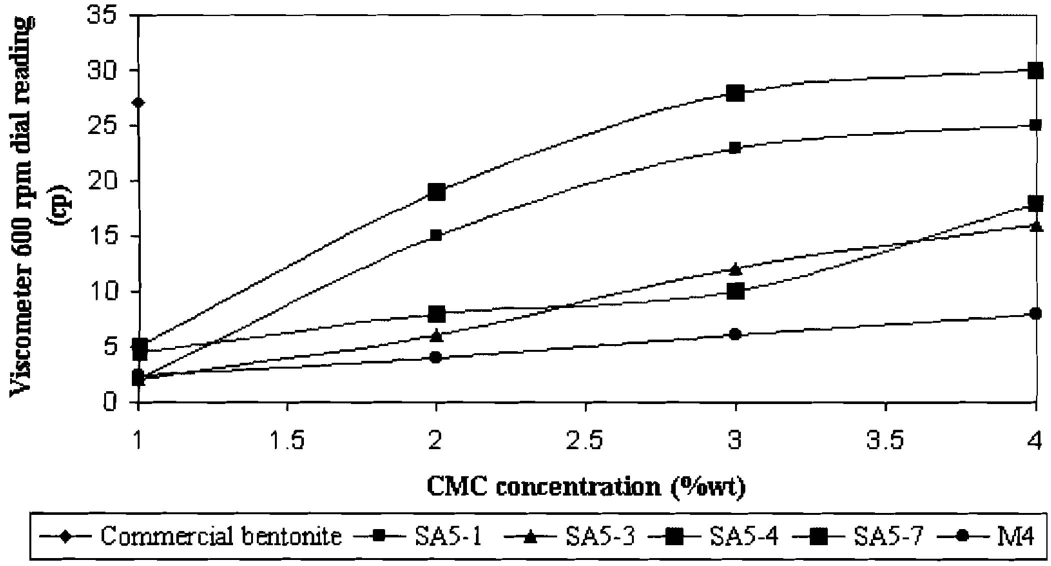

Figure 3: Viscometer 600 rpm dial reading of beneficiated bentonite suspension with addition of CMC

CONCLUSIONS

The bentonite can be beneficiated based on organic acid treatment by applying organic acid concentration of 7.1 Kg m^{-3}, pH less than 2, 80°C temperature and 2 hours stirring time. It was found that the highest CEC is 72 meq/100 g from original value of 27 meq/ 100 g. In addition, Sabah bentonite can not meet API Spec 13A of drilling mud material. The beneficiated bentonite performance as drilling mud material can be improved by 3% wt Tannathin addition.

REFERENCES

Yusairi Hj. Basiran & Yan, A.S.W., 1995, "Investigation of bentonite (montmorillonite clay) resources on The Andrassy area, Tawau, Sabah". Jabatan Penyiasatan Kajibumi Malaysia.

Aidil Mohamed Osman Hussein, 2001. "*Study Of Malaysian Local Bentonite As An Oilwell Cement Additive*". Master Thesis. Faculty of Chemical and Natural Resources Engineering, UTM, Malaysia.

Ariffin Samsuri, Radzuan Junin and Adil Mohamed Osman Hussein, 2001. "The Utilization of Malaysian Local Bentonite As An Extender And Free Water Controller In Oil-Well Cement Technology". *SPE paper no. 68674.*

Zanariah Mohamed, 2000. "*Kesesuaian Bentonite Lahat Datu Sebagai Bahan Tambah Lumpur Penggerundian Menggunakan Proses Rawatan Natrium*". Bachelor Thesis, Faculty Chemical and Natural Resources Engineering. UTM, Malaysia.

Koch, W.H., and Licht, W., 1979. "New Design Approach Boost Cyclone efficiency". *Chem. Eng.* (84) : 79-89.

British Standards Institution,1990. *"Part.3:9.0. pH Analysis"*. London: BS1377.

Santamarina J.C., Klein K.A., Wang Y.H. and Prencke E. 2002. *"Specific Surface: Determination and Relevance."* Canada: Canada Geotech Journal (39): 233 - 241.

ASTM D4318-84, 1993. "Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils." U.S.A.: American Society for Testing and Materials.

ASTM. Committee D4318-00 on Soil and Rock, 2001. "ASTM Standards Test Method for Moisture Content, Moisture Absorption and Ignition Loss of Soils." United States.

American Petroleum Institute, 1993. *"Specifications for Drilling Fluids"*. Spec. 13A, 10th edition: 1–3.