Rheology of modified water based Isinya and Amboseli Clays: Effect of sodium carbonate and sodium carboxymethylcellulose.

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Abstract

Two Kenyan state owned entities are investing heavily in geothermal power exploration in Rift valley, to find enough steam for developing geothermal plants with capacities of up to 10,000 MW. This will require more than 1,000 wells to be drilled using Bentonite as a drilling mud. The aim of this study is to evaluate the suitability of six different samples of bentonite from two different geographical regions (Isinya and Amboseli) in Kenya, for possible use in well drilling in their raw and modified forms. Particle – particle interactions in the clay suspensions was considered in the study of the rheological properties. The samples were modified with Na_2CO_3 *(reduce the amount of calcium) and CMC (reduce the amount of water lost to the formations) in various concentrations. It was observed that flow properties (apparent and plastic viscosity, shear stress and yield point) changed depending on the clay source, additive chemical composition and concentration.*

Keywords: Bentonite, Rheology, Carboxymethylcellulose, Viscosity, Sodium carbonate, Shear stress

I. INTRODUCTION

THE weathering process of volcanic ash leads to formation of Bentonite clays from the parent rocks that change their occurrence due to climatic change, topography, vegetation and exposure period [1, 2]. This clay exists either as sodium or calcium montmorillonite, primarily composed of smectite minerals [3]. Sodium based bentonite swells relatively more than calcium based bentonite since it has a higher hydration of its ions, [4] and its ions are more dominating than those of calcium [5]. Natural occurrence of clays in varying physical and chemical structure enables them to have a wide range of industrial applications [6].

Bentonite is widely used in drilling applications because of its high viscosity, swelling capacity and low filtration loss. In most cases, the quality of sodium bentonite may not have the required physical and rheological properties to be used as a drilling mud in its natural occurrence.

Analysis of the rheological properties is vital in determining the deformation and flow of the drilling fluids. This process is also relevant during design and process evaluation, quality control, and storage stability of bentonite [7]. A number of modifiers have been utilized in bentonite suspensions to regulate its rheological properties to meet the required specifications for different applications [8]. The process of using additives (modifiers) and activating raw bentonite with alkali viscosifies and reduces the fluid loss to the formation. The increase in viscosity creates higher chances for the sodium-calcium and calcium bentonites to meet the drilling application [9]. Some of the additives used in the activation process of sodium-calcium and calcium bentonites include soda ash, caustic soda, bicarbonate of soda (calcium reducers, acidity or alkalinity change) sodium carboxymethylcellulose (filtrate reducers) [10], which gives adequate properties for drilling applications.

Kenya has a geothermal installed capacity of 249 MW (1.92% of the World's geothermal installed capacity) which is generated from less than 100 drilled wells. This capacity is projected to rise to 5,000 MW (to be generated from 1,400 wells) by the year 2030 [11]. This will create investment opportunities in geothermal development, supplies and service sectors. Therefore, there is need to invest in local and relatively low cost drilling material which will lower the cost of geothermal power generation. In this study, the rheological properties of two types of bentonite clays (with varying Na^+/Ca^{+2}) sampled from two different regions (Isinya, and Amboseli) were evaluated for their suitability in the geothermal well drilling application as a drilling mud.

Currently, very little work has been done in exploiting the existing Kenyan bentonite clays for geothermal and oil wells drilling applications [12-14]**.** Therefore the oil and geothermal exploration in Kenya relies fully on imported bentonite from China and India to support the drilling activities. The success to be realized through this study will enable the country to reduce importation costs, create employment opportunities to the rising educated population, conserve foreign exchange and reduce power cost due to reduced cost of production.

II. MATERIALS AND METHODS

A. Geology

The local bentonite samples (greenish greyish in colour) for this study were collected from two different geological sites in Kenya which included Isinya, and Amboseli as shown in Figure 1. Isinya area lies on Athi plains which are on the southern part of Athi River town. It is located on the latitude 258 379E and longitude 9 822 231N. This is a dry and hot area experiencing occasional heavy rainfall within the year. Bentonite clays in this area mainly occur on the upper Athi Tuff formation that was formed from the volcanic ash, into the paleolake basin and concentrating on the riverine channels [13].

The geological report of Kajiado area indicates that bentonite deposit beds vary between 1-4 metres in association with gypsum, silicified lithic and limestone. Amboseli area borders the Kajiado County, hence shares the climatic conditions with Isinya area. It lies on the latitude 310 537E and longitude 9 706 460N near the Tanzanian border, below the snow-capped Mt. Kilimanjaro (volcanic). In an unpublished report of the Mines and Geological department, Nairobi Kenya, the occurrence of bentonite clay in Amboseli basin was observed citing its origin to volcanic origin. Consequent examination of the clay and surface limestone showed that montmorillonite appeared to be the most significant. Its expansion and contraction was attributed to the wet and dry seasons experienced in the area [15].

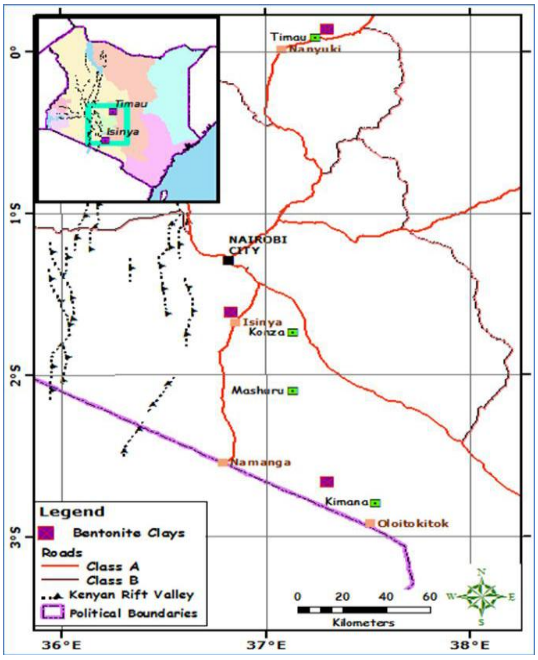

Fig. 1 Geographical representation of the sampled regions

B. Materials Preparation

Two different types of bentonite from two different geographical sites (Isinya and Amboseli) in Kenya were used in this study. Six samples (three samples from each region) of 3 kgs each were randomly collected from three different regions and packed separately in 5 kgs bags. The samples were dried in the hot sun and crushed using a Retsch RS-200 pulveriser at a speed of 150 rpm for 15 minutes and sieved through 90 µm mesh size laboratory sieve mounted on a sieve shaker machine to improve the surface area during analysis.

Moisture content was determined to establish the level of samples dryness by heating the samples at 110 ^{0}C and determining the mass loss gravimetrically. The samples were repackaged in zipped plastic bags of 1 kg weight that prevented any moisture entry, awaiting for different tests to be carried out. The samples were labelled as IS-1 (location 1), IS-2 (location 2), IS-3 (location 3), AM-1 (location 1), AM-2 (location 2), and AM-3 (location 3).

The chemical analysis of Isinya and Amboseli clays is shown in Table 1, with silica and alumina as the main contents. Isinya and Amboseli samples can be classified as Ca-bentonite with average Na^+/Ca^{+2} ratios of 0.700 and 0.322 respectively. Isinya average Na^+/Ca^{+2} ratio was close to Na-bentonite as confirmed in the previous research work [7].

C. Rheological Properties

Two mud samples suspension were prepared by adding varying weights 2g (10%), 3g (15%), 4g (20%), 5g (25%) and 6g (30%) of sieved (90 µm) powders in 20 ml of distilled water. Homogenization of the mixture was done using Heindolph MR 3001 K magnetic mixer at 400 rpm for 20 minutes, and allowed to stay for 16 hours at room temperature before test. Shear stress (τ) and shear rate (γ) were determined using Rheolab QC equipment and Physical Rheoplus software at ambient temperature (19 ^{0}C), varying the rotor speed from 1 – 776 rpm [8].

The API Recommended practice of Standard procedure [16] for field testing drilling fluids was utilized in determining the apparent viscosity, plastic viscosity and yield point by considering the 300 and 600 rpm readings.

Apparent viscosity (μ_a) = $\phi_{600} / 2$ (cP)
Plastic viscosity (μ_p) = $\phi_{600} - \phi_{300}$ (cP)
Yield point (y_p) = $\phi_{300} - \mu_p$ 0.5 N/m^2

III. Results and Discussion

A. Characterization

From the moisture content analysis, it was established that Isinya, and Amboseli samples contained an average moisture content of 14.3 %, and 15.6 % respectively. The moisture content levels of the two clays were found to match well with the standard level of 15 % [17].

TABLE I: CHEMICAL COMPOSITION OF THE RAW SAMPLES.

Samples / Oxides	AM-1	AM-2	AM-3 (Mass %)	IS-1	IS-2	IS-3
Al_2O_3	11.89	11.9	13.14	20.53	20.46	20.40
BaO	0.08	0.08	0.08	0.14	0.14	0.15
CaO	10.67	8.84	6.76	5.00	4.95	5.01
Fe_2O_3	5.30	5.19	5.33	9.05	9.01	9.00
K_2O	4.19	4.22	4.71	1.60	1.63	1.63
MgO	6.39	6.55	6.36	2.12	2.13	2.17
MnO	0.08	0.07	0.07	0.06	0.05	0.05
Na_2O	2.71	2.68	2.77	3.52	3.47	3.48
P_2O_5	0.09	0.05	0.07	0.06	0.06	0.06
SiO_2	56.81	56.99	59.96	52.77	52.78	53.05
SO_3	0.08	0.11	0.09	3.41	3.43	3.43
TiO_2	0.83	0.78	0.84	0.97	0.96	0.96
Total	99.12	97.46	99.18	99.23	99.07	99.39

B. Rheological analyses

Figure 2 represents the effect of varying concentration on viscosity of the analysed sample suspensions. From the results, it was observed that an increase in sample concentration led to an increase in viscosity. Isinya samples gave an increase in viscosity from 15.0 wt. % to 30.0 wt. % (pseudoplastic behaviour) of the varied concentrations than Amboseli samples which increased from 20.0 wt. %, At 30.0 wt. %, all the samples exhibited a significant increase in viscosity as compared to other solid concentrations.

Figures 3 and 5, present the shear stress (τ) versus shear rate (γ) curves for Isinya, and Amboseli samples respectively. The graphs obtained indicated that the samples had yield point, and corresponded well with typical flow curves of Bingham model used to describe the rheological behaviour of bentonite clays [18]. It was observed that Isinya samples attained a maximum average strength (extrapolation of linear portions of Fig. 3 curve to $\gamma = 0$) as compared to Amboseli (Fig. 5) samples, hence giving a relatively higher yield stress which is suitable for drilling application. The significant yield stress developed in the high concentration suspensions was associated with the occurrence of the interconnecting three dimensional networks of flocs [7]. From the previous work [19] it was confirmed that the number and the strength of particle-particle linkages determined the yield point of the analysed suspensions. It was also observed that the shear stress in Amboseli (Fig. 5) samples changed at relatively high rate beyond the 710 S^{-1} shear rate as compared to Isinya samples, which may be attributed to varying homogeneity due to particle segregation in the concentrates. The change of viscosity of Isinya (Fig. 4), and Amboseli (Fig. 6) samples as a function of shear rate, shows a decrease of viscosity at lower levels of shear rate. All the analysed samples showed pseudoplastic behaviour at high solid concentration as represented in Figures 4 and 6. In these flow curves, there was a progressive decline in viscosity at low shear rate (linked to continual destruction of networking structures), but as the shear rate increased further, there was a constant viscosity. Figure 7 was used to compare the shear stress of 6g of IS-3, and AM-3 samples. It was observed that Isinya sample had the highest yield point compared to Amboseli samples. This implies that Isinya sample requires relatively more applied stress to deform its resisting solid particles than Amboseli samples. Figure 8 shows the comparison in progressive decline, further increase and constant viscosity of 6g of IS-3, and AM-3 Isinya sample exhibited a significant increase in viscosity at the same solid concentration as Amboseli samples, hence bringing about an increase in almost all the rheological properties [7].

In Figure 9, different concentrations of Na_2CO_3 (0.5g, 1.25g and 2.5g) were used in converting the Ca-bentonite to Na-bentonite. It was observed that an increase in Na_2CO_3 led to a decrease in the viscosity of the suspensions. This might have occurred due to ion exchange of the original Isinya bentonite (Ca-bentonite) to Na-bentonite by Na_2CO_3 modification, hence changing the dispersion behaviours of Isinya bentonite after the activation process.

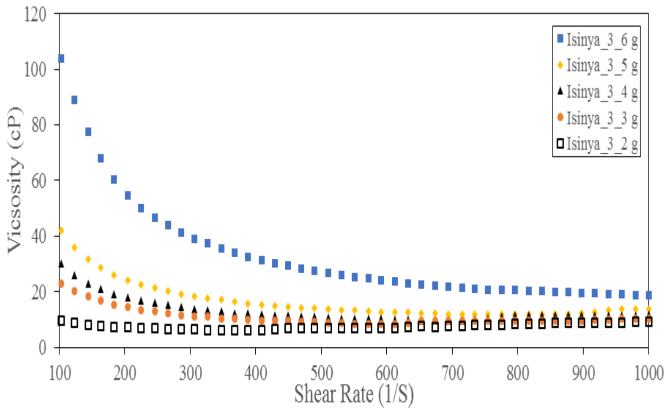

Fig. 2. Viscosity vs. Shear Rate for Isinya 3 samples at varying solid concentrations.

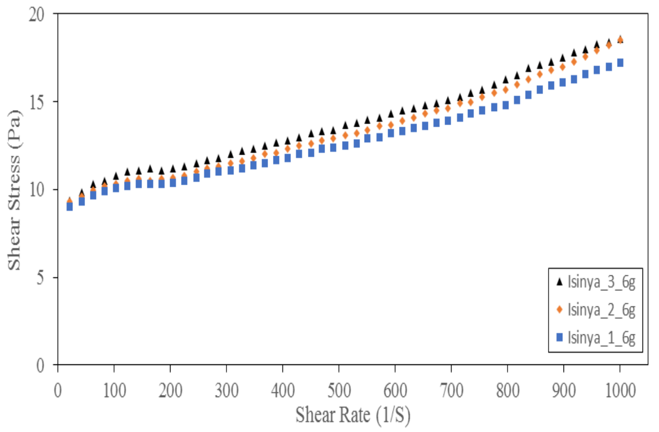

Fig. 3. Shear Stress vs. Shear Rate for Isinya Samples at constant solid concentrations.

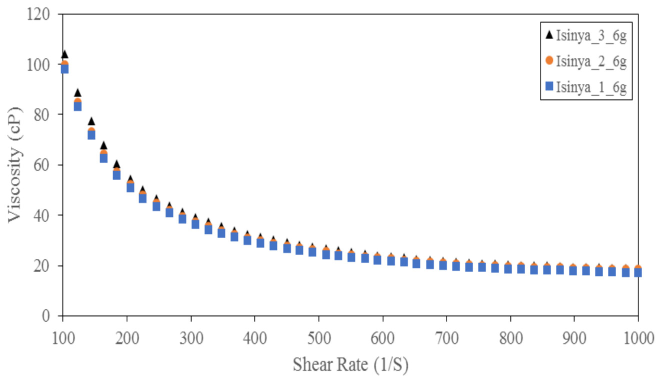

Fig. 4. Viscosity vs. Shear Rate for Isinya samples at constant solid concentrations.

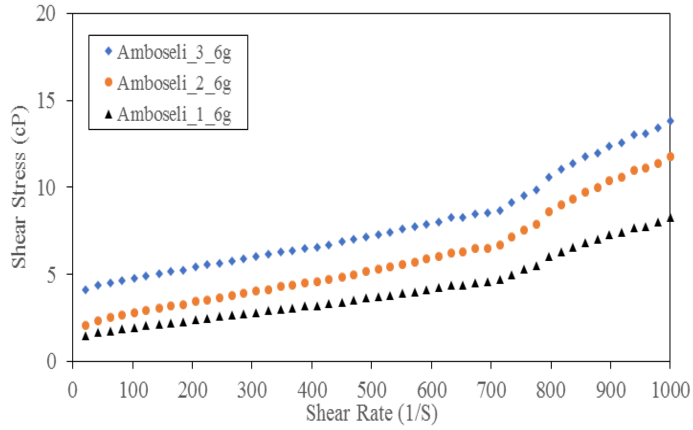

Fig. 5. Shear Stress vs. Shear Rate for Amboseli Samples at constant solid concentrations.

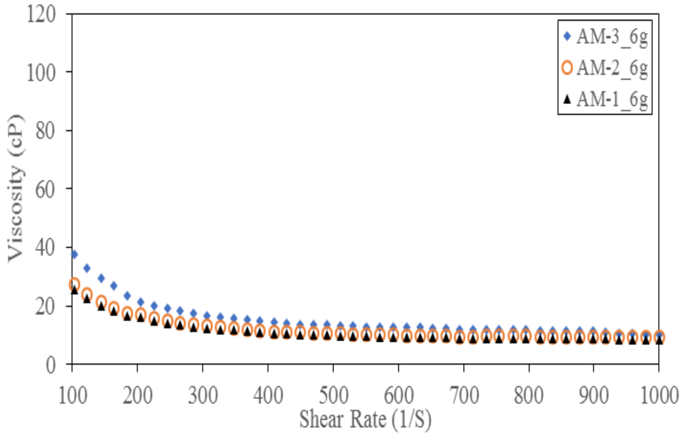

Fig. 6. Viscosity vs. Shear Rate for Amboseli samples at constant solid concentrations.

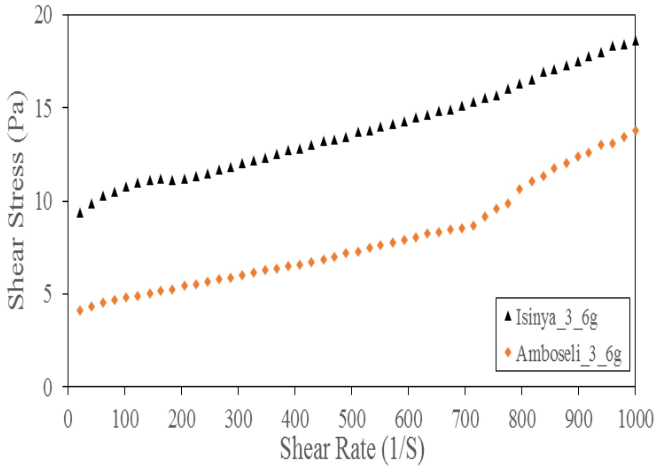

Fig. 7. Shear Stress vs Shear Rate of Isinya and Amboseli Samples

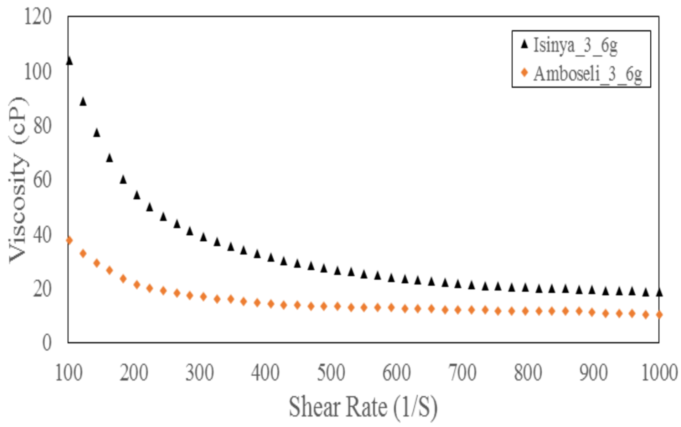

Fig. 8. Viscosity vs Shear Rate of Isinya and Amboseli Samples.

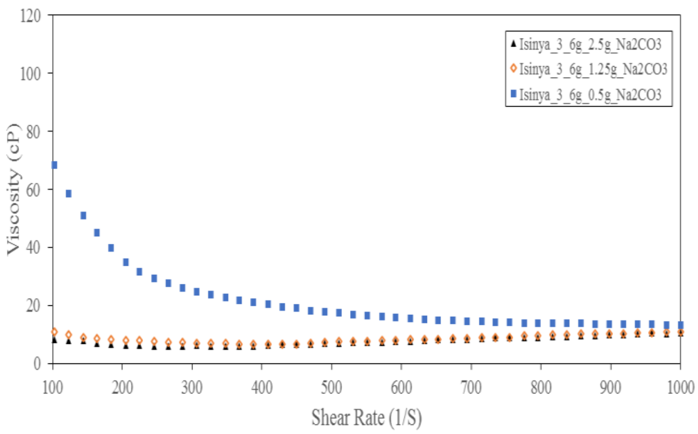

Fig. 9. Viscosity (cP) vs Shear Rate of Isinya 3 modified with varying concentrations of Na_2CO_3

Table II shows the rheological properties of varying concentrations of Isinya bentonite in water. There was increase in apparent viscosity and yield point but minimal increase in plastic viscosity. For effective control of total solids in drilling application [8], 30 g/l of Isinya and Amboseli bentonites were considered for further analysis due to less required quantities. Modification of the samples was done with several concentrations of Na_2CO_3 (2.5 g, 6.25 g and 12.5 g). Its effect on the rheological properties of 30 g/l (6% w/v) of Isinya and Amboseli bentonite-water suspension is shown in Tables III and IV. A decrease in apparent viscosity, plastic viscosity and yield point was observed. This is attributed to the change in dispersion behaviours as discussed earlier. In this case further modification was required to improve the rheology of the clays, hence CMC was considered.

CMC is a carbohydrate polymer consisting of some hydroxly groups of the glycopyranose monomers that make up the cellulose backbone [20]. Tables V and VI depicts the effect of CMC on the rheological properties of 10 g/l Na_2CO_3 and 30 g/l of Isinya and Amboseli bentonite-water suspensions respectively. An increase in apparent viscosity, plastic viscosity and yield point was observed with an increase in concenration of CMC. This is attributed to the introduction of hydrogen bonding of hydroxyl groups of CMC with the sampled clays (Isinya and Amboseli). The CMC improved the dispersion rate of the clays, hence increasing its rheological properties.

TABLE II: EFFECT OF CONCENTRATION OF BENTONITE (ISINYA) ON RHEOLOGY OF BENTONITE-WATER SUSPENSION.

Conc. of Bentonite (g/l)	Apparent Viscosity (cP)	Plastic Viscosity (cP)	Yield Point (N/m^2)
10	4.07	1.00	5.50
15	4.76	1.00	9.44
20	5.55	1.00	11.6
25	5.90	4.00	13.8
30	11.30	10.2	27.5

TABLE III: EFFECT OF CONCENTRATION OF Na_2CO_3 ON RHEOLOGY OF 30 g/l (6% w/v) BENTONITE-WATER SUSPENSION (ISINYA).

Conc. of Na_2CO_3 (g/l)	Apparent Viscosity (cP)	Plastic Viscosity (cP)	Yield Point (N/m^2)
2.50	6.09	3.05	17.84
6.25	4.74	1.84	8.95
12.50	3.89	1.54	8.55

TABLE IV: EFFECT OF CONCENTRATION OF Na_2CO_3 ON RHEOLOGY OF 30 g/l (6% w/v) BENTONITE-WATER SUSPENSION (AMBOSELI).

Conc. of Na_2CO_3 (g/l)	Apparent Viscosity (cP)	Plastic Viscosity (cP)	Yield Point (N/m^2)
2.50	1.99	1.08	4.53
6.25	1.92	1.02	4.32
12.50	1.63	0.96	3.73

TABLE V: EFFECT OF CONCENTRATION OF CMC ON RHEOLOGY OF 10 g Na_2CO_3 AND 30 g/l (6% w/v) OF BENTONITE-WATER SUSPENSION (ISINYA).

Conc. of CMC (g/l)	Apparent Viscosity (cP)	Plastic Viscosity (cP)	Yield Point (N/m^2)
1.00	7.00	3.08	15.54
1.55	8.24	4.24	18.62
2.00	9.68	4.98	21.85
2.50	10.94	6.58	25.17

TABLE VI: EFFECT OF CONCENTRATION OF CMC ON RHEOLOGY OF 10 g Na_2CO_3 AND 30 g/l (6% w/v) OF BENTONITE-WATER SUSPENSION (AMBOSELI).

Conc. of CMC (g/l)	Apparent Viscosity (cP)	Plastic Viscosity (cP)	Yield Point (N/m^2)
1.00	3.20	2.56	7.68
1.55	4.78	3.74	11.43
2.00	5.86	3.98	13.71
2.50	7.44	5.26	17.51

IV. CONCLUSIONS

Based on the chemical analysis of Isinya, and Amboseli samples, it was confirmed that the samples contained montmorillonite. The investigated clays were found to have better characteristics to fulfil the fundamental swelling conditions. And could, hence be considered a suitable replacement of imported bentonite in drilling application. The swelling capacity to be achieved from the analysed mud formulation will now depend on the Na+ available, which has the ability to absorb enough water to form viscous suspension [21].

From the rheological analysis, a pseudoplastic behaviour was experienced from 15.0 wt. % solid concentration of Isinya clay as compared to Amboseli samples (as from 20.0 wt. %). It was established that Isinya samples gave the best and consistent rheological properties, since the earliest transition to non-Newtonian behaviour was experienced before Amboseli samples. The conversion of the analysed samples from Ca-bentonite to Na-bentonite by use of Na_2CO_3, led to a decrease in the rheological properties of the clays. Further modification of the clays with CMC produced relatively favorable rheological properties. For excellent use in drilling application, Isinya sample was most preferred as compared to Amboseli.

This work has provided information on the different types of bentonites from different regions in Kenya and their flow characteristics. It has also determined the level of modification required in drilling application.

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