COMPARATIVE ANALYSIS IN PHYSICO-CHEMICAL PROPERTIES OF LOCALLY AVAILABLE BENTONITE AND IMPORTED WYOMING BENTONITE USED IN GEOTHERMAL DRILLING IN KENYA

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Abstract

Kenya's economy like other economies in the world relies heavily on electric power for industrial development. Due to ever increasing demand for energy, efforts towards more energy production have been given priority. This has been hampered by impacts of climate change worldwide which has led to the diversification in investments in both renewable and non renewable energy sources. The energy sector is currently attracting a lot of focus due to its critical role in driving economic development. Geothermal is one of the renewable energy sources available for electric power generation in Kenya. Most of the drilling equipment and consumables in geothermal drilling are imported; these includes drilling bits, drilling rods, drilling rigs and Bentonite (drilling mud). These increases the drilling costs and eventual costs of electricity to the consumer. There is need to look for ways of reducing costs that are involved in the drilling of geothermal resources by obtaining materials locally. The objective of this study was to assess the suitability of local Bentonite which can be used as a drilling mud in geothermal development in Kenya. This involved a comparative analysis of the physico-chemical properties of imported Wyoming Bentonite and local Bentonite. Samples were collected from the Parminters and the Krigers field in the Lewa Wildlife conservancy and were analysed in laboratories at the Kenya Electricity Generating Company in Olkaria Naivasha, Ministry of Natural resources and the Ministry of Public works. The tests carried out were; on trace metals, specific gravity and cation exchange capacity. The study results show that there was no difference in physico-chemical properties between the local Bentonite and the imported Wyoming Bentonite. The study recommends that geothermal drilling operations in Kenya should substitute the imported Bentonite for local Bentonite to save on drilling costs.

Key words: Bentonite, climate change, geothermal, trace elements

1.0 Introduction

In Kenya the energy policy was conceived with the appreciation that the overall national development objectives of the government are accelerated economic growth and rising productivity of all sectors. The realization of these objectives is only feasible if quality energy services are made available in a sustainable, cost effective and affordable manner to all sectors of the economy. Energy is the basic building block for industrial development and future economic growth crucially depends on the long-term availability of energy in increasing quantities from sources that are environmentally friendly and socially acceptable.

Electricity demand in Kenya has continued to grow steadily over the years and has caused great pressure on the conventional sources of energy. There is need for Kenya to exploit the geothermal resource mainly located in the Rift Valley for electricity generation as it will help to ease the need for fossil fuels thereby combating climate change. Drilling for geothermal resource in Kenya uses Wyoming Bentonite from the United States of America. This importation of materials makes the exploitation of this resource expensive and electricity is unaffordable to majority. Due to these reasons the physico-chemical properties local bentonite deposits were analysed and compared to the Wyoming Bentonite. The samples were collected from the Parminter and Krigers (Figure 1) and subjected to test on trace elements, specific gravity and cation exchange strength after the field and physical properties. Total rock analysis whose data has been used to plot a graph of silicon oxide against the total oxides is also determined. The results discussed did not show any significant difference as compared to the Wyoming Bentonite used currently. Through this study results it is been recommended that the local Bentonite can be used for drilling at Olkaria geothermal prospects substituting the imported Wyoming Bentonite and therefore reduce drilling costs to make electric energy affordable.

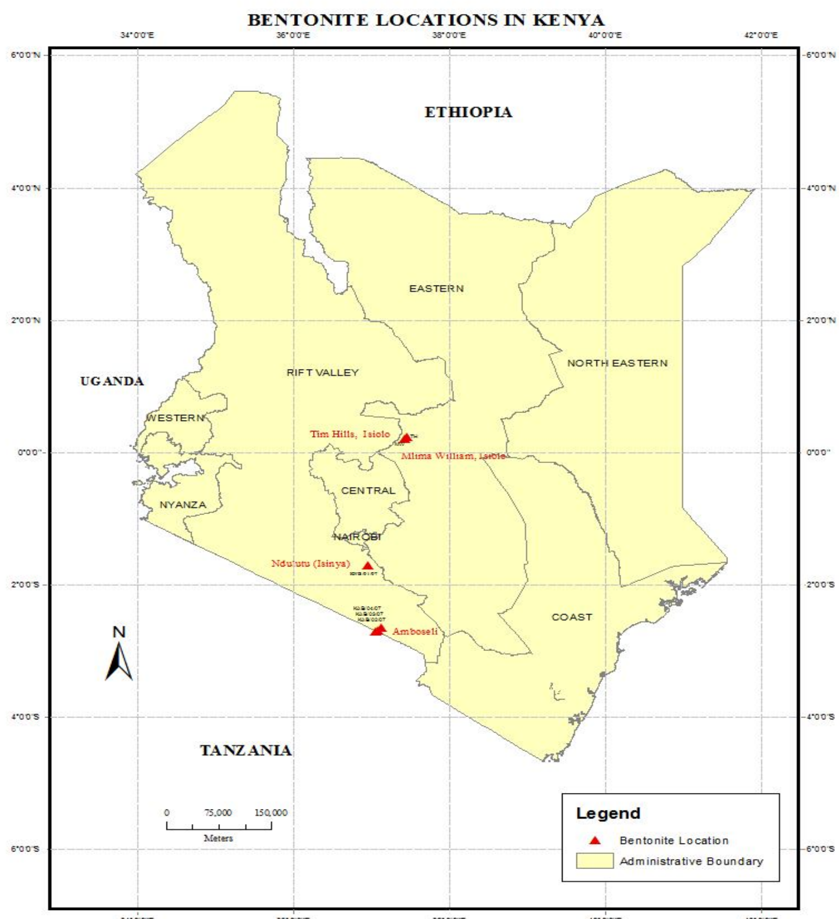

Figure 1: Parminters and Krigers Location (Tim Hills and Mlima Williams)

2.0 Materials and Methods

The materials and methods involved in an attempt to achieve the objectives of this study included consistency limits determination(Atterberg limits), X-ray Diffractometry test, Petrochemisry test, trace metals, specific gravity and cation exchange capacity determination. Atterberg limits procedure was carried out specified by Albert Aterberg and refined by Arthur Casagrade uses a standard "Liquid Limit Device, which drops a shallow cupfull of soil 1 cm consistently. When a groove cut through the sample closes 1/2", the number of drops is recorded and a moisture content sample processed. Repeating the procedure for a total of four drop-count ranges provides enough data to plot on a semi-log scale.

X-Ray Diffractionmetry technique as discovered by Max von Laue, 1912 was applied to characterize the crystalline material, which was done using Shimadzu D6000 X-ray Diffractometer located at KenGen's laboratories. The procedure included nine tenths of a gram of the material, as pure as possible and grounding of the sample to a fine powder, typically in a fluid to minimize inducing extra strain (surface energy) that could offset peak positions, and to randomize orientation. This was placed into a sample holder or onto the sample surface (Figure 2.)

Figure 2: Sample Preparation

The specimen is smeared uniformly onto a glass slide, assuring a flat upper surface and packed into a sample container then sprinkled on double sticky tape.

The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample.

Figure 3: XRD machine at Kengen geothermal laboratory

1) Trace Metals, Specific gravity, Cation Exchange capacity and Petro chemistry test which gave total rock analyses of clay samples. This was carried out to obtain the bulk chemical composition of the samples that would be necessary in determining the characteristics of the clay deposits. The test was carried out according to API specifications 13A section 4, Fourteenth Edition requirements. Only the major elements were analyzed alongside the Wyoming type to allow for comparisons. The Petro chemistry analysis and specific gravity were carried out at the Ministry of Environment and Natural Resources, Mines and Geology Department, Nairobi whereas Trace metals and Cation Exchange were done at Ministry of Public Works Mineral Branch at Industrial Area.

3.0 Results and Discussions

2) The results constituted of field properties and physical properties as given on Table 1. The moist density of local bentonite falls within a narrow range of 14.89 – 16.44 kN/M^3. Moisture content of the analyzed samples fell in the range of 58.2 - 67.87 per cent. The Wyoming type has its value in this range. This shows that a clear trend is evident in the Kenyan samples. Dry density values for the samples fall in the narrow range of 9.22-11.57 kN/m^3. The Wyoming type has a dry density of 9.36 kN/m^3.

Table 1: Field and physical properties

	Field properties			Plasticity			Swell
Sample number	Moist density (*k*N/M^3)	Moisture content (%)	Dry density	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Swell pressure (*k*N/M^3)
PBJ1/06/11	16.12	58.2	10.17	145	54	91	211
PBJ2/06/11	15.55	60.0	9.90	170	52	120	120
PBJ3/06/11	16.40	64.9	11.57	120	58	62	40
KBJ1/06/11	14.89	60.4	9.22	110	57	53	40
KBJ2/06/11	15.49	64.3	11.04	98	48	49	50
KBJ3/06/11	15.92	67.87	10.13	119	54	65	60
WBJ/06/11	15.59	66.9	9.36	157	58	100	176

Wyoming Bentonite has liquid limit of over 157 per cent which is much within the range for that of Parminters (145-170 per cent). The limit for Krigers is found low than that of Wyoming at only (110 -120 per cent). The plastic limit for the wyoming bentonite is generally in the range with the Kenyan bentonites, one sample from Perminters has a similar value at 58 per cent. The plasticity index (PI) defines the complete range of plastic state. The Wyoming bentonite indicates PI of 100 per cent while all the Kenyan samples have values in the range of 49 and 120 per cent respectively. The Wyoming bentonite has a high swell capacity at 176 kN/m^3. One Parminters sample has a higher value at 211 kN/m^3 while the Krigers sample is moderate in capacity at 120 *k*N/m^3.

X-Ray Diffractionmetry test as given in Table 2 indicate that montmorrilonite is the dominant clay mineral in the Parminters and Krigers deposits, other clays identified in the deposits include illite, chlorite, interlayered illite smectite, smectite illite, and kaolinite. Other gangue minerals include calcite, quartz and gypsum. The results further indicate that the montmorrillonite content of deposits in Krigers is high. Illite and interlayered smectite-illite is also significant.

Table 2: X-ray D-spacing values and Interpretation

Reference number	Air dried (D-spacing)	Glycolated (D-spacing)	Heated to 550 °C (D-spacing)	Interpretation
Krigers-1	20.03(16),18.04(38),16.91(55),15.96(74),15.11(89),14.49(80),13.78(79)	20.44(19),16.29(91),10.14(37), 7.66(32)	11.24(16), 10.10(78), 7.35(6)	Montmorillonite, illite, smectite,/illite, chlorite, kaolinite,
Parminters-1	15.85(11),15.37(11),14.77(12), 10.22(7),7.65(100)	24.64(14),22.03(22),19.58(49), 18.48(54),17.76(57),16.21	10.57(43),10.07(82)	Montmorillonite, illite, kaolinite, chlorite
Krigers-2	12.48(10),10.37(17),13.52(75), 14.96(97)	10.11(10),11.15(10),13.92(5)	10.69(17), 13.87(39)	Montmorillonite, smectite,/illite, illite
Perminters-2	12.32(100),10.45(42), 13.90(37)	12.54(100),10.35(48), 14.37(100)	12.21(67), 10.45(100)	smectite,/illite, illite, Montmorillonite
Krigers-3	12.38(81),10.55(100)	14.96(9),12.69(67),10.56(100)		Chlorite, smectite,/illite,illite
Perminters-3	13.57(19),12.73(19),10.32(37)	10.31(23)	13.57(30),12.84(23),10.47(91)	smectite,/illite, illite
Krigers-4	15.86(100),10.62(5)	18.36(100)	10.32(95), 11.61(50)	Montmorillonite
Perminters-4	16.32(100),11.89(15), 10.32(3), 7.55(5), 5.94(5)	18.01(100),11.52(12), 10.03(12),8.99(18), 7.27(18), 6.80(6), 6.26(24), 5.99(24)	13.70(14), 11.70(57), 10.68(100), 6.49(7)	Other than the chlorite indicator in the heated sample 13.70 (14), the air dried and the
Krigers-5	24.47(14),16.37(100), 14.21(95),12.45(50), 10.88(12), 9.12(5), 6.64(5)	17.36(100),13.00(67), 11.49(1),10.35(67), 9.50(83), 9.50(83), 8.96(33), 8.39(33), 8.20(17), 8.06(33), 7.34(17), 6.74(33), 6.43(50), 5.95(67)	22.37(8), 17.76(12), 16.13(32), 13.57(32), 10.70(100), 8.11(12), 14.65(78), 15.03(87).	Chlorite – illite mixed layer clays, Montmorillonite.
Perminters-5	16.85(60),14.72(100), 12.91(67),10.75(40), 7.46(7), 6.64(20)	17.90(100),15.53(100), 13.10(60),11.55(20), 10.07(100),9.42(80),8.95(80)8.68(40), 7.99(20), 7.16(80), 6.45(60), 6.29(40), 6.13(60), 6.00(40)	18.95(18), 16.66(6), 14.01(12), 11.85(53), 10.61(100), 8.75(6), 6.44(18)	Chlorite - illite mixed layer clays
Krigers-6	20.66(80), 18.19(20), 17.36(60), 16.45(60), 15.16(100), 13.49(80), 14.59(20), 10.46(80), 8.75(20), 6.69(60)	22.29(83),20.17(100), 18.33(83),11.12(83), 10.09(17),6.03(33), 14.76(91)	13.45(25), 12.63(50), 11.92(63),10.84(100), 10.13(25)	Except for the air dried and heated samples that indicated the presence of Montmorillonite.
Perminters-6	18.11(73), 14.03(68) 15.27(91), 13.74(100), 12.55(45), 10.75(73), 7.83(55)	19.29(100), 15.29(50), 12.11(13), 9.74(25), 8.55(1), 7.80(25), 6.77(25), 6.03(25)	11.29(75), 10.52(100), 7.55(13), 6.79(25)	Montmorillonite, Mixed layer clays

Petrochemical analysis of the sample as given on Table 3 indicates that Parminters and Krigers Bentonite have
slight differences with the Wyoming type of bentonite in some areas as follows:
The Kenyan samples have generally higher SiO_2, CaO, and K_2O contents; lower F_2O_3 and TiO_2 but similar range with the Wyoming type in Na_2O and MnO contents.

Table 3: Total rock analysis of major elements

Reference number	SiO_2	Al_2O_3	CaO	Mg O	Na_2 O	K_2O	TiO_2	Mn O	P_2O 5	Fe_2O 3	LOI	Total (%)
KPBJ1/06/11	39.4	15.6	7.6	3.6	0.8	1.1	1.0	0.1	0.7	10.7	21.1	101.70
KPBJ2/06/11	43.8	17.4	4.2	2.4	0.8	1.2	2.0	0.2	0.6	13.2	18.4	104.20
KPBJ3/06/11	47.3	18.4	1.7	1.6	0.8	1.2	2.3	0.1	0.7	13.3	16.5	103.90
KPBJ4/06/11	43.93	14.77	2.48	2.65	0.78	1.77	2.31	0.03	0.57	13.30	19.84	102.43
KPBJ5/06/11	42.99	16.06	1.07	2.00	2.00	0.02	1.40	0.13	0.65	11.07	18.99	96.38
KPBJ6/06/11	45.98	14.99	0.76	1.99	2.00	1.07	1.99	0.14	0.6	9.09	17.87	96.48
WYOMING	48.00	15.10	1.49	2.46	1.86	0.14	1.03	0.11	0.65	10.30	19.22	100.36

These variations can be seen in the various figures (Figure 1 through 6) plotted against SiO_2 on the 100 per cent volatile free basis.

Table 4: Total rock analysis of the clay samples on volatile free basis

Reference number	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	Total (%)
KPBJ1/06/11	64.87	5.71	7.49	10.11	2.29	4.7 4	0.4 9	0.08	4.22	100.00
KPBJ2/06/11	67.89	17.72	0.67	2.59	1.72	1.9 2	0.8 2	0.02	6.63	100.00
KPBJ3/06/11	64.98	19.79	1.93	2.16	2.29	1.4 4	0.5 9	0.01	6.80	100.00
KPBJ4/06/11	66.43	25.17	0.29	1.06	0.53	1.4 6	0.5 4	0.00	4.52	100.00
KPBJ5/06/11	50.37	12.25	20.39	3.36	2.01	2.7 7	0.6 8	0.37	7.91	100.00
KPBJ6/06/11	54.60	23.79	1.81	3.10	2.30	0.1 8	1.2 8	0.14	12.80	100.00
WYOMING	59.53	18.86	1.85	3.06	2.31	0.1 7	1.2 8	0.13	12.81	100.00

SiO_2 versus AL_2O_3

There is a small variation between the Wyoming type bentonite and the Kenyan samples on their aluminium contents. The variation could be due to the presence of gangue minerals like gypsum, however, Parminters samples have much lower AL_2O_3 than Wyoming type while Krigers sample has higher values.

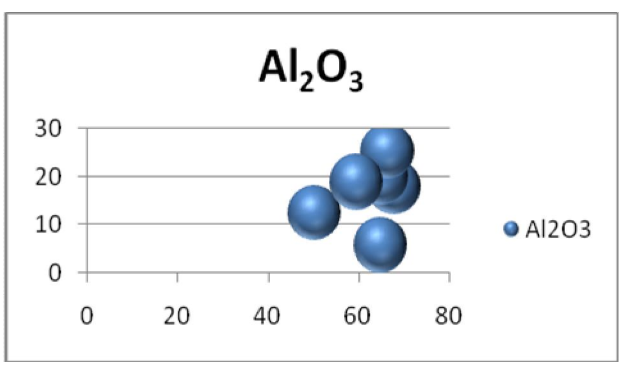

Figure 1: Silcon oxide and alminium oxide

SiO_2 versus CaO

Washed samples generally have comparable CaO contents except for one sample from Parminters and one from Krigers which have higher values due to the presence of gypsum crystals.

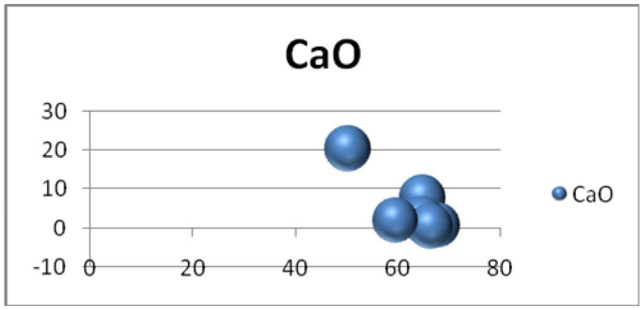

Figure 2: Silcon oxide and calcium oxide

SiO_2 versus MgO

Parminters and Krigers samples generally have similar range of MgO contents as the Wyoming type bentonite, however, one sample has a higher value and lower MgO content.

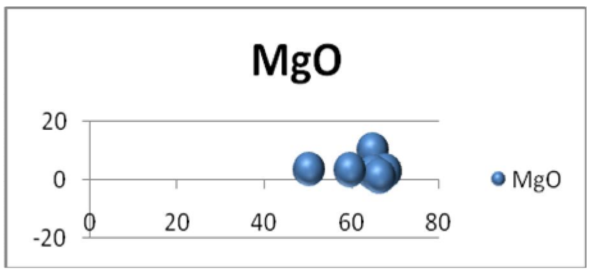

Figure 3: Silcon oxide and magnesium oxide

SiO_2 versus Na_2O

The Plot indicates that the value of Na_2O is comparable for both Parminters and Krigers with Wyoming bentonites.

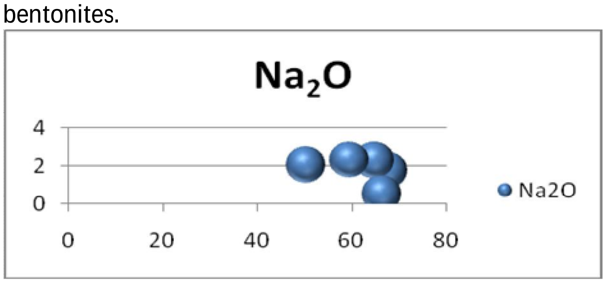

Figure 4: Silicon oxide and sodium oxide

SiO_2 versus Fe_2O_3

The plot indicates that all the Kenyan bentonite samples have lower Fe_2O_3 contents compared to the Wyoming type.

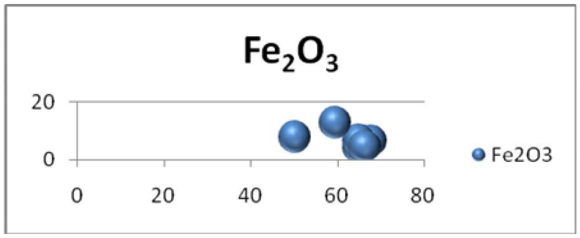

Figure 5: Silicon oxide and iron oxide

3) SiO_2 versus K_2O

All the Kenyan bentonite samples have high K_2O contents than the Wyoming type with the highest value recorded in the Parminters sample.

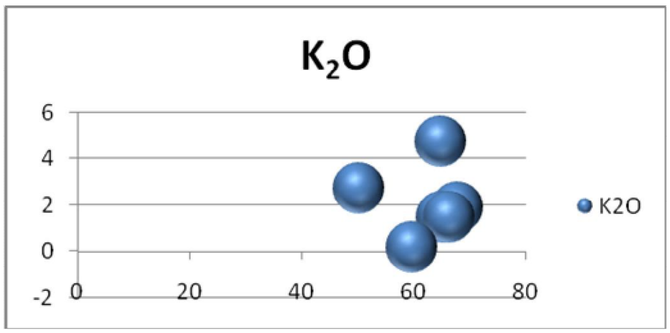

Figure 6: Silcon oxide and potassium oxide

Table 4: Trace metals

METAL	**P.P.M**
Arsenic	0.1
Barium	< 1.0
Cadmium	< 0.01
Chromium	< 0.05
Lead	< 0.1
Mercury	< 0.02
Selenium	< 0.02
Silver	< 0.05

Table 5: Specific gravity, Ph, and cation exchange capacity

Specifi gravity	2.55
Ph (5% Suspension)	9.1
Cation Exchange Capacity	80 - 90

3.1 Dicusssions

The Parminters and Krigers bentonite occurrence in Kenya are in similar tectonic environment as most of the main bentonite occurrences in the world. The bentonite occurrences in Parminters occur from about 1m depth; however, the bottom of the deposit was not determined. At Krigers, the upper surface of the deposit varies from 1m to more than 4m depths. The bottom surface deposit was not determined but it is estimated that the deposit could be greater than 5m thickness. The Kenyan bentonite deposits from Parminters and Krigers have low content of undesirable gangue minerals that include gypsum and calcite which lowers the quality of the clay as drilling mud. Parminters clay deposits have very low gangue minerals contents and XRD analyses indicate abundant montmorrillonite (bentonite clay) content.

Petrochemical analyses indicate that Parminters and krigers samples show no significant deviations from the Wyoming type, more so in their K_2O contents. Most of the oxides are generally high in the Kenyan samples. These differences are reflected in the physical properties of the bentonites. Analyzed physical properties of the samples indicate that the Parminters and Krigers samples are of good quality as that of the Wyoming type for potential use as drilling mud. The Kenya clay deposits analyzed have lower values of the critical properties like plasticity index, linear shrinkage and swell pressure than the Wyoming type bentonite. The largest deviation is recorded in the Krigers Samples. The Parminters deposits sampled have a trend in plasticity index, linear shrinkage and swell pressure to be considered for use as drilling mud. Generally sampled deposits are close to the Wyoming type bentonite and may be considered as an alternative to the Wyoming Bentonite.

4.0 Conclusion and Recommendations

The results of this research have shown that local Bentonite collected from the parminters and Krigers have close physico-chemical properties to the Wyoming Bentonite. It is important that it is considered for geothermal drilling at Olkaria. The test viscosity and filtrate loss should also be carried and ensure that the material meets International Standards Organization. Presence of minable quantity of the Kenyan deposits needs to be determined by using shallow core holes and other methods within the high potential areas in the country. Applications of local materials in drilling for geothermal resources is possible in all regions of rift valley which have been explored and will result in savings as a result of reduced costs of drilling materials.

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