

# An Investigation to Establish the Presence, Quality and Rank of Coal from Parts of Mui Basin in Kenya

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**Abstract:** A study was conducted in which Seventy nine samples of coal were collected from four different wells of the Mui basin between November, 2005 and July, 2006, and analyzed for calorific value, fixed carbon, moisture content, ash content, volatile matter, sulphur and iron content. Calorific value was analyzed using the bomb calorimetric method, by igniting a weighed portion of each sample in the bomb for one hour and measuring the corrected rise in temperature. For sulphur, one gram of each sample was mixed with three grams of Eschka mixture and ashed at 825°C for 1 ½ hours in a muffle furnace. The resulting residue was dissolved in hot water, filtered and the filtrate reacted with barium nitrate to precipitate barium sulphate. The Sulphur content was then determined from the total barium sulphate content. Iron in the coal sample, was analyzed using atomic absorption spectrophotometry. Samples were first ashed at 950°C in a muffle furnace before extracting the iron using aqua regia (a 3:1 mixture of concentrated hydrochloric acid and concentrated nitric acid). The aim of the research was to use these experimental results to ascertain the presence of coal in the already sunk wells and also establish its quality as to whether it was anthracite coal, bituminous or lignite coal. Results of the coal quality were of vital use to the Ministry of Energy in Kenya in establishing as to whether this coal could be used for power generation or in steel industry among other uses. The coal exploration programme under the Ministry of Energy in Kenya has been going on with an aim of establishing Coal in different parts of the Country, so that it can be used to limit overdependence on imported petroleum and Coal. From the proximate analysis results, the coal samples were found to have an average calorific value of 21.16Mj/Kg, 52.16% fixed carbon, 45.89% volatile matter, 26.53% ash content, 2.10% sulphur, 2.04% iron and 2.04% moisture. About 33% of the samples were found to be anthracite. The rest were classified as 20.3% bituminous, 11.4% lignite, 11.4%peat, 3.8%carbonaceous shales, and 20.1% rock.

**Keywords:** Kenyan coal, Coal analysis, Coal rank and quality, Mui basin

## 1. Introduction

Coal is a fossil fuel that has variety of uses depending on its quality. It is used as a source of energy in the cement industry, while it is used in metallurgical industry in coking for the manufacture of iron metal. In addition, coal is used in the manufacture of gaseous fuels. It has remained the main fuel of choice for electricity generation Worldwide over the years; producing 38% of the Worlds electricity which doubles that of oil and nuclear energy. In addition Coal has been an essential input to two-thirds of the world steel production [1]. Countries reported to be heavily dependent on coal for electricity generation by 2003 included: Poland 94.7%, India 90.1%, South Africa 90%, Australia 84%, USA 52% among others [1]. A large part of Kenya's foreign exchange earnings is spent on importing crude oil. In addition, the country currently imports over 100,000 metric tonnes of coal for use in cement industry [2]. The main sources of electricity generation in Kenya are hydropower and thermal power [3]. However, the hydro power generation has quite often been affected by weather patterns and droughts while thermal power generation is becoming expensive due to increasing fuel oil costs. The energy demand in Kenya is projected to double by the year 2020 [2]

The coal exploration programme under the Ministry of Energy in Kenya has been going on with an aim of establishing Coal in different parts of the Country so that it can be used to limit overdependence on imported petroleum and Coal. The exploration programme has been based on the following: delineating the sedimentary basin, assessing the thickness of the sediments, assessing the geological structures in the basement rocks to analyse the basin evolution, ascertaining the presence of coal deposits in the

basin, establishing the quality of the coal deposits and establishing the quantity of the coal deposits. This research was based on establishing the quality of the coal deposits from the already sunk wells in Mui basin in Mwingi and Kitui districts. In this study we report on procedures that were used to establish the quality and rank of Kenyan coal obtained from the sections of Mui basin that had been drilled and had shown some physical presence of coal. The composition of coal varies widely and hence it is necessary to analyze and interpret the results from the points of view of commercial classification, price fixation and proper industrial utilization. Two international standards of coal sample analysis are used. These are the American Society for testing and Materials (ASTM) and the international standards organization (ISO) [4]. In this research, the ASTM method was used. Different international countries have also ranked coal basing on proximate analysis, more specifically the calorific value or fixed carbon. These includes the British coal ranking system, the south African coal ranking system and the American coal ranking system and the international classification number system[5],[4],[6]. The south African coal ranking system was used in ranking coal from Mui basin for comparison purposes since the coal that is being used in Kenya now is from south Africa. The quality of coal was only done for the sections of Mui basin that had been drilled and had shown some physical presence of coals. Thus, the exact size of coal deposits in Kenya could not be done at this initial stage since exploration in other parts of Mui and other areas of the country is still going on.

1.1 The Mui Basin

The Mui basin is situated within Mwingi and Kitui district. The area of interest is bound by latitudes of 0° 53' S and 1° 29' S and longitudes 038° 09'E and 038° 19'E. The Mui basin is a narrow sediment filled depression that stretches roughly North – South from Mwingi, Garissa road in the North to Kyengomo hills past Zombe in the South. According to geologists, the Mui basin is a trough bounded by Mutitu ranges to the west and Nuu hills to the East, mainly composed of meta – sediments. These Meta – sediments consists of biotite, schists, biotite, gneisses, migmatites and granitoid gneisses. The basin covers an estimated area of 330km<sup>2</sup>. Initial geological investigation suggests that faulting along the North – South fault line of Mutitu ranges initiated formation of the Mui basin, followed by Sedimentation, resulting to formation of sub-basins within the main trough. Mass wasting and the influence of gravity accelerated movement of detached masses from higher elevation to lower areas. This facilitated the infilling of the basin. The sediments filling the basin are mainly terrigenous, though biogenic sediments occasionally occur. Sands and sandstones are the main component, filling up riverbeds and channels of Mui and Ikoo rivers. The Geo physical survey identified sub-basins in the main Mui basin using gravity and magnetic methods.

2. Experimental

2.1 Sampling

Samples from each of the four already sunk borehole from Mui basin(table a), described as “well” were parked in wooden boxes representative of each well and transported to the Ministry of Energy in Nairobi, where samples were then selected from coal bearing zones in each box, for analyzing various substances which determine the coal quality. These were calorific value, fixed carbon, ash content, sulphur, iron, volatile matter content and moisture content. Only a portion of each of the coal sample was given to me for analysis by my supervisor at the Ministry of Energy. The rest were left in the wooden boxes for future reference. The selected samples were well sealed in plastic bags before being taken to the laboratory for analysis at the University of Nairobi.

Table a: Site stratification and sampling frame

Well	Description of well	Sample size
1	Well 1 was sunk in the South of Mwingi district at the border between the two districts. Coal bearing regions were between 120m – 170m. Samples were selected at this range	29
2	Well 2 was parallel to well 1 and was 1km from well 2.The well was on the positioning 038° 13.016'E, 010 05.178' South and on an altitude of 711 metres. The well was in the compound of Mui Catholic Church, the well had substantial coal shows that intercepted at various depth ranges. Coal samples were selected at the following depth ranges; 81 – 86m, 99 – 103m, 110 – 112m, 122 – 124m and 134 – 158m	11
3	Coal bearing region was found at depth ranges 126m – 127m where a total of eight samples were selected. The well was sunk between Mui dispensary and Miambani market	8

4	Well 4 was located between Mathuki and Mui markets along well was Mathuki – Mui main road. It was on the position of 01° 03.669' South and 038° 13.519' East. The wells datum elevation was 740 metres above sea level. The well was 150 metres from the Southern banks of the Nguinini river which is a major tributary of the Mui river. The well was drilled up to a depth of 201 metres. However, coal bearing regions were found at the following depth ranges coal samples were a total of 31 samples were selected.	31
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2.2 Experimental Procedures

2.2.1 Calorific Value Determination

The calorific value of coal samples was determined using the bomb calorimetric method [7], [8], [9]. The heat of combustion and calorific value of each sample material was calculated by multiplying its corrected ΔT by the calorimeter constant and then divided by the weight of the sample in grams. The calorific value was recorded in calories per gram cal/g and equivalent in other units obtained by using the approximate conversion factors. The heating value was measured as the gross calorific value.

2.2.2 Fixed Carbon

The following reagents were used; calcined sodium hydroxide, manganese dioxide and naphthalene.

- (a) Drying of Manganese dioxide.
 

The manganese dioxide powder was placed in a Pyrex beaker and then heated in an oven at a temperature of 110oC for 2 hours. The dried contents were then placed in a desiccator.
- (b) Preparation of calcined sodium hydroxide
 

The calcium oxide powder was mixed with sodium hydroxide pellets in a mortar and then crushed to small pieces with a pestle. The contents were then kept in a desiccator. Fixed carbon was determined by first heating about one gram of the coal sample in a bomb calorimeter for 1 hour. The exit gases from the bomb calorimeter were first passed through a massing tube well packed with magnesium perchlorate desiccant, which removed water from the stream. The increase in mass of this tube gave a measure of hydrogen content of the sample. The carbon dioxide in the gas stream was removed in the second massing tube packed with (sodium hydroxide mixed with calcium oxide). Since the absorption of carbon dioxide was accompanied by the formation of water, an additional desiccant (calcium oxide) was also placed in this tube [10]. Before passing the gas through second massing tube, it was passed through a guard tube containing manganese dioxide. This was used to remove (absorb) oxides of nitrogen, Sulphur and chlorine. The difference in mass of the first massing tube and the second massing tube after combustion gave the weight of water and carbon dioxide respectively. These two tubes were accurately weighed before passing the gas through them. The percent carbon content was determined by taking the product of weight of carbon dioxide and the gravimetric factor of carbon when massed as carbon dioxide (0.2729) divide by the weight of the sample and multiplying by a hundred absorbents [7], [9], [11].

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### 2.2.3 Sulfur Content

Sulphur content was determined using the Eschka method and gravimetric method respectively. The following reagents were used: the Eschka mixture and 0.01M Ba(NO<sub>3</sub>)<sub>2</sub>. The Eschka mixture was prepared by accurately mixing 1 gram of sodium carbonate powder with 2 grams of Magnesium oxide powder. The mixture was then well mixed on a crucible. The sulfur content was determined by mixing one gram of the sample with 3 grams of the Eschka mixture and then heated slowly in a muffle furnace at a temperature. A temperature of 800° C ± 25°C was held for 1 ½ hours, ASTM D 3177, ISO 334 and 351 [4], [5]. The cooled mass was extracted with 50 milliliters of hot water, filtered and 20 milliliters of the solution precipitated with 80 milliliters of 0.01 M Ba(NO<sub>3</sub>)<sub>2</sub>. The precipitate on the filter paper was then dried in an oven at temperatures of 40°C for 4 hours, where all the water was removed and then precipitate weighed as Barium sulphate. The weight of Sulphur was then determined using the gravimetric method based on its chemical factors and results recorded as a percentage of the weight of the sample.

### 2.2.4 Ash Content

The ash content was determined by heating 1 gram of the coal sample in a muffle furnace at 400°C, where most of the carbonaceous matter was burnt off, and then heated at a temperature of 750°C to complete combustion for one hour. ASTM D3174 [5]. The crucible and the ash were weighed after cooling in a desiccator. The nature and colour of ash was also noted. The results were expressed as percentage of the coal sample used.

### 2.2.5 Moisture Content

Moisture content was determined by a two stage method, where the as – received samples were first air dried at room temperature and residual moisture determined. The moisture content was determined by heating 1 gram of the air-dried coal sample in an oven at 110°C for one hour and the loss in mass calculated as a percentage, ASTM D 3173 [4], [5].

### 2.2.6 Volatile Matter Content

The volatile matter was determined by heating 1 gram of each air-dried coal sample in a muffle furnace for 7 minutes at a steady temperature of 950°C. The volatile matter was determined by taking the loss in weight as a percentage minus the percent moisture, ASTM D 3175 [4], [5].

### 2.2.7 Iron Content

Iron content was analyzed using flame-acetylene (AAS) at 248.3 nm [4], [7], [10].

#### (a) Digestion of samples for iron analysis using AAS. (Flame)

The crushed samples were placed on a crucible and ashed in a muffle furnace at a temperature of 750°C for one hour. After ashing, 0.1 g of each sample was accurately weighed and placed in a Pyrex beaker. 10 milliliters of the aqua regia was added in the beaker and then heated to near dryness where the remaining volume was approximately 1 ml [12]. This volume was then diluted with deionised water, filtered and then volume obtained diluted to a constant volume of 50 ml for all samples and kept in well labeled 60 ml plastic bottles.

#### (b) Calibration Curve

250 ml stock solution of 1000 ppm was prepared by accurately weighing 1.7597 g of (NH<sub>4</sub>)<sub>2</sub> SO<sub>4</sub>, FeSO<sub>4</sub>, 6H<sub>2</sub>O(s) and dissolving it into a 250 ml volumetric flask with de-ionized water. This solution was stabilized using 0.5 M sulphuric acid by adding 6.8 ml of concentrated sulphuric acid to the prepared ferrous ammonium sulphate and then diluted to 250 ml [10], [12].

#### (c) Preparation of primary stock and calibrating standards

100 ml secondary stock of 100 ppm was prepared from 1000 ppm primary stock by taking 10 ml of 1000 ppm and diluting it to the mark in 100 ml volumetric flask. Working standards of 1 ppm, 2 ppm, 3 ppm, 4 ppm, and 5 ppm were prepared from 100 ppm secondary stock by taking 1 ml, 2 ml, 3 ml, 4 ml, and 5ml respectively and diluted to 100 ml in a 100 ml volumetric flask. These

standards together with the stock were transferred into plastic bottles as they are better compared to glassware. The blank was de-ionised water that was used in preparing standards. The blanks (de-ionised water used in preparation of standards) were first aspirated and then the instrument adjusted to zero. Each of the prepared standards was then aspirated in turn into the flame and the absorbance recorded. A calibration curve of standards against their concentrations was automatically plotted by the instrument. Since a straight line was obtained, the samples were analyzed straight away.

**(d) Analysis of samples:**

The nebulizer was rinsed by aspirating with de-ionised water. The blanks for the samples were then atomized and the instrument adjusted to zero. Each sample was then atomized and its absorbance and concentration directly determined.

**(e) Calculation:**

The appropriate calibration curve was referred to and initial concentration of each sample determined in ppm. However, since the concentration of most samples were very high, they were diluted further together with calibrating standards and blanks using appropriate dilution factors which gave the final concentration of iron that was within the required range. The exact iron concentration in ppm was obtained after subtraction of the blank.

Since the initial concentration of iron in each sample was different resulting to various dilution factors; the quantity of iron in each sample expressed as g/g was determined by taking; Initial volume of the digested sample x exact concentration in ppm X dilution factor X 10<sup>-6</sup>. Weight of the sample concentrations in mg/g or as a percentage were also determined by multiplying by a thousand and a hundred respectively.

**2.2.8 Coal Ranking**

The ranking of the coal samples from Mui basin was based on the calorific value of each sample. Samples were classified as anthracite (highest quality), bituminous, lignite, peat carbonaceous shales, or rock. This was based on the South African coal ranking system. Ranking of the coal samples was first done per Well and overall rank established after critically analyzing the results for the four Wells.

**2. Results and Discussion**

A total of seventy nine samples from four different wells were examined in order to establish the presence, and quality and rank of coal. The research was based on a proximate analysis which involved analysis of seven parameters per each sample. The parameters were; determination of calorific value, fixed carbon, sulphur content, volatile matter, moisture content, ash content and iron.

**3.1 Coal Ranking**

The calorific value obtained for each sample was used to establish its rank, and the results per Well were recorded in the tables below. The classification of coal by rank is fundamental in coal characterization [4], [13], [14], [15].

Ranking of coal from Mui basin was based on calorific value. Coal can either be ranked as anthracite, bituminous, lignite or peat. Anthracite is the highest quality while peat is the lowest quality. Table b, c, d and e below shows the coal rank established per each Well.

**Table b: Coal ranking of samples from Well 1**

Coal rank	Calorific value range (cal/g)	No. of Coal Samples	Percent (%)
Anthracite	6020 – 6964	6	20.69
Bituminous	4810 – 5400	4	13.79
Lignite	4007	1	3.45
Peat	2005 – 3499	5	17.24
Rock	Did not ignite	13	44.83
Total		29	100

In Well 1, a large percentage of the samples analysed was rock. Anthracite comprised of the highest percent 20.69%. Only 1 sample 3.45% was lignite.

**Table c: Coal ranking of samples from Well 2**

Coal rank	Calorific value range (cal/g)	No. of Coal Samples	Percent (%)
Anthracite	6774 - 7958	6	27.27
Bituminous	4597 – 5271	4	27.27
Lignite	-	1	-
Peat	2067	5	9.09
Rock	Did not ignite	13	18.18
C Shales	1264 – 1902	2	18.18
Total		29	100

27.27% of the samples analysed from Well 2 were anthracite and bituminous respectively. There was no lignite. Peat comprised of 9.09%, while carbonaceous shales and rock comprised of 18.18% respectively. Well 2 was of high quality compared to Well 1 since it had the highest % anthracite coal compared to Well 1.

**Table d: Ranking of samples from Well 3**

Coal rank	Calorific value range (cal/g)	No. of Coal Samples	Percent (%)
Anthracite	5756 – 6468	2	25%
Bituminous	4677 – 5350	3	37.50%
Lignite	3891	1	12.50%
Peat	2829	1	12.50%
Rock	Did not ignite	1	12.50%
TOTAL		8	100

In Well 3, a higher percentage of the coal was bituminous (37.5%). This was also found to be higher compared to well 1 and well 2 where bituminous coal was only 13.79% and 27.27% respectively. Well 3 and 2 had approximately equal percentage of anthracite coal which was 25% and 27% respectively. On the other hand, well 3 had the highest percent of high quality coal (anthracite and bituminous) compared to Well 1 and 2.

**Table e:** Ranking of coal samples from Well 4

Coal rank	Calorific value range (cal/g)	No. of Coal Samples	Percent (%)
Anthracite	5721 – 6395	15	48.39
Bituminous	4725 – 5567	6	19.35
Lignite	3627 – 4489	7	22.58
Peat	2821 – 3304	2	6.45
Rock	427	1	3.23
<b>TOTAL</b>		<b>31</b>	<b>100</b>

Coal from well 4 comprised mainly of anthracite (48.39%), which is also the highest percent compared to well 1, 2 and 3. Generally, well 4 had the highest percentage of high quality coal (anthracite and bituminous).

**Table f:** Overall Coal Rank

Coal rank	No. of Coal Samples	Percent (%)
Anthracite	26	32.9
Bituminous	16	20.3
Lignite	9	11.4
Peat	9	11.4
C/shales	3	3.8
Rock	16	20.2
<b>TOTAL</b>	<b>79</b>	<b>100</b>

Generally, the coal from Mui basin was mainly anthracite and bituminous although anthracite was slightly higher than bituminous. The percentages were 32.9% and 20.3% respectively. This comprised of 53.2 % of all the samples analysed. 22.8% of the coal was lignite and peat, while the rest was carbonaceous shales and rock.

### 3. Conclusion and Recommendation

The coal from Mui basin is basically anthracite coal, bituminous and lignite, which can be suitable for use both as industrial fuel and domestic fuel in power generation, metallurgy and process heat in key industries, and if cleaner coal technologies can be adopted upon establishment of enough recoverable coal in Mui basin, then coal exploitation and use in Kenya will ensure diversification of source of power supply which will limit dependence on hydro and thermal source, thereby promoting security of energy supply and save on forex for fuel imports.

### 4. Acknowledgments

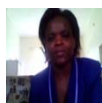
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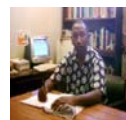
### Author Profile



**Joan Mwiluka Tenge** obtained her undergraduate degree in Education science at Kenyatta University in the year 1997. Thereafter, she enrolled for her Masters degree in environmental chemistry at Nairobi University where she graduated in the year 2009. Currently, she is a doctorate student in Analytical Chemistry at the University of Eldoret



**Prof. Jumba** is a Kenyan national and citizen. He holds a Bachelor of Science degree in Chemistry and Biochemistry (1977), Masters of Science in Chemistry (1981) and PhD in Chemistry (1989) from the University of Nairobi. He is a Professor of Chemistry in the Department of Chemistry, College of Biological and Physical Sciences, University of Nairobi. Currently he is the Deputy Principal in charge of Kenya Science Campus, College of Education and External Studies (CEES), University of Nairobi, a position he has held since 3rd October 2007.



**Dr. Kariuki** joined the University of Nairobi in 1992 as a Graduate Assistant. He enrolled for PhD in Analytical/Inorganic Chemistry in 1994 at the University and graduated in 2000. He was promoted to Lecturer position in 2001 a post he holds to date. His areas of interests include trace elements in bio-systems, spectrofluorimetry analytical techniques, environmental

assessments and remediation in soils, water, air, natural pesticides formulations and degradation, and safe coal use and mining.



**Don** is one of Africa's most respected petroleum geologists. Currently, Don Riaroh is one of the management team of Bahari Resources where he is the operations director. Don's previous positions include Director of SOHI-Gas Lamu Ltd, Chief Geologist and Director of E & P at Kenya's Ministry of Energy where he was in charge of Petroleum, Geothermal, Coal and Nuclear Energy. He has been a Board member of many state corporations including the National Oil Corporation of Kenya (NOCK), Kenya Electricity Generating Company (KenGen) and Ewaso Ngiro Development Corporation and a Consultant Geologist for a number of companies operating in Kenya. He has served as the national chairman of various professional bodies and committees including the international Geological Correlation Project and the World Petroleum Congress and was one of the founders of the East African Petroleum Conference (EAPC), now the major forum for the petroleum industry in eastern African. He is a member of African Rift Geothermal Development Facility, the National Science Committee and Kenya National Commission for UNESCO.

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