Kenya Journal of Sciences Series A Vol. 13 No. 1, 2008

Alternative Energy Sources from Mui Basin in Kitui District, Kenya - A Case of Coal

Author:
D.K. Kariuki*[1], J.M. Ndolo[2], I.O.Jumba[1], D.R.O. Riaroh[2]
[1] Department of Chemistry, University of Nairobi, P.O. Box 30197, Nairobi
[2] Geology Department, Ministry of Energy, P. O. Box 30582, Nairobi

ABSTRACT

Four coal exploration wells were sunk in the Mui Basin area lying in two administrative districts of Kenya, Mwingi and Kitui districts. The average depths sunk ranged between 17 – 135 m. Coal samples encountered were analysed for calorific value, ash content, carbon content, and were subsequently coal ranked. The samples were found to have calorific values ranging from 3318 – 3980 cal/g and were ranked from bituminous to peat. The average ash content ranged between 25 - 50 % while the carbon content ranged between 40 - 48.5 %. The coal may be exploited for power generation.

KEYWORDS: *Coal rank, calorific value, exploration wells, Mui basin*

INTRODUCTION

The need for affordable, reliable and dependable power for provision of essential services such as lighting, heating, cooking, mobility and communication as well as driving industrial growth is of paramount importance to any nation. Secure, reliable and affordable energy is fundamental to economic stability and development. Interruption of energy supplies can cause major financial losses and create economic havoc, as well as potential damage to health and wellbeing of the population. Improving access to energy in sub-Saharan Africa offers significant opportunity for achieving sustainable development goals as envisaged in the Millennium Development Goals (MDG) agenda. Environmental conservation programs such as the Carbon Capture & Storage (CCS) on coal use, will allow it to play a vital role in improving accessibility to energy worldwide [1,2].

Coal not only provided the energy which fuelled the Industrial Revolution of the 19th century but also launched the electricity era of the 20th century. Currently some 37% of the electricity generated worldwide is produced from coal. In 1994, United State of America generated approximately 56 % of its electricity using coal. Coal-fired power plants are expected to generate 47% of the developing countries' electricity needs by 2030. The world electricity generation is projected to rise from 16,074 TWh in 2002 to 31,657 TWh in 2030, a close to 100% increase. The developing countries will have an increase in demand for coal for this power generation. The World Energy Outlook [3] has linked poverty to energy scarcity and that the world's poorest are also deprived of modern energy services. Kenya imports over 100,000 metric tones of coal per annum, but mainly for the cement production industry [4].

Kenya's sources of electric power generation include hydro, geothermal and fossil fuel oil. The country's installed and effective total output per source is listed in Table 1 below.

Table 1: Kenya's Electricity Existing Sources

Source Type	Installed (MW)	Effective (MW)
Hydro-power	677.3	646.1
Thermal	277	263
Geothermal	128	128
Others (wind, solar)	9.65	8.8
TOTAL	**1091.95**	**1045.9**

Source: Ministry of Energy Communication [4]

From Table 1 it is noted that the total effective source utilization is 96% of the installed energy sources in the country. This is when other parameters such as weather for hydroelectric power generation are favourable and fuel is in good supply. The largest source of Kenya's electric power is hydroelectric power, which is a renewable energy source. Renewable electric generation sources are themselves not trouble-free. They depend on weather patterns, hence are at times unreliable and may too cause environmental degradation. Kenya has seven hydroelectric power generating dams on River Tana, which due to siltation and other impacts are a constant cause of environmental concern. During drought, power rationing is occasioned by the reduction of water levels in these dams. Power step-up during low hydroelectric power production periods is sourced from independent power producers who use thermal generation. Geothermal power production is constant and not feasible to step it up at a short notice in addition to high cost in terms of equipment and technology.

World Coal Reserves

Coal is the altered remains of prehistoric vegetation that originally accumulated as plant material in swamps and peat bogs. The accumulation of silt and other sediments, together with movements in the earth's crust (tectonic movement) buried these swamps and peat bogs, often to great depths. The plant material was subjected to elevated temperatures and pressures, which caused physical and chemical changes in the vegetation, transforming it into coal. The **peat**, the precursor of coal was converted into **lignite** or **brown coal** (coal- with low organic 'maturity'). Over many more millions of years, the continuing effects of temperature and pressure produced additional changes in the lignite, progressively increasing its maturity and transforming it into the range known as **sub-bituminous** coals. As the process continued, further chemical and physical changes occurred until these coals became harder and more mature, at which point they are classified as **bituminous** or hard coals. Under the right conditions, the progressive increase in the organic maturity continued ultimately to form **anthracite**[1,4].

The degree of 'metamorphism' or coalification undergone by coal, as it matures from peat to anthracite, has an important bearing on its physical and chemical properties, and is referred to as the **'rank'** of the coal. Low rank coals, such as lignite and sub-bituminous coals are typically softer, friable materials with a dull, earthly appearance: they are characterized by high moisture levels and low carbon content, and hence low energy content. Higher rank coals are typically harder and stronger and often have a black vitreous luster. Increasing rank is accompanied by a rise in the carbon and energy contents and a decrease in the moisture

content of the coal. Anthracite is at the top of the rank scale and has a correspondingly higher carbon and energy content and lower level of moisture.
Large coal deposits only started being formed after the evolution of land plants in the Devonian period, some 400 million years ago. Significant accumulations of coal occurred during Carboniferous period (350 - 280 million years ago) in the Northern Hemisphere, the Carboniferous/Permian period (350 - 225 million years ago) in the Southern Hemisphere and more recently, the late Cretaceous period to early Tertiary era (approximately 100 - 15 million years ago) in areas as diverse as the USA, South America, Indonesia, South Africa, Australia and New Zealand [5].

Table 2 gives estimates of coal reserves as of January 2004, for regions and countries in the world that have greatest known reserves. Reserves are defined as those resources that are identified with geologic certainty and are economically recoverable by using current mining technologies [3]. Coals vary greatly from country to country, seam to seam, mine to mine, and even from within mines. They can be characterized in a variety of ways, both physically and chemically. The analysis for a particular sample from a mine is accurate only for that sample and only generally represents the production from a given mine [5]. The world is known to have coal reserves that can last for over 200 years with the current energy usage estimates.

Table 2: World Coal Reserves (million short tones)

North America	276,285
United States	264,682
Central and South America	10,703
Colombia	5,003
Western Europe	329,457
Former U.S.S.R	265,657
Middle East	213
Iran	213
South Africa	60,994
Rest of Africa	68,429
Far East and Oceania	335,020
China	126,215
Australia	100,244
WORLD TOTAL	**1,145,011**

Source: *World Energy Outlook 2004 [3]*

World Coal Demand

The overall world coal consumption increased by about 18 percent between 1980 and 1993 with a peak in 1989 to 5318 million short tones (4823 million tones) [3]. Coal demand for energy production is projected to increase by 1.4% per year between 2002 and 2030. Power stations will absorb most of the increase, as coal remains the dominant fuel for power generation particularly in the developing countries. Asian countries are estimated to have the most increase in demand for coal, with China and India alone accounting for 68% of the demand increase by 2030. It is projected that the world primary energy demand will expand by 60% over the next 30 years[2,5].

Other fossils fuels (oil and gas) and alternative energy sources (such as nuclear and renewable) are important. However, none of these alternatives offers a trouble-free, long-term economical source of energy. It is worth noting that all fossil fuel reserves are finite hence they need to be used as efficiently and commercially as possible in order to conserve valuable resources. Renewable energy sources, such as hydro, wind, solar, biomass, wave and tidal do provide alternative sources for power generation. However, they all face problems including economic viability and environmental acceptability except for hydroelectric power [4, 6].

Table 8: Market shares in electricity generation (%)

	OECD		**Transition Economies**		**Developing Countries**	
	2002	**2030**	**2002**	**2030**	**2002**	**2030**
Coal	38	33	22	16	45	47
Oil	6	2	4	2	12	5
Gas	18	29	37	54	17	26
Nuclear	23	15	18	11	2	3
Hydro	13	11	19	15	23	16
Other renewable	3	10	0	2	1	3

Source: World Energy Statistics 2004 [8]

Coal is the world's most abundant, safe and secure economical and the current user technologies renders it a clean and cost-effective fossil fuel. There are abundant-extensive reserves of coal present in many countries that guarantees coal user's security of supply at competitive prices. This also assures constant electricity supplies for industrial and domestic use. Coal is stable and hence the safest fossil fuel to transport, store and use. It is the major single energy source for power generation worldwide and will continue to play a key role in the world energy mix, meeting 22% of all energy needs in 2030, which is a small decrease from the current level of 23% [9, 10]. Kenya can be part of this knowledgeable clique of countries and regions that will rise to the occasion of meeting its electricity power demands with the aim of supporting economic development of its people.

Coal and the Environment

Coal is a highly carbon-intensive fossil fuel, and may have negative environmental impacts, air pollution due to coal combustion, groundwater pollution including disruption of ecosystems particularly when mining. One of the most probable effects is in the emission of carbon dioxide, which is a green house gas. Other gases such as nitrogen oxides may be curbed through coal washing or the sulphur dioxide by scrubbing when using the coal. There are new technologies that are rendering coal use safe. The International Energy Agency (IEA) recently published the study 'Prospects for CO_2 Capture & Storage' which reported that CO_2 capture and storage is a promising emission reduction option with potentially important environmental, economic and energy supply security benefits [1, 7].

Kenya's Coal Exploration

Kenya spends a large proportion of its foreign exchange earnings on importing crude oil for domestic use. The Government of Kenya therefore puts a high priority in the exploration and development of indigenous energy sources as stated in the National Power Development Plan in order to curb the high expenditure on imported fuels. Efforts to explore the utilization of coal reserves for power generation and other uses with the aim of reducing the dependency on hydropower have been instituted. One of the first sites to be explored is the Mui Basin transecting Kitui and Mwingi Districts [11,12]. This study aims at quantifying through proximate analysis the quality of coal explored in Mui Basin area so as to establish its viability in power generation and industrial use in Kenya. It is envisaged that with the realization of commercial viable quantities of high ranking coal, the country may not only stop the importation of the commodity but will be self sufficient in power generation.

METHODOLOGY

Exploratory drilling area's geology

The Mui Basin lies in both Kitui and Mwingi Districts and has an area of 330 km^2, with a width of 6 km and 55 km length. It lies in the latitudes 0° 53′ S and 1° 29′ S and longitudes 038° 09′ E and 038° 19′ E (See Figure1). Ndolo (2003) reported that, the presence of coal in Mui Basin, had been sited in the 1950's, though no quantification or exploration was commenced [4, 12]. The geological survey of the basin reveals that, it is a trough bordered by Mutitu ranges to the West and Nuu hills to the East, mainly composed of meta-sediments. These meta-sediments consist of biotite schists, biotite gneisses, migmatites and granitoid gneisses. Faulting along the North-South fault line of the Mutitu ranges initiated formation of the Mui Basin. Sedimentation followed 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 facilitated infilling of the basin. The sediments filling the basin are mainly terrigenous, though biogenic sediments occasionally occur. Sands and sandstones are the main components filling up the riverbeds and channels of Mui and Ikoo rivers [12].

Shales in the basin are composed of mud-size particles and show laminations. The laminated shales were semi-lithified at Zombe and caped coal seam from the depths of 18 m [12]. Drilling to the standard 200 m was not achieved in some wells due to frequent wall collapsing. Drilling in Yoonye II well was shallow seam of less than 30 m deep, while Kateiko II well was sunk close to 200 m.

Analytical procedures

Proximate analysis that involves determining various parameters that constitute the coal ore samples was carried out in order to rank and classify the coal.

The following parameters were analysed in this work;

a) Ash content
b) Calorific value
c) Volatile organic matter
d) Fixed Carbon

e) Iron
f) Sulphur
g) Moisture content
h) Coal rank

'hese parameters have particular aspects that relate to the production or mining, and nvironmental impact to the use of coal.

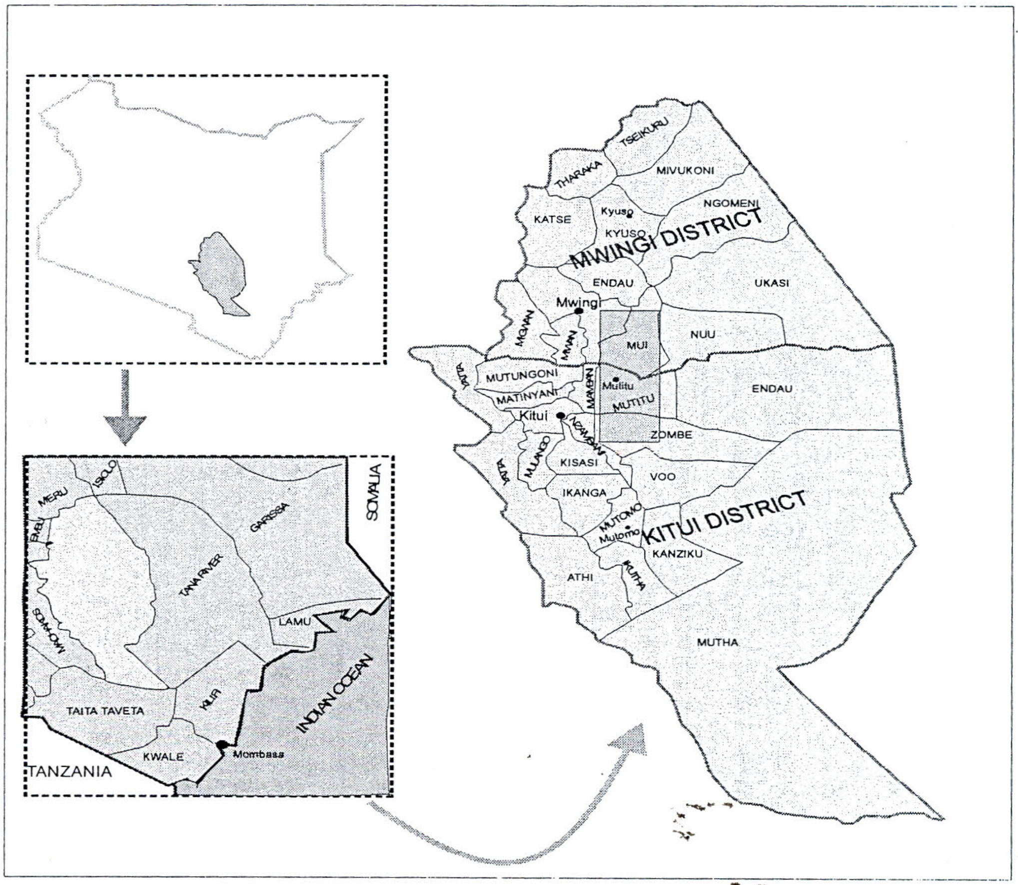

Figure 1: Mui Basin lying across Mwingi and Kitui Districts

isture content

e gram of coal sample was put in a porcelain crucible and weighed. It was then heated to ; – 376 K for about one hour. The crucible and the dry coal were then put in a dessicator :ool and then re-weighed so as to establish the weight lost [14].

ed carbon

: gram of coal sample was put in a boat shaped crucible. It was put in a pipe and heated in ɔt flame for 7 minutes. The contents were then cooled in a dessicator and reweighed [13].

Calorific value

Calorific value was analysed using a Bomb calorimeter Model Chadwell Health Essex Britain. One gram of coal sample was ignited in a metric bomb filled with 25 atmospheres of oxygen gas. The bomb was placed in a calorimeter with 1700 cm^3 of water. The increase in temperature in the water was then measured. The calorific value of the sample was obtained from corrected rise in temperature, the heating capacity of the meter and the weight of coal used. The calorific values were measured in calories per gram [13,14].

Iron

One gram of sample was ashed in a Muffle furnace at 800 °C. After ashing, it was digested with 100 cm^3 of aqua ragia (1 part conc. HNO_3 with 3 parts conc. HCl) for one hour. The solution was then diluted to 50 cm^3 and iron content determined using the Atomic Absorption Spectroscopy Model shimadzu AA 6300 [13].

Sulphur

One gram of the sample was mixed with 3 grams of the Eschika mixture (2g magnesium oxide + 1g sodium carbonate) and then heated slowly in a furnace at a temperature of 800 ± 25 °C for one and a half hours. The cooled mass was extracted with 50 cm^3 of hot water, filtered and 20 cm^3 of the sample solution precipitated with 80 cm^3 of 0.01 M $Ba(NO_3)_2$ The precipitate on the filter paper was then dried in an oven at temperatures 100–110 °C where all the water was removed and the precipitate weighed as barium sulphate. The weight of sulphur was then determined using gravimetric method based on its chemical factor and expressed as a percentage of the weight of sample [13, 14].

Volatile organic matter

One gram of air-dried coal sample was heated for 7 minutes in a muffle furnace at a steady temperature of 800 °C. The volatile matter was determined by taking the loss in weight as a percentage minus the percentage of moisture [14].

Ash content

One gram of coal sample was heated in a muffle furnace at 400 °C where most of the carbonaceous matter was burnt off. It was then heated at a temperature of 800 °C for one hour to complete the combustion. After heating, the sample in the crucible was cooled in a dessicator and weighed. The nature and colour of ash were noted [13].

Coal ranking

Coal ranking takes into consideration all the parameters analysed above in establishing the quality of coal. The ranking of coal gives rise to two different types, low quality 'soft coal' and 'hard coal' which is of higher quality in terms of calorific value. Thus the most determining factor of coal ranking is the amount of energy in a given coal and is therefore derived from the calorific value. The following ranking (Table 3) was used in this work [13].

Table 3: Coal ranking

Calorific Value Range (cal/g)	Coal Rank
No value (Did not ignite)	Rock
1 - 2000	Carbonaceous shales
2000 - 4000	Peat
4000 - 5500	Lignite
5500 - 7500	Bituminous
≥ 7500	Anthracite

SULTS AND DISCUSSIONS

ılysis and coal ranking

›les 4 - 7 show the results of the parameters analysed in the coal samples and their ›ective coal ranking down the exploration wells. The samples were found to be of good l ranking with average calorific values of 3318 – 3980 cal/g. The minimum calorific value electricity producing coal is 3346 cal/g. This implies that of the four exploration wells lysed, three of the wells' coal may be used for power generation, while the fourth one, eiko IV's coal may have to be 'washed' as it had some samples that exceeded the ımum value.

ʼoonye II exploration well, coal deposits were encountered at relatively shallow levels of 26 m. The well appears to have one continuous seam of about 17 m thick. The seam has ıverage calorific value (AV) of 3048 cal/g with an ash content of 52 %, sulphur 1.98 mg/g iron of 31.44 mg/g. On correcting the values by removal of the carbonaceous shale ples that are not coal, we obtained a corrected average calorific value (C.AV) of 3692 g, ash content 47 %, sulphur 2.00 mg/g and iron 30.40 mg/g. If proved to be ıomically viable in terms of deposit quantities, this seam would be exploited as an open mine see Table 4 below.

ty coal samples were collected from Kateiko II Well. This is a relatively deep well of up 52 m but the average depth is 86 m and the average calorific value is 3849 cal/g. The first ı depth yielded no significant coal quality samples, the well was found to be promising deep mine well. It however retains the 200 m limit economical coal mining depth. The age calorific value is high enough for electricity producing coal with an average ash ent of 33 % which is lower than that of Yoonye II well.

ːiko IV exploration well produced coal samples from between 85 - 160 m deep (Table 6 w). However the average calorific value from the sixteen samples collected is low, 3318 ;. The highest coal rank gotten from this well was lignite at 3585 cal/g. The seam appears ıve either dipped further below the 160 m level sunk below the surface or has deviated to ɜ different direction and that the well encountered only the tip of it.
average ash content remained at 50 % while the average carbon content was found to be ›. The total thickness dug with sparsely found coal is 75 m.

Kenya Journal of Sciences Series A Vol. 13 No. 1, 2008

Table 4: Results of coal samples from Yoonye II Well

Sample	Depth (m)	Sulphur (mg/g)	Iron (mg/g)	Carbon (%)	Ash (%)	C.V. (Cal/g)	Coal Rank
1	9.3	0.55	24.15	42	55	3435	Peat
2	10.5	1.24	23.94	32	63	2614	Peat
3	10.8	4.26	31.56	31	55	2526	Peat
4	11.0	0.82	17.22	32	64	2603	Peat
5	11.4	1.51	34.35	60	37	5849	Bituminous
6	11.7	0.69	20.19	49	36	4022	Lignite
7	11.8	2.31	157.20	38	43	3877	Peat
8	12.2	2.34	24.90	46	47	4201	Lignite
9	12.5	3.16	38.40	42	34	3420	Peat
10	12.8	4.56	72.00	45	48	3873	Peat
11	13.0	1.37	25.77	44	49	3609	Peat
12	13.4	3.30	23.85	48	47	4426.	Lignite
13	13.5	3.85	31.62	38	56	3155	Peat
14	13.9	1.51	27.84	21	62	1742	C/shales
15	14.8	2.06	25.80	16	66	1320	C/shales
16	15.0	1.24	21.36	49	45	4559	Lignite
17	15.4	1.51	23.67	32	61	2649	Peat
18	15.9	4.67	76.10	31	61	2776	Peat
19	16.0	0.41	27.00	36	56	2983	Peat
20	16.4	0.55	32.01	40	59	3244	Peat
21	16.8	4.72	128.50	5	68	383	C/shales
22	17.4	1.10	33.96	34	61	2785	Peat
23	17.5	1.24	28.44	33	62	2743	Peat
24	17.9	0.41	12.87	59	18	5734	Bituminous
25	18.3	1.24	22.89	3	65	228	C/shales
26	18.5	0.27	20.55	20	67	1648	C/ shales
27	19.5	5.49	17.76	46	50	4195	Peat
28	19.7	1.37	9.57	10	76	781	C/shales
29	20.3	2.20	11.82	3	70	231	C/ shales
30	20.9	1.92	58.50	2	59	170	C/shales
31	21.4	1.79	21.33	32	72	2585	Peat
32	21.5	1.51	12.06	34	60	2754	Peat
33	22.0	0.82	17.19	46	40	3765	Peat
34	22.4	1.79	10.68	4	72	325	C/ shales
35	22.8	1.24	10.14	33	62	2722	Peat
36	22.9	3.85	17.88	28	55	2334	Peat
37	23.1	1.51	64.50	44	37	3986	Peat
38	23.6	1.65	5.58	63	4	6130	Bituminous
39	24.4	2.47	9.42	70	14	6519	Bituminous
40	24.8	1.79	2.97	50	15	4536	Lignite
41	25.8	0.82	13.50	43	47	3521	Peat
AV	**17.14**	**1.98**	**31.44**	**34.98**	**52**	**3048**	
C.AV	**17.14**	**2.00**	**30.40**	**42.19**	**47**	**3692**	

le 5: Results of analysis of coal samples from Kateiko II Well

ple	Depth (m)	Carbon (%)	Ash (%)	Moisture (%)	Sulphur (mg/g)	Iron (mg/g)	V.M. (%)	C.V. (Cal/ g)	Coal Rank
1	18.2	N.D	75	7.2	40.50	16.15	5.3	D.I	Rock
2	18.4	N.D	77	8.9	67.00	12.10	8.7	D.I	Rock
3	18.6	N.D	51	11.1	43.00	9.55	9.7	D.I	Rock
4	19.7	N.D	74	7.6	41.50	16.10	12.2	D.I	Rock
5	22.1	N.D	76	8.7	63.00	8.00	15.0	D.I	Rock
6	24.5	N.D	75	8.7	63.50	10.90	2.1	D.I	Rock
7	26.0	N.D	77	7.5	45.00	8.65	9.9	D.I	Rock
8	34.5	N.D	74	8.7	43.30	12.85	8.7	D.I	Rock
9	36.0	N.D	63	8.5	50.00	10.35	0.5	D.I	Rock
0	40.2	38.33	48	8.4	40.80	5.15	18.8	3145	Peat
1	43.0	N.D	66	7.0	41.80	16.95	9.7	D.I	Rock
2	48.8	17.58	49	10.5	52.00	11.25	2.6	1443	C/shales
3	51.0	24.25	60	10.1	48.00	5.20	11.4	1990	C/shales
4	52.5	N.D	64	8.3	37.30	11.45	1.8	D.I	Rock
5	54.3	4.43	60	7.8	43.00	10.60	5.5	363	C/shales
6	59.0	N.D	67	7.2	40.00	10.15	4.2	D.I	Rock
7	67.4	N.D	68	4.9	45.00	35.10	3.7	D.I	Rock
8	123	30.68	60	2.1	45.00	10.70	4.0	2846	Peat
9	139.8	63.10	15	6.4	65.00	21.15	15.7	5178	Lignite
0	140.7	64.12	10	10.4	66.50	12.10	4.3	5261	Lignite
1	142.5	74.57	11	7.2	42.50	12.90	5.5	6529	Bituminous
2	146.5	83.01	4	7.7	34.75	1.90	3.9	6812	Bituminous
3	150	79.99	5	6.6	37.50	8.85	7.7	6564	Bituminous
4	152	32.03	52	3.6	60.30	31.40	18.7	2673	Peat
5	154	65.79	9	8.4	52.50	15.00	10.4	5398	Lignite
6	154.3	45.40	41	6.3	44.00	11.65	7.9	3725	Peat
7	155	40.64	36	6.0	45.80	10.30	16.8	3335	Peat
8	160.5	22.53	60	2.9	55.50	13.45	5.1	1849	C/shales
9	161.2	54.01	8	9.7	41.00	5.55	6.3	5252	Lignite
0	162	37.46	27	6.6	42.50	20.25	16.6	3074	Peat
V	**85.86**	**46**	**49**	**7.5**	**47.92**	**12.86**	**8.42**	**3849**	
AV	**85.86**	**46**	**33**	**7.1**	**48.04**	**12.20**	**9.48**	**3849**	

Well (Table 7 below) is a deep exploration well that encountered coal at a range of 61 – m. The average depth sunk hence was 104.5 m with 30 samples collected. The average ific value from this well was 3980 cal/g with carbon content of 48.5 % and ash content .8 %. This is the most promising of all the wells though deep. The coal seam appears to ick of about 127 m and of good quality. The coal would be exploited for power ration.

L PROFILE DOWN THE EXPLORATION WELLS

qualities of coal samples, calorific values were assessed down the well's depth to lish the coal profile with the depth in each well. Figures 3 - 6 show the coal profile each of the four exploration wells implying that the coal was encountered at different is and for different breaths (seam thicknesses) down the wells. The wells exhibited ng profiles with depths that proved existence of uneven coal seam thickness in Mui .

Kenya Journal of Sciences Series A Vol. 13 No. 1, 2008

Table 6: Results of analysis of coal samples from Kateiko IV

Sample	Depth (m)	Ash (%)	V.M. (%)	Iron (mg/g)	Carbon (%)	Sulphur (mg/g)	C.V. (Cal/g)	Coal Rank
1	85.6	40.8	7.2	9.95	14.98	11.12	1249	C/shales
2	101	65.5	10.1	2.60	15.34	58.00	1259	C/shales
3	111.5	40.4	2.0	2.50	43.68	54.10	3585	Lignite
4	123.5	59.8	4.9	4.95	N.D	36.67	D.I	Rock
5	125.8	69.4	12.9	6.45	28.78	44.88	2444	Peat
6	137.8	58.3	19.8	8.95	20.02	49.80	1643	C/shales
7	139.5	58.9	9.3	5.90	23.01	69.50	1888	C/shales
8	140.8	63.9	5.7	6.40	28.56	39.00	2344	Peat
9	141.0	58.6	9.9	11.65	N.D	45.00	D.I	Rock
10	144.0	25.8	37.2	9.65	59.07	67.50	4817	Lignite
11	145.0	62.2	8.7	5.10	36.38	42.00	2986	Peat
12	146.5	52.4	7.4	3.45	N.D	41.00	D.I	Rock
13	150.9	58.0	8.9	3.30	N.D	35.00	D.I	Rock
14	156.0	58	5.5	5.65	22.93	18.80	1882	C/shales
15	157.3	32.7	11.5	3.45	45.44	51.00	3729	Lignite
16	157.3	76.7	2.1	10.75	N.D	55.57	D.I	Rock
AV	**135.2**	**55.1**	**10.2**	**6.29**	**21.14**	**44.93**	**1739**	**C/shales**
C.AV	**135.2**	**49.1**	**13**	**5.6**	**40.32**	**49.8**	**3318**	**Peat**

Yoonye II well is to the south tip of the exploration area in Kitui District. It is a shallow well where economical open cast mining would be carried out. The Yoonye II well results showed that high coal rank was obtained at very shallow depths of even 9.0 - 26 m. It is worth noting that the coal rank profile, in general, in this well is high. It was found to contain low sulfur and volatile matter content. Though the well is shallow, it exhibits a constant quality profile ranging from 2500 – 6500 cal/g with depth.

Mat II well is to the north tip of the exploration area in Mwingi District. This is a relatively deep well of up to 190 m. Possible coal seam was found between 80– 92 m depth. There appears to be a gap in this well where rock was encountered for 90 m thickness, with reappearance of coal at depth of 184 - 187 m. There is a general decrease of coal quality down the well when even the last seam was included.

Table 7: Results of analysis of coal samples from Mathwezeni II

Sample	Depth (m)	Ash (%)	Moisture (%)	Carbon (%)	Sulphur (%)	Iron (mg/kg)	V. M (%)	C. V. (Cal/g)	Coal Rank
1	185.5	26.4	18.2	44.2	1.1	<0.001	76.9	3629	Peat
2	185.8	41.8	15.9	34.0	0.3	4.72	57.9	2787	Peat
3	186.4	27.3	21.8	44.3	1.7	41.94	73.5	3642	Peat
4	186.8	20.1	16.7	48.6	1.8	<0.001	75.9	3989	Peat
5	187.2	31.8	14.9	40.6	3.9	12.93	71.7	3329	Peat
6	91.2	47.2	7.0	10.2	1.00	8.79	46.8	840	C/shales
7	90.8	24.5	4.8	57.9	1.5	<0.001	87.5	4753	Lignite
8	90.5	23.4	10.9	44.9	1.0	313.67	76.7	3687	Peat
9	89.4	25.3	15.5	36.8	0.6	12.32	72.3	3021	Peat
10	88.9	31.2	12.7	46.3	1.7	50.05	67.7	3797	Peat
11	88.4	51.2	5.6	38.1	0.6	99.58	47.5	3122	Peat
12	87.6	54.6	3.6	22.3	0.2	103.35	44.3	1830	C/shales
13	87.3	31.5	4.1	58.4	1.1	12.23	67.3	4790	Lignite
14	86.9	4.0	16.8	60.9	0.5	1.51	97.2	5000	Lignite
15	86.0	16.3	6.6	54.8	1.1	24.20	85.4	4499	Lignite
16	85.5	11.2	12.9	56.3	3.6	54.19	86.2	4615	Lignite
17	84.9	23.3	10.9	50.4	0.9	17.02	74.8	4139	Lignite
18	84.6	4.6	15.6	63.7	1.3	34.26	96.3	5229	Lignite
19	83.3	27.7	9.7	53.5	1.9	24.02	84.3	4388	Lignite
20	79.6	22.6	15.2	63.5	4.5	0.15	79.0	5212	Lignite
21	83.0	16.3	11.2	69.6	2.0	95.03	90.0	5714	Bituminous
22	81.1	11.3	14.2	60.5	3.3	45.02	88.9	4967	Lignite
23	61.0	9.6	19.5	57.3	1.1	11.95	91.7	4703	Lignite
24	61.3	8.5	19.4	58.3	2.7	20.74	90.5	4780	Lignite
25	61.5	18.8	19.0	39.6	0.6	153.10	67.8	3246	Peat
26	63.0	34.9	11.2	36.6	0.9	<0.001	65.2	2999	Peat
27	127.0	29.8	12.3	32.4	1.1	50.59	68.2	2655	Peat
28	127.5	11.3	15.8	54.5	4.5	209.15	86.3	4474	Lignite
29	128.6	55.0	12.2	29.9	0.5	16.19	85.3	2456	Peat
30	135.5	99.1	0.2	N.D	1.4	<0.001	0.18	D.I	Rock
AV	**104.5**	**28.1**	**12.5**	**47.2**	**1.6**	**47.2**	**73.4**	**3872**	**Peat**
C.AV	**104.5**	**24.8**	**13.1**	**48.5**	**1.6**	**50.3**	**77.0**	**3980**	**Peat**

Kateiko II exploration well was sunk in the south of Mwingi District at the border of Kitui district. This is slightly above the middle of the exploration site, and would reflect the possible status of the seam as we move to the north. This well was found to contain coal at depths of more than 120 m below surface. The coal rank was erratic with bituminous coal found at depths of 145 m. The coal rank reduces slightly in value along the well depth profile with peat being found at 162 m below surface.

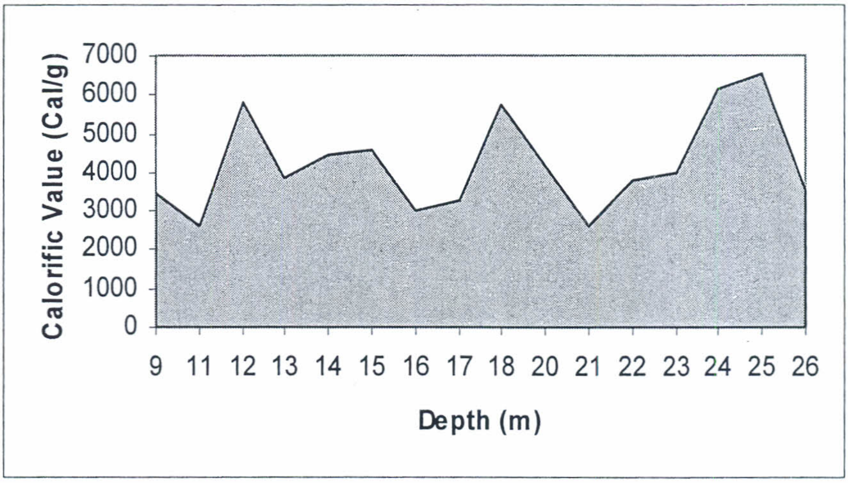

Figure 3: Coal depth profile of Yoonye II exploration well

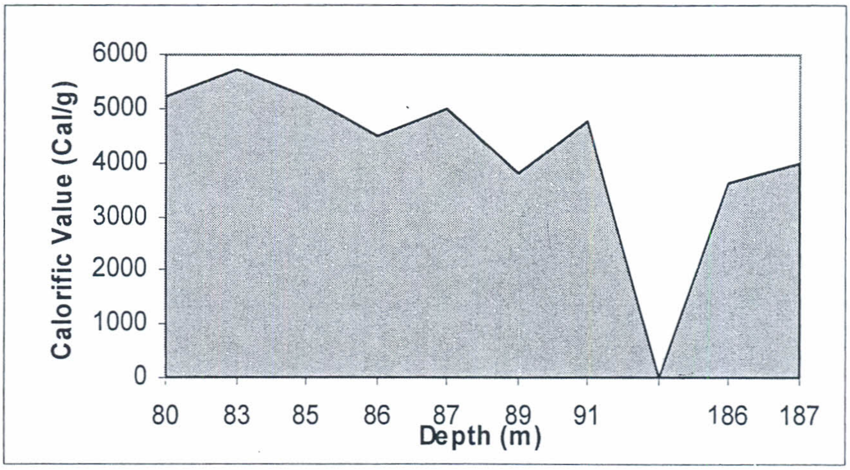

Figure 4: Coal depth profile of Mat II exploration well

Kateiko IV exploration well is parallel to Kateiko II well but to the west. It is a deep coal well of 85 - 157 m. The coal rank seems to be increasing with depth though not significantly. The well has the lowest coal rank in general as well as being erratic. The range of coal rank is peat (1200 cal/g) at about 86m to bituminous (5000 cal/g) at 143 m while at a depth of about 157 m the coal rank is becomes sub-bituminous (4000 cal/g).

The well has a similar profile as Kateiko II well and seems to prove that the coal seam could be tilting to the north from the south. The increase in coal rank with depth in Kateiko IV is in contrast to the reduction profile in Kateiko II. This may suggest that there could be a general coal seam tilt to the east.

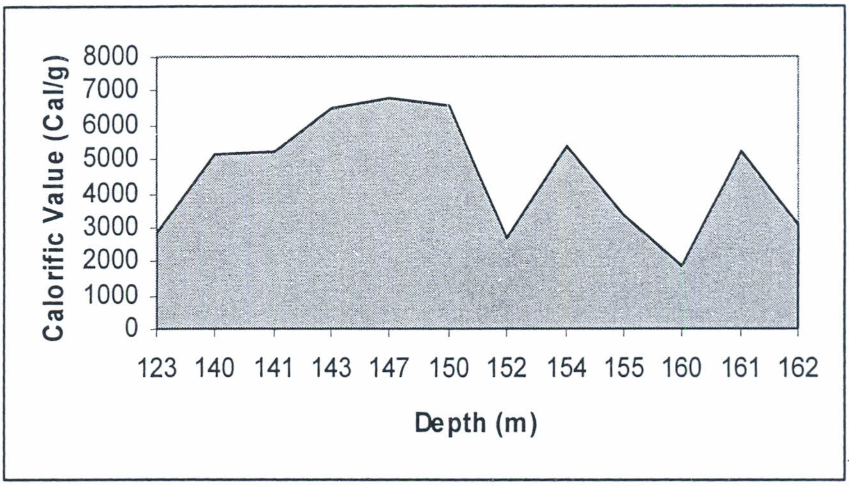

Figure 5: Coal depth profile of Kateiko II exploration well

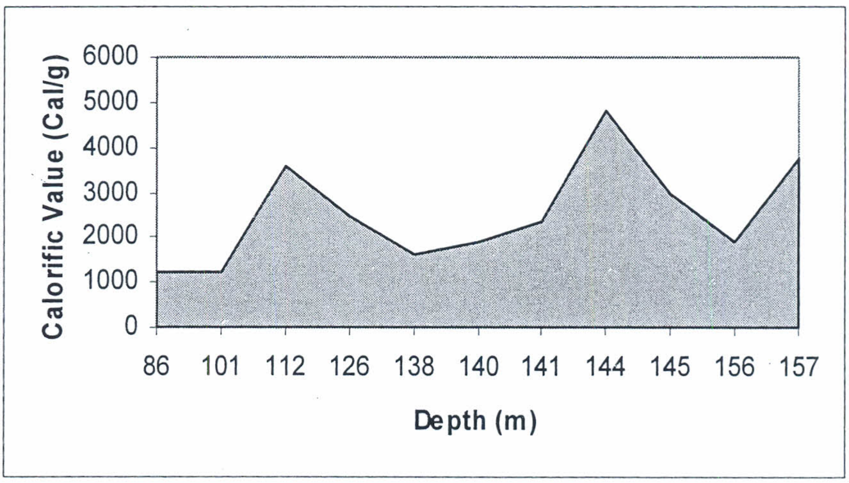

Figure 6: Coal depth Profile of Kateiko IV exploration Well

COAL PROFILE ACROSS THE EXPLORATION WELLS

The exploration wells were sunk to different depths as the coal was encountered but not exceeding the 200 m mark. At Yoonye Well coal was encountered at shallow depths of 9 m, and is the shallowest of all, Mat II is the deepest that was sunk to 187 m. Figure 7 shows the comparison of the exploration wells depths.

Figure 8 shows the average coal value of each of the four exploration wells analysed. Mat II coal samples showed the highest average calorific value of the four exploration wells although it is the second deepest of them. Kateiko IV has coal samples with the least average calorific value although it was the deepest sunk well of the four.

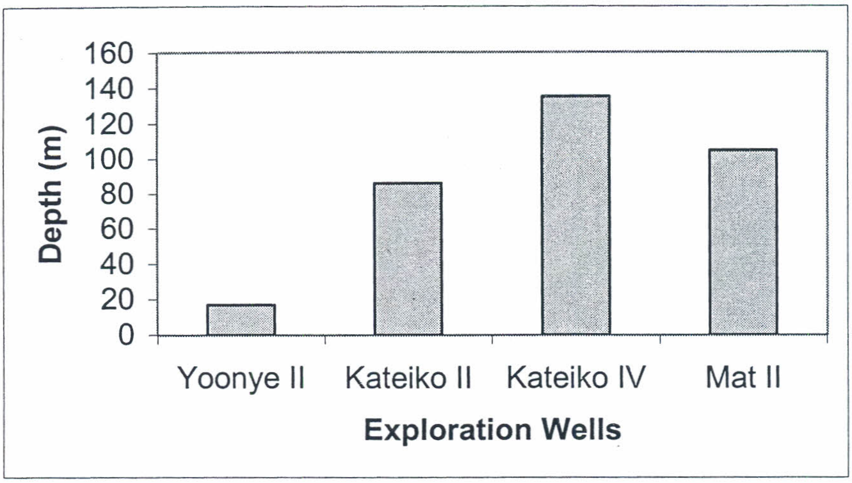

Figure 7: Comparison of average exploration Well depths

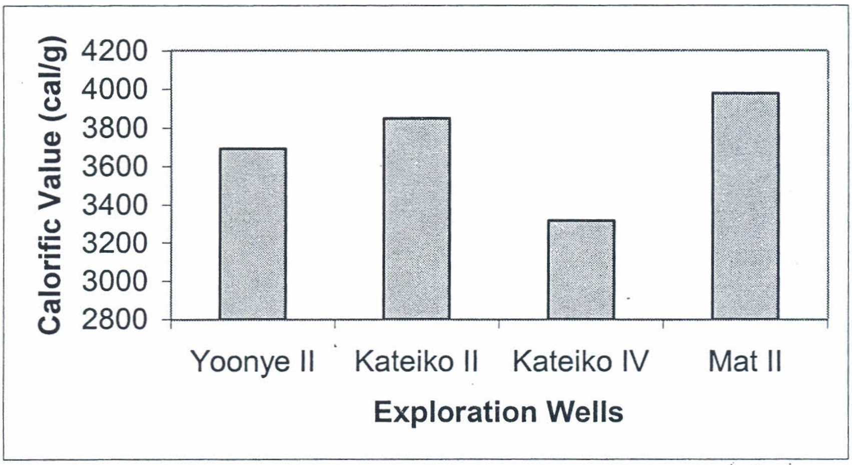

Figure 8: Relative average exploration Well calorific values

CONCLUSION

Samples from the four wells in Mui Basin were found to contain relatively high ranking coal of bituminous value of above 5000 cal/g. The average calorific value range recorded in all the four wells is 3318-3980 cal/g. This type of coal may be used for industrial purposes such as cement production as well as for electricity production which would reduce the looming power shortage currently being experienced in the country. Three of the wells (Kateiko II & IV and Mat II) had deep cropped coal seams while the fourth, Yoonye II well was relatively shallow with 9-26m coal seam. This implies that an open-cast mining operation may be used at Yoonye area, which is cheaper to commission, operate and decommission on a trial basis.

The coal seam at Mui basin appears to be dipping towards the Kateiko area (North) in Mwingi district from Yoonye area in the South in Kitui district. The crop may be extending longer and deeper than currently thought.

ACKNOWLEDGEMENT

We are indebted to the Ministry of Energy, Geo-Exploration Department for sponsoring this work and the University of Nairobi, Department of Chemistry for providing the analytical instruments and facility that made this work a success.

REFERENCES

1 Barbara J. Arnold (2005): Energy Resources for Power Generation *Prep Tech, Inc. Apollo, Pennsylvania* (Pg 1.11-1.20)

2 ECOAL World Coal Institute (2005): Assessing the Potential Carbon Capture & Storage, *Vol.* **53** (Pg 4-6)

3 ECOAL 52 (2004): World Energy Outlook 2004, *World Coal Institute Vol.* **52** (Pg 7)

4 Ndolo J.M., Mutunguti F.N., Wawiye F.O., and Ndogo J.M. (2003): Coal Exploration in Kenya, *Ministry of Energy Communication*. (Pg3- 4)

5 Wicks Roger and Keay Malcom (2004): Can Coal Contribute to Sustainable Development? Paper presented to the *19th World Energy Congress, Sydney, Australia* 5-9th September 2004 (Pg 1-9).

6 International Institute for Environment and Development, McCloskey Group (2002): Coal Case Study April 2002. *No.66* A report of the Mining, Minerals and Sustainable Development Project sponsored by World Business Council for Sustainable Development (WBCSD) (Pg 4-11).

7 World Bank Group (1998): Coal Mining and Production. *Pollution Prevention and Abatement Handbook* (Pg 282-285).

8 International Energy Agency (2004): Key World Energy Statistics 2004 (Pg14-15).

9 Milton Catelin (2004): Coal- Supply and Demand by 2030. *World Coal Institute* (Pg1-8)

10 Morris L. (1997): A Resource for Senior Students and Teachers. The New Zealand Coal Industry, (Pg13-17).

11 Ndolo J. M. (2004): Coal Exploration Monthly Report, Ministry of Energy (Pg4-9).

12 Ministry of Energy (2002): Mui Basin Coal Exploration Progress Report (Pg 3-11).

13 American Society for Testing and Materials (1991): Annual Book of Standards, Gaseous Fuels; Coal and Coke; Philadelphia, 1991 Section 5 (Pg 26).

14 Speight James (1983). *The Chemistry and Technology of Coal* Marcel Dekker. Inc. New York and Basel. 1st edition (Pg 99 – 54).