



**AN ASSESSMENT OF COAL FROM MUI BASIN AS AN ALTERNATIVE ENERGY
RESOURCE FOR KENYA**

**A thesis submitted in partial fulfillment for the degree of Masters of Science
(Environmental Chemistry)
University of Nairobi**

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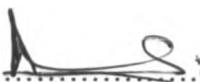
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To my parents, John W. Tenge and Salome N. Tenge.

To my husband Dr. Isaac Wanjala and

lastly to my children: Angel Wanjala and Anderson Wanjala

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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 objective of the analysis was to rank the coal and establish its suitability for use as an alternative energy resource in Kenya.

From the proximate analysis results, the coal samples were found to have an average calorific value of 21.16 Mj/kg, 52.16% fixed carbon, 45.89% volatile matter, 26.53% ash content, 2.01% 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% mere rock. About 80% of the samples could be classified as industrial fuel, while the rest could be suitable for domestic fuel. But with reference to specific

uses, 63% of the coal samples were found to be suitable for power generation, 19% for domestic fuel, gaseous fuel or tar distillation while the rest (18%) could be suitable for use in metallurgical coking.

These results indicate that coal deposit in the Mui basin of Mwingi and Kitui districts are of economic value compared to that from South Africa, and may be suitable for exploitation provided such processing is accompanied by modern environmentally - friendly coal - use technologies, such as carbon capture and sequestration. Combination of these technologies would make coal a valuable alternative energy resource for sustainable development in Kenya.

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LIST OF ABBREVIATIONS

| | |
|-----------|---|
| AMD | Acid Mine Drainage |
| ASTM | American Society of Testing and materials |
| CBM | Coal Bed Methane |
| CCT | Cleaner Coal Technologies |
| E.C.D | Energy Commission Directorate |
| GATS | General Agreement on Trade and Services |
| H.E.P | Hydro Electric Power |
| I.E.A | International Energy Agency |
| IEA | International Energy Agency |
| IGCC | Integrated Gasification Combined Technology |
| ISO | International Society Organization |
| KPLC | Kenya Power & Lighting Company |
| M.O.E | Ministry of Energy |
| Mtoe | Million tonnes of oil equivalent |
| PF | Pulverized Fuel |
| SA | South Africa |
| SCR | Selective Non-Catalytic Reduction |
| UNEP | United Nations Environmental Programme |
| USC | Ultra Super Critical Power Plant |
| W.C.I | World Coal Institute |
| W.E.C | World Energy Council |
| W.E.O | World Energy Outlook |
| W.S.R.S.D | World Summit Report on Suitable Development |

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CHAPTER ONE

1.0 INTRODUCTION

In the last century, the world witnessed an accelerating technological development in all aspects of human life, which resulted in improved living standards in a large number of countries. This development would have been impossible without natural resources and energy. The growing demand for energy has led both to the discoveries of new energy sources and the development of energy technological use. While the world's attention has been shifting between the "oil era" and the "nuclear age", "the dash for gas" and the "renewable future", coal has firmly stayed in the background playing vital role of conferring supply security and price stability. Price stability in fuel supplies is fundamental to world economic prosperity and political stability (W.E.C, 2004). The geo-political events among the oil producing countries such as the uncertainty in the Israel – Palestinian conflict, the wars in Iraq and Afghanistan and social unrest in Pakistan, Nigeria and Venezuela highlight, the fragility of the world's energy supply system regarding supply disruptions of energies and volatility of prices.

Coal is one of the world's major energy sources providing in 2000, 24.9% of the world's primary energy requirement. This compares with oil at 40% and natural gas at 24.7% (IEA, 2002: WEC, 2004).

Table 1.1a: Total World Energy supply (Mtoe) 2000

| Specification | Energy supply (Mtoe) |
|--|----------------------|
| Coal | 2,340 |
| Crude Oil | 3,474 |
| Gas | 2,101 |
| Nuclear | 676 |
| Hydro | 277 |
| Renewable (Geothermal solar, wind, combustable renewable and waste | 1095 |
| TOTAL WORLD | 9,963 |

Source: IEA, 2002; Energy Balances of Non- OECD Countries 2002, Pg 11224 – 11231, WEC. 2004

1.1 JUSTIFICATION

Other fuels such as oil, gas, nuclear and H.E.P, though important and widely used, do not offer a trouble-free, long term economical source of energy. At current production levels, known coal reserves are forecast to last for over 200 years (longer than known reserves of oil or gas) (McCloskey *et al* 2002). Coal is the world's most abundant, safe, stable and secure economically and the current user technologies render it a clean and cost-effective fossil fuel. This allows for ease of transportation, storage and use.

Coal is a fossil fuel that has variety of uses - depending on its quality. It is used as 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 also used in the manufacture of gaseous fuels. It has remained the main fuel of choice for electricity generation worldwide over the years, producing over 38% of the world's electricity, which is double that of oil and nuclear energy. In addition, coal has been an essential input to two-thirds of the world's steel production (W.E.O. 2002).

Table 1.1b: Hard Coal Supply and End-Use (Mt) 2002

| Specification | Quantity (Mt) | Percentage Use (%) |
|-------------------------------|---------------|--------------------|
| World Hard Coal Supply | 3853 | |
| of which: | | |
| steel Industry | 536 | 14 |
| Power and Heat Stations | 2541 | 66 |
| Households | 123 | 3.2 |

Source: IEA, Coal Information 2003 table 1.13 and tables 111 4 to 111 11, WEC 2004 Table 17 Pg. 156

Table 1.1c: Electricity Production from Coal – Selected Countries

| Specification | 2000 Electricity production TWh | | | % of total | |
|-----------------------|---------------------------------|----------------|-----------------|-------------|-------------|
| | Total | From Hard Coal | From Brown Coal | Hard Coal | Brown Coal |
| World Total | 15453.7 | 5136.0 | 749.1 | 33.2 | 4.8 |
| OECD total | 9699.5 | 3060.8 | 570.5 | 31.6 | 5.9 |
| Australia | 208.4 | 110.2 | 50.4 | 52.9 | 24.2 |
| Canada | 605.3 | 56.1 | 61.7 | 9.3 | 10.2 |
| Czech Rep. | 73.4 | 5.5 | 47.0 | 7.5 | 64.0 |
| France | 540.7 | 27.0 | 0.4 | 5.0 | 0 |
| Germany | 571.3 | 143.2 | 148.3 | 25.1 | 26.0 |
| Italy | 276.6 | 26.0 | 0.3 | 9.4 | 0 |
| Japan | 1091.5 | 205.9 | - | 18.9 | - |
| Korea | 294.1 | 115.9 | - | 39.4 | - |
| Mexico | 204.4 | - | 18.6 | - | 9.1 |
| Netherlands | 89.6 | 22.6 | - | 25.2 | - |
| Poland | 145.2 | 82.3 | 53.4 | 56.7 | 36.8 |
| Spain | 225.2 | 67.6 | 11.5 | 30.0 | 5.1 |
| Sweden | 145.9 | 1.9 | - | 1.3 | - |
| Turkey | 124.9 | 3.0 | 34.4 | 2.4 | 27.5 |
| UK | 374.9 | 120.0 | - | 32.0 | - |
| US | 4030.3 | 2005.4 | 97.2 | 49.8 | 2.4 |
| Non OECD total | 5754.1 | 2075.2 | 749.1 | 36.1 | 13.0 |
| Egypt | 75.7 | - | - | - | - |
| South Africa | 210.4 | 193.4 | - | 91.9 | - |
| Argentina | 89.0 | 1.2 | - | 1.4 | - |
| Brasil | 349.2 | 7.7 | - | 2.2 | - |
| Chile | 41.3 | 11.1 | - | 26.9 | - |
| Colombia | 43.9 | 2.8 | - | 6.4 | - |
| Paraguay | 53.5 | - | - | - | - |
| Venezuela | 85.2 | - | - | - | - |
| India | 542.4 | 401.5 | 18.4 | 74.0 | 3.4 |
| Indonesia | 92.6 | 28.8 | - | 31.1 | - |
| Malaysia | 69.2 | - | 1.8 | - | 2.4 |
| Pakistan | 68.1 | 0.2 | - | 0 | - |
| Taiwan | 193.0 | 91.4 | - | 47.4 | - |
| Thailand | 96.0 | 0.9 | 16.7 | 0.9 | 17.4 |
| China | 1355.6 | 1055.6 | - | 77.9 | - |
| Romania | 51.9 | 0.4 | 18.5 | 0.7 | 35.6 |
| Kazakstan | 51.6 | 36.1 | - | 70.0 | - |
| Russia | 877.8 | 99.6 | 68.7 | 11.3 | 7.8 |
| Ukraine | 171.5 | 46.0 | - | 26.8 | - |
| Iran | 121.4 | - | - | - | - |
| Saudi Arabia | 128.4 | - | - | - | - |

Source: IEA, Electricity Information 2002, WEC, 2004

Countries reported to be heavily dependent on coal for electricity generation by 2003 included:- Poland 94.7%, India 90.1%, South Africa 90%, Kazakhstan 69.9%, Czech Republic 61.8%, Denmark 55.1%, Germany 52.2%, Australia 84%, and USA 52.2% (WE.O, 2002).

Coal will continue to play a key role in the world energy mix, meeting 22% of all energy needs in 2030, (W. C. I, 2004). Kenya may be part of this knowledgeable clique of countries and regions that should rise to the occasion of meeting its electricity power demands if she were to exploit her coal reserves.

Electricity is one of the most effective and environmentally responsible ways of delivering the modern energy needed for social development. Coal generates power in an affordable, safe and reliable manner and may be the economic driver in the developing world where there is often no alternative route to achieving widespread access to electricity within a reasonable time-frame. An estimated 575 million people rely in biomass for their energy (WCI, 1999) Sub-Saharan Africa, for instance, suffers from acute energy poverty, with an average electrification rate of little over 10 percent (excluding South Africa) (Roger, 2004).

Studies carried out estimate that approximately 1.6 billion people in developing countries have no access to electricity, while 2.4 billion rely on primitive biomass for cooking and heating, against the background of the poor health, environmental degradation and other impacts that pose a significant developmental challenge. This situation is likely not to change in the next 30 years (I.E.A, 2002).

Reliable energy is a key component of economic and social development and lack of energy is among the key forces slowing growth of rural sector and poverty reduction (Lallment, 2002).

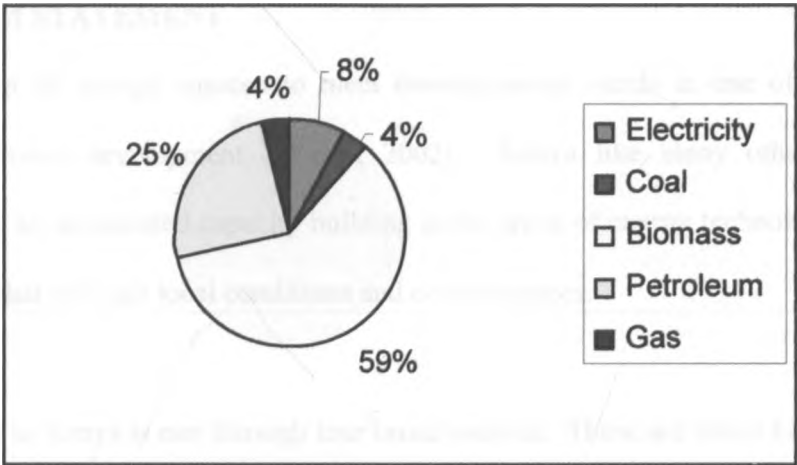


Figure 1.1: Energy consumption by type in Africa (2001) IEA, 2003.

Due to low levels of modern energy consumption in Africa, policy makers should be more concerned by the persistent under consumption of modern energy, contributing to high levels of poverty and under development and also the health impacts associated with traditional biomass energy use in Africa, which range from indoor air pollution to deforestation and soil degradation (W.E.C, 1998). 1.9 million deaths in rural areas and 450,000 deaths in urban areas, annually, are as a result of using biomass for cooking (I.E.A, 2002).

Table 1.1d: Sub-regional patterns of energy consumption in Africa, IEA, 2003

| Region | Biomass % | Petroleum % | electricity % | Gas % | Coal % |
|--------------------|-----------|-------------|---------------|-------|--------|
| North Africa | 4.1 | 61.5 | 15.1 | 18.0 | 1.3 |
| Sub-Saharan Africa | 81.2 | 14.5 | 2.9 | 1.0 | 0.5 |
| South Africa | 16.5 | 29.3 | 25.9 | 1.6 | 26.8 |

North Africa is heavily reliant on oil and gas consumption. South Africa depends heavily on coal and the rest of sub-Saharan Africa is largely reliant on traditional biomass. (I.E.A, 2003).

1.2 PROBLEM STATEMENT

The need to tap all energy sources to meet developmental needs is one of the ways of ensuring sustainable development (W.E.O, 2002). Kenya like many other developing countries, needs an accelerated capacity building in the arena of energy technology, appraisal and adaptation that will suit local conditions and circumstances.

Energy demand in Kenya is met through four broad sources. These are wood fuel, petroleum, hydro electric power and renewable energy sources (solar and wind energy). Wood fuel is the largest form of energy consumed in the country, accounting for about 68% of the national total. Petroleum is the next most important accounting for 22% followed by hydro electric power 9%. Renewable forms of energy; solar, wind, account for about 1% (M.O.E, 2005). A large part of Kenya's foreign exchange earning is spent on importing crude oil. In addition, the country currently imports over 100,000 metric tonnes of coal for use in cement industry (M.O.E, 2005). The main sources of electricity generation in Kenya are hydropower and thermal power (KPLC, 2005). 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 (M.O.E, 2005).

Table 1.1 a: Projected Energy demand in Kenya from 2003 to 2020

| Energy form | Energy demand 2003 | Projected demand by 2020 |
|-------------|--------------------|--------------------------|
| Biomass | 36 million tonnes | 53.4 million tonnes |
| Electricity | 1172 Mw | 2839 Mw |
| Petroleum | 2.3 million tonnes | 3.5 million tonnes |

Source: M.O.E, 2005

It is clear that petroleum fuels are the most important source of commercial energy used for transport, commercial and industrial sectors in Kenya, while coal is exclusively used in industrial sector, particularly in cement industry for process heat. Both petroleum fuel and the bulky of coal used in cement industry are imported. Similarly, there is over dependence on biomass as a source of energy, which is an environmental threat due to deforestation and also indoor air pollution - a health hazard especially to mothers and children under 5 years. In addition, majority of people in Kenya have no access to the electricity and the main electricity sources have not been reliable. In addition, the renewable energy sources are under utilized and thus there is no energy security in Kenya.

Energy is pivotal for economic and social development. While lack of access to energy services constitutes a major obstacle to sustainable development, its improved access to the poorer sections of Kenya's population would contribute directly to poverty alleviation. Therefore, access to affordable and appropriate energy services must and should grow significantly to improve the living standards of the country's growing population. The development and promotion of renewable energy resources and coal in the country will provide sustainable alternative options to problems related to deforestation, desertification, environmental pollution and over dependence on imported fossil fuels.

The availability of coal in Kenya will help in ensuring cheap availability of electricity and also as a cheap source of energy in key industries. Coal will help achieve another nearer term objective of facilitating the penetration of renewable energy sources, by exploiting synergies with renewable (Cassedy, 1998).

Kenya is unlikely to see low fuel prices in the near future, due to escalating cost of crude oil, fuelled by geopolitical tensions in crude oil producing states and soaring demand. According to analysts, the fuel prices are going to stay high and volatile. As per now, Kenyans are paying 29 percent more for fuel and power compared to the year 2005. On average, a litre of super petrol increased from Ksh. 69.98 in June 2005, to Kshs 89.50 in December (2008), giving a rise of 29% and annual increase rate of 10% in price. The increased demand for crude oil in China, India and USA, lack of spare capacity to raise production by the organizations of petroleum exporting countries (opec) and the geopolitical problems worldwide has also been cited as the main factors for escalating and unreliable oil prices.

There is need for other energy resources to ensure diversification of source of power supply to limit dependence on hydro and thermal source, where, high priority should be given to the development of indigenous resources and also save on money spent on fuel imports, hence the need to assess the quality of coal from four already drilled wells of Mui basin as an energy resource in Kenya.

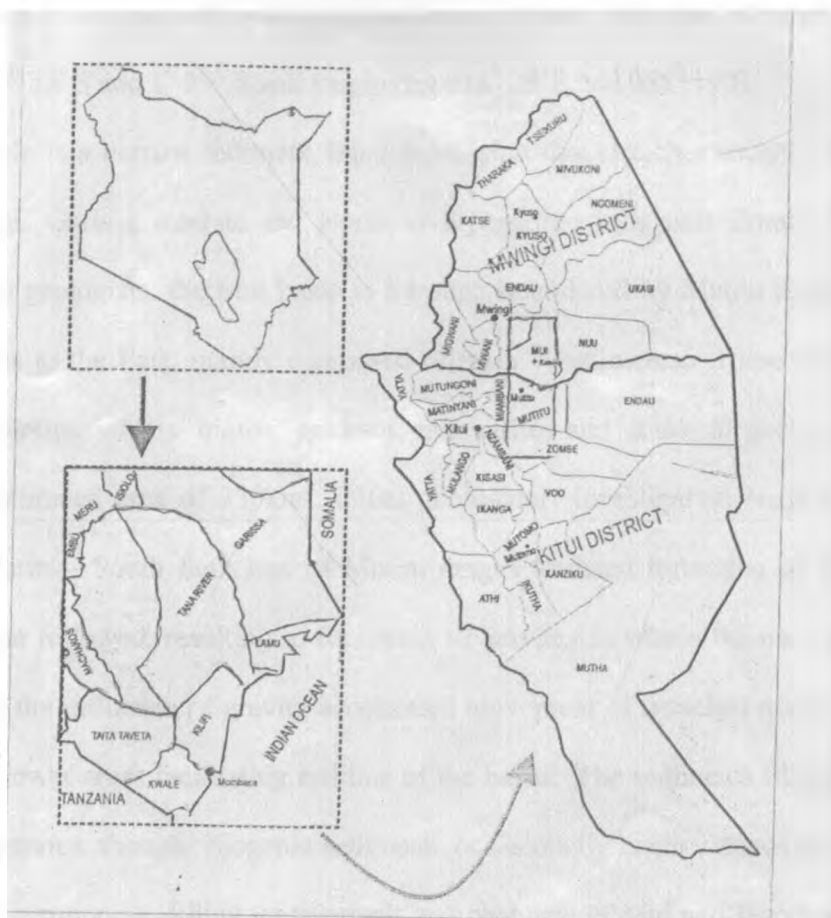


Fig 1.2: Location map of coal project area in Kitui and Mwingi districts

THE MUI BASIN

The Mui basin is situated within Mwingi and Kitui district. The area of interest is bound by latitudes of $0^{\circ} 53' S$ and $1^{\circ} 29' S$ and longitudes $038^{\circ} 09' E$ and $038^{\circ} 19' E$.

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^2 , initial geological investigation suggest that faulting along the North – South fault line of 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 facilitating 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 Geophysical survey identified sub-basins in the main Mui basin using gravity and magnetics methods.

The coal exploration programme was based on the following:-

- a) Delineating the sedimentary basin
- b) Assessing the thickness of the sediments
- c) Assessing the geological structures in the basement rocks to analyse the basin evolution
- d) Ascertaining the presence of coal deposits in the basin
- e) Establishing the quality of the coal deposits
- f) 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.

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.

1.3 OBJECTIVES

Main Objectives

1. To assess the quality of coal samples from four different wells of Mui basin that stretches between Mwingi and Kitui districts in Kenya.

Specific Objectives

1. To carry out a proximate analysis based on calorific value, moisture, fixed carbon, sulphur, volatile matter content and iron content on coal from 4 drilled wells of Mui basin in Kenya.
2. To rank the coal from Mui basin based on proximate analysis.
3. To access the possible use of coal from Mui basin in Kenya.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 COAL FORMATION AND COALIFICATION PROCESS

Coal is formed from partially decomposed plant debris which had collected in regions where water logged or swampy conditions prevailed, that prevented their complete decay. The debris consisted of trees, ashes, sea weeds bushy vegetation, desert plants and several thousand plant species. Similar amounts of plant remains may be found in all types of coal but in varying amounts. On this basis, coal differs markedly in composition from one locus to another. The many types of chemical reaction that occur during the maturation process can also bring about differences in coal from one particular scene. The geological age and overlying sedimentally cover also influences the resulting, quality of coal. Depending on the quality and degree of coalification, coal can either be classified as anthracite, bituminous, lignite or peat. Anthracite is of the highest quality followed by bituminous, lignite and then peat (Barbaras, 1991).

Two distinct categories of coal exist, steam coal or energy coal mainly used for electricity generation or conversion into other forms of secondary energy and coking coal employed by the steel industry in the production of blast furnace iron. All categories of coal can be used for electricity generation, although power plants have to be designed to handle specific types of coal. For example, a plant designed to burn bituminous coal would not be capable of burning brown coal (Dara, 2004).

Coking coal always comes from bituminous category. To be used as a coking coal, it has to be converted to coke in a coke oven or other carbonization process. All coals used by the steel industry should have low level of ash and sulphur as possible. The grades most favoured in international trade are sub bituminous, bituminous and anthracite coal (W.E.C, 2004).

2.2 COAL RESERVES AND PRODUCTION PROSPECTS

Significant deposits of coal exist in all of world's major continents and production is widespread, including some of the world's most stable economies. Table 2.2 below describes the distribution of known coal reserves across the world.

Table 2.2: World Coal Reserves

| Country | Coal reserves in Million short tonnes |
|---------------------------|--|
| 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 |
| Africa | 68,429 |
| South Africa | 60,994 |
| Far East and Oceanic | 335,020 |
| China | 126,215 |
| Australia | 100,214 |
| World Total | 1,145,011 |

Source: W.E.C, 2004

The World coal supplies are reported to be enormous and compared with oil and natural gas, they are widely dispersed, where proven coal reserves world wide totals to 907 billion tonnes or about 200 years production at current levels. In energy terms, this exceeds the combined reserves of both oil and gas by a very wide margin. Hard coal, coking coal and steam coal makes up 83% of proven reserves, the rest is brown coal. Australia, Russia and the U.S.A, all have high grade coking coal. Australia, China, India, Indonesia, Russia, South Africa and the USA, all have very large reserves of steam coal (W.E.O, 2002).

2.2.1 COAL DEMAND

The table below shows an overview of the coal production, consumption, export and import in selected countries for the year 2002

Table 2.2.1: Coal production, consumption, export and import in selected countries

(Mt)

| | Belgium | France | Germany | UK | Poland | Russia | US | Australia | China, | India | S.A |
|-------------------------|---------|--------|---------|------|--------|--------|-------|-----------|---------|-------|-------|
| Production (Mt) | | | | | | | | | | | |
| Coking coal | - | - | 18.0 | 0.4 | 15.9 | 53.4 | 41.2 | 114.0 | 134.8 | 26.2 | 1.3 |
| Steam coal | - | 1.9 | 11.2 | 29.2 | 86.7 | 110.2 | 875.6 | 162.0 | 1,191.2 | 307.5 | 221.7 |
| Total | - | 1.9 | 29.2 | 29.5 | 102.6 | 163.6 | 916.7 | 276.0 | 1326.0 | 333.7 | 223.0 |
| Consumption (Mt) | | | | | | | | | | | |
| Coking coal | 4.0 | 6.0 | 20.8 | 6.8 | 12.3 | 44.7 | 25.0 | 8.2 | 122.7 | 38.9 | 1.8 |
| Steam coal | 8.7 | 12.9 | 39.4 | 51.2 | 68.2 | 94.9 | 871.2 | 70.0 | 1,129.3 | 318.0 | 154.0 |
| Total | 12.7 | 18.9 | 60.2 | 58.0 | 80.5 | 139.5 | 896.2 | 78.1 | 1252.0 | 356.8 | 155.8 |
| Export (Mt) | | | | | | | | | | | |
| Coking coal | - | - | - | - | 3.5 | 9.0 | 18.3 | 105.8 | 13.8 | - | - |
| Steam coal | 2.0 | - | 0.1 | 0.5 | 19.1 | 36.1 | 16.2 | 92.0 | 72.0 | - | 67.7 |
| Total | 2.0 | - | 0.1 | 0.5 | 22.6 | 45.1 | 34.6 | 197.8 | 85.8 | - | 67.7 |
| Import (Mt) | | | | | | | | | | | |
| Coking coal | 4.0 | 6.0 | 4.0 | 6.3 | - | - | 2.2 | - | - | 12.8 | - |
| Steam coal | 9.9 | 11.8 | 27.0 | 22.4 | - | 20.8 | 11.8 | - | 10.1 | 12.0 | - |
| Total | 13.9 | 17.8 | 31.0 | 28.7 | - | 20.8 | 14.0 | - | 10.1 | 24.8 | - |

Source: IEA, Coal Information, 2003, tables 1.9 – 1.30, WEC, 2004 table 10 – 20 Pg. 144 - 157

US, China, India and South Africa are the main producers and consumers of steam coal and coking coal.

The international coal market has been split into two distinct areas, the Pacific and the Atlantic. The Pacific region is dominated by countries from Europe, with the major importers being United Kingdom, Germany, Spain and the U.S.A. The patterns of supply differ by region and by category of coal. The major suppliers of steam coal into the Pacific region are:

Australia, China and Indonesia, while the suppliers into Atlantic region are South Africa, Colombia and Russia. The major suppliers of coking coal are Australia and Canada. South Africa and North America's coal has replaced U.S. coal as they are unable to compete against the lower production cost in these countries. The USA is still a major supplier of high volatile coking coal into the European market (I.E A, 2004).

Coal Demand by 2030

The demand for coal will be driven by the surging needs of developing Asia, particularly China and India. In these countries, increased domestic production from abundant indigenous sources will also be accompanied by increasing imports of coal from external sources. It is projected that, by the year 2030, consumption of steam coal (principally used for generating electricity and process heat) will grow by 1.5% per annum. Coking coal (mainly used for making iron and steel) will increase by 0.9% per annum. Lignite or brown coal (used in power generation) will increase by 1.0% per annum [Roger, 2004]. High demand of coal will especially be realized in China and Poland which heavily rely on coal as an alternative source of energy (WCI, 2004). For consumers, coal offers excellent value, low prices and choice. In addition to already mentioned uses of different ranks of coal, coal is also recognized as a source of valuable elements and inorganic materials such as uranium, germanium and other desired elements.

This key role in meeting the world’s energy and industrial needs is set to continue – the IEA projects that coal use in power generation will rise by around 60 percent over the next three decades due to affordability (McCloskey *et al*, 2002).

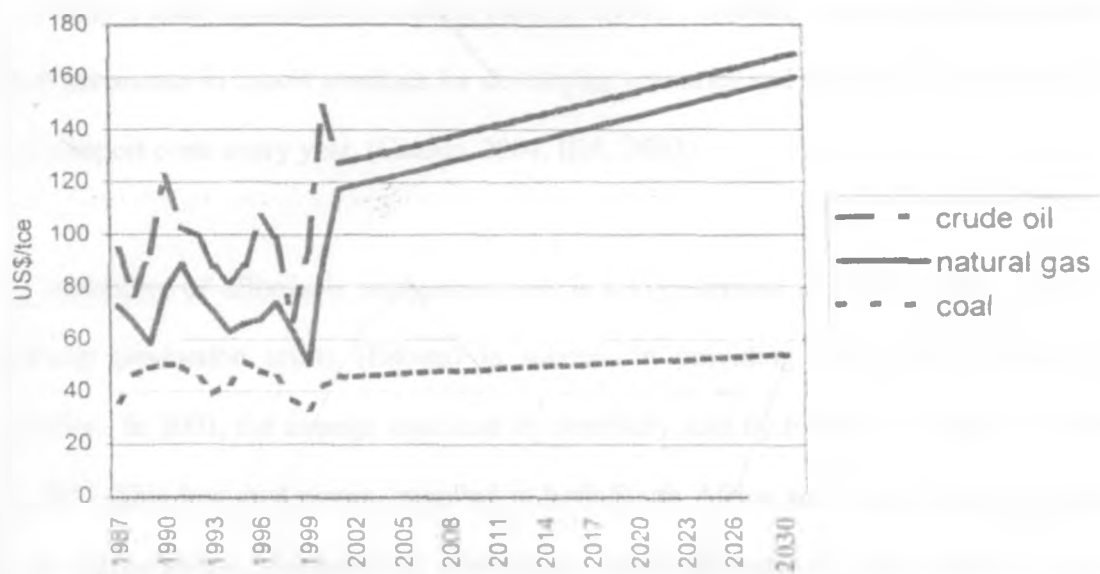


Figure 2.2.1b: Actual and projected international fuel prices 1987 – 2030

Source: W.E.C, 2004

From the above figure, the price of coal will remain low compared to other fossil fuels for a long time. In addition, since coal reserves are so widely distributed, economic benefits are enjoyed by many coal producing countries in both the developed and developing world. Coal is currently mined in over 50 countries and the coal industry directly employs some seven million people worldwide, 90 percent of them in developing countries (IEA, 2003). In South Africa, the industry directly employs more than 50,000 people and pays out some US \$ 450 million in salaries every year. Salaries paid out by the industry indirectly support a further

350,000 – 500,000 people (IEA 2003, WCI 1999). In many developing countries, the coal industry is export-oriented and constitutes one of the main sources of foreign earnings as well as saving on substantial import costs. Coal has become South Africa's third largest earner of export revenue where in 2001, export coal sales were US \$ 1.6 billion accounting for 6.2% of the country's total merchandise exports (W.C.I, 1999). Overall, coal generates around \$7 billion per annum in export revenues for developing countries and saving up to \$60 billion in energy import costs every year, (Catelin, 2004, IEA, 2003).

The availability of affordable indigenous coal is a key element in South Africa's national electricity production utility (Eskom) in success in providing the world's lowest cost electricity. In 2001, the average total cost of electricity sold by Eskom was only US \$ 0.01 per kWh. This low cost power, supplied in both South Africa and neighbouring countries such as Mozambique, underpins the international competitiveness of key industries such as gold and diamond mining and aluminium smelting, enabling much – needed growth. Coal - based generation has permitted ready access to reasonably priced electricity for households, improving indoor air quality, reducing health hazards, boosting household income and enhancing educational opportunities. Since 1994, 2.5 million households have been connected to grid-based electricity services supplied by Eskom, and currently more than 1,000 homes are being connected every day. Research in South Africa by Eskoms has shown that between ten and twenty new economic activities are started for every 100 homes connected with electricity (W.C.I, 1999).

2.3 PROVED COAL RESERVES AND COAL CONSUMPTION IN AFRICA

Coal deposits have been exploited in other African countries, notably in Tanzania, Zimbabwe, Malawi, Swaziland, Mozambique and South Africa. Coal as a source of commercial energy has been mixed and utilized in other countries worldwide.

TABLE 2.3.1: Coal proved recovery reserves and coal consumption in Africa at the end of 1999

| Country | Bituminous including Antracite | | Sub-bituminous | | Lignite | | Total | |
|-------------------|-----------------------------------|-----------------------------------|------------------|-----------------------------------|------------------|-----------------------------------|------------------|-----------------------------------|
| | Reserves (Mt) | Consumption Thousand tonnes | Reserves (Mt) | Consumption Thousand tonnes | Reserves (Mt) | Consumption Thousand tonnes | Reserves (Mt) | Consumption Thousand tonnes |
| Algeria | 4300 | 490 | | | | | 4300 | 490 |
| Botswana | | 945 | | | | | 3 | 945 |
| C. Africa | 88 | - | | | | | 88 | - |
| Democratic Rep | | 100 | | | | | | 100 |
| Egypt | 2 | 2000 | | | | | 2 | 2000 |
| Malawi | 212 | 75 | | | | | 212 | 75 |
| Morocco | 70 | 168 | | | | | 70 | 168 |
| Mozambique | 21 | - | 169 | | | | 190 | - |
| Niger | 49520 | 153460 | | 20 | | | 49520 | 153460 |
| Nigeria | 208 | - | | | | | 208 | - |
| S. Africa | 200 | 180 | | | | | 200 | 180 |
| Swaziland | 10 | 5 | | | | | 10 | 5 |
| Tanzania | 502 | 1 | | | | | 502 | 1 |
| Zambia | - | 121 | | | | | | 121 |
| Zimbabwe | - | 4750 | 193 | | 3 | | 196 | 4750 |
| Ghana | - | 3 | | | | | | 3 |
| Kenya | - | 100 | | | | | | 100 |
| Libya | - | 5 | | | | | | 5 |
| Gsplas | - | 14 | | | | | | 14 |
| Madagascar | - | 17 | | | | | | 17 |
| Total Africa | 55133 | 165640 | 362 | 20 | 3 | | 55501 | 165640 |

Source: W.C.I, 2004, W.E.C, 2004

The above table shows that African countries consumes mainly bituminous coal while lignite coal is only found in Zimbabwe.

2.4 COAL PROSPECTS FROM MUI BASIN AND USE IN KENYA

Coal deposits have been discovered from the Mui Basin in South-central Kenya. The Mui Basin is located in the Mwingi and Kitui Districts, and has been the focus of a coal exploration program being undertaken by the Ministry of Energy since 1996. The exploitation of indigenous coal resources can cut down the burden of country's foreign exchange, which could then be employed more profitably for other national uses.

Kenya spends a large part of its foreign exchange earnings on importing crude oil as no indigenous oil or natural gas resources have been discovered and exploited commercially. The country currently imports over 100,000 metric tonnes of coal for use in the cement industry. The Government has assigned high priority to the development of indigenous energy resources according to the current National Power Development Plan.

2.5 COAL AND ENVIRONMENTAL IMPROVEMENT

Given the importance of electrification, and the production of cement, iron and steel, to economic development, coal will remain an essential input to sustainable development if every effort will be made to protect the environment. Coal has to respond to the new emphasis on environmental protection especially in relation to greenhouse gas emissions, in order to maintain the positive contribution to sustainable development. This is however an achievable goal since possible routes towards the objective, primarily through deployment and development of clean coal technologies have been developed (Roger, 2004; E.C.D, 2003; W.E.C, 2004). Similarly, according to the world energy council, coal is acceptable in so far

as by 2030 where an estimate of 72% of coal-based power generation in the world would, under market conditions, use cost effective clean coal technologies (E.C.D, 2003).

2.5.1 COAL MINING

The depth, thickness and configuration of the coal seams have been identified as the main factors that determine the mode of extraction. Two mining methods; surface mining and underground mining have been selected. Strip mining has been considered the most economical surface mining process compared to open bit mining. Underground mining is used for deep seams and vary according to site conditions. Modern mining technologies have emphasized the following to ensure efficiency and acceptability; up grading of mined coal on the side of coal preparation to ensure environmentally friendly use of coal in power generation. The capture of methane from coal mines where methane gas is valued as a fuel mostly used for on-site power generation in gas power plants or sold as natural gas for variety of offsite uses. The energy content of 1m^3 of methane gas has been approximated at 37mj (W.E.C, 2004). The use of methane gas in power generation has been argued as the most effective way of helping lower release of greenhouse gas to the atmosphere. In addition, the natural gas from coal mines could replace electricity in domestic water heating and displace oil, coal and other natural gas in heating applications. In a situation where the exploitation of methane gas is not technically and economically viable, installation of flaring facilities at the mines to burn methane and convert it into carbon dioxide has been considered as an alternative of ensuring reduction of carbon dioxide equivalent released into the atmosphere by 85% (W.E.C, 2004).

Re-utilization and Re-cultivation / Reclamation

The emphasis has been directed towards creating new cultivated land, where landscaping and reclamation plans must achieve three objectives of creating a landscape that ensures; Sustainable use and ecological stability and maintaining its regional character where preservation and resettlement of the fauna and flora species typical of the landscape should be given high priority in the post-mine landscape. Essential elements emphasized are: water management, pollution control, and resource preservation of life-cycle management and settlement (McCloskey Group, 2002).

2.5.2 CLEANER COAL TECHNOLOGIES

Various processes have been discovered as very important stages to ensuring environmental improvement in the coal industry. Notable stages cited are: Enhanced uptake of existing options, deployment of advanced technologies, exploiting synergies with renewable and development / commercialization of next generation technologies (McCloskey Group, 2002).

Enhanced uptake of existing options

The enhanced uptake of existing options which emphasizes on coal preparation, washing, drying and briquetting have been considered as the starting point to ensuring environmental improvement by minimizing the emission of SO_x, NO_x and CO₂ in the atmosphere (W.C.I, 2004). Coal cleaning has been considered to reduce the ash content of coal by over 50 percent, reduce SO₂ emissions and also improve thermal efficiencies leading to lower CO₂ emissions (FiField, 2000).

The emission of SO_x has been considered a major environmental problem, resulting from using greater amounts of coal in energy production. Coal with sulphur content of less than 1% has been recommended (Bailey, 2003). From the literature, it has been revealed that about a half the sulfur in coal is in form of pyrite (FeS_2), which can be removed from coal by mechanical cleaning, while the remainder which is covalently bound to the carbon can be removed by chemical reaction. For coal with high sulphur content, removal of stack gasses after coal is burnt or changing coal chemically via coal gasification or liquefaction so as to remove covalently bound sulphur have been emphasized. (UNEP, 2004).

The use of limestone to absorb SO_2 emissions has also considered as the most efficient method of sulphur reduction. However, it has been established that when this method is used, 350 lb of limestone are required to absorb the SO_2 emissions from a tonne of high sulphur bituminous coal with sulphur content range of 3 – 6%. (W.E.C, 2004). As a consequence 8 to 9 ft of sludge must be dispersed of per ton of coal processed. (World Bank Group, 1996). However, current technologies of flue gas desulphurization using wet scrappers which have SO_2 removal efficiency of up to 99 percent have been reported to have been installed in 27 countries (W.E.C, 2004).

Various technologies to limit NO_x emissions are widely available. These include: the use of low NO_x burners, selective catalytic reduction, which can achieve reductions of 80 to 90 percent, and selective non-catalytic reduction where emissions can be reduced by 30 to 50 percent (Roger, 2004).

Deployment of advanced technologies

The introduction of a wider range of advanced technologies is another step in ensuring environmental improvement in the coal industry. Newer technologies such as fluidized bed combustion now available have been reported to offer superior environmental performance, reducing SO_x and NO_x by 90% or more (McCloskey Group, 2002).

Super critical / Ultra super critical power plant technology and integrated gasification combined technology have also been developed to ensure reduction of CO₂ emissions in power plants. Super critical coal-fired power plant operates at higher temperatures and pressures and at significantly high efficiencies and hence lower emissions. Even higher efficiencies have been reported in ultra super critical power plant, operating at very high temperatures and pressures. Recent reports shows that super critical plant have capital costs only slightly higher than those of conventions plant and significantly lower fuel costs because of increased efficiency. It has also been established that, more than 40 super critical plants are in operation, worldwide, including a number in developing countries such as China which is now installing super critical plant as standard (Roger, 2004; Catelin, 2004).

Integrated gasification technology offers another promising option for environmentally improved option for environmentally improved coal use. In Integrated gasification technology system, coal is not combusted directly but reacted with oxygen, and steam to produce syn-gas composed of mainly hydrogen and carbon monoxide. The syn gas is cleaned of impurities and then burned in a gas turbine to generate electricity and to produce steam for steam power cycle. Around 160 gasification plants have been installed worldwide. Examples of Integrated gasification technology includes: Tampa Electric Polk Project in the US, the Elcogas Puertollan Integrated gasification technology in Spain and the Wabash River

coal gasification project in the US. It has also been projected that the integrated gasification technology will in future provide a primary building block of future hydrogen economy. (Lallment, 2002).

Carbon Capture and Sequestration

The technologies described above, all offer significant advances in environmental performance through emissions reduction and higher efficiencies. But the challenge of reducing greenhouse emissions is more fundamental; since coal consists predominantly of carbon; its combustion produces carbon dioxide as a direct consequence, rather than as an incidental by-product. This problem has already been addressed via the introduction of carbon capture and sequestration technologies, which enable emission of carbon dioxide to be captured and sequestered and then disposed off in such a way that they do not enter the environment (Cook, 2002).

The pre-combustion capture of CO₂ or oxy-fuel combustion has been selected as a potential route to achieving lower capture costs of producing a more concentrated pressurized stream of CO₂. In this technique, emphasis is on the production of carbon dioxide rather than carbon monoxide, along with hydrogen. The hydrogen is then combusted in a gas turbine and CO₂ is available for storage. Oxy-fuel combustion which relies on the relatively simple principle of burning coal in an oxygen rich atmosphere to produce a pure stream of CO₂, has been considered as another alternative option; a technology that is also used in steel making showing that there is no insurmountable technical barriers to CO₂ storage linked to oxy-fuel power generation in the future (W.C.I, 2005).

Storing and using CO₂

A number of options for storage of CO₂ have been researched. These includes, geological storage and mineral sequestration injection of compressed CO₂ into the subsurface which offers a great potential for geological storage of CO₂ and has been the most comprehensively studied storage option (W.E.C, 2004). One major project to store CO₂ in deep saline aquifer has been conducted by the Norwegian Company statoil, in the sediments of the North sea basin, where about one million tonnes a year of CO₂ are being injected into the utisira formation at a depth of about 800 to 1000 metres below the sea floor, similarly, some work has been reported to be underway in the Albert Basin of Canada. In addition, literature survey has revealed that a comprehensive regional analysis of the storage of potential of saline reservoirs has been undertaken in Australia as part of GE ODISC (Geological Disposal of Carbon dioxide Project). Major demonstration project was hoped to be completed between 2005 – 2006 (IEA, 2004). Mineral sequestration is reported to be still at the laboratory stage of development, where research is focusing on how to accelerate reaction rates (Cook, 2002).

Coal as an option for production of hydrogen for electricity generation

Hydrogen could be used to produce electricity from fuel cells, emitting only water as a waste stream. This fuel cell could then be used to produce electricity for use in many applications and even potentially in motor vehicles, with minimum environmental impacts. A key uncertainty surrounding the widespread up take of fuel cells relates to the availability of hydrogen which does not naturally occur in usable quantities. It would therefore have to be manufactured and fossil fuels are one possible source. Coal, with the biggest and most widespread reserves of any fossil fuel, is a prime candidate to provide the hydrogen necessary for the widespread and sustainable development of such energy systems. More countries are

starting to implement hydrogen programmes and some of them Europe, the US, Japan and New Zealand are considering coal as an option for the production of hydrogen (Roger, 2004).

Research Efforts

Various projects are being researched on, for example the future Gen project. This is a US \$ 1 billion project that was launched in 2003 to demonstrate the near zero emission 275 Mwe coal fuelled IGCC plus hydrogen production plant, incorporating CO₂ separation together with geological sequestration. The project is intended to create the world's first zero emissions fossil fuel plant which, when operational, will be the cleanest fuel fired plant in the world. Cooperation between government, industry and international partners is a key element of future Gen (McCloskey Group, 2002).

A number of comparable projects are underway elsewhere in the world. In Australia, Europe, Japan and Canada - and total of 15 countries are involved in the carbon sequestration leadership forum initiative, focusing on the development of carbon capture and storage technologies through international collaboration (E.C.D, 2003).

2.6 COAL ANALYSIS

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 were the American Society for Testing and Materials (ASTM) and international standards organization (ISO) (Barbaras, 1991). In this research, the ASTM method was used.

The quality of coal is ascertained by two types of analysis, the proximate analysis and the ultimate analysis. The proximate analysis, which includes the determination of moisture, volatile matter, ash and fixed carbon is very important as it gives quick and valuable information regarding commercial classification and determination of suitability of coal for a particular industrial use. The ultimate analysis on the other hand, deals with elemental composition of a particular coal. It includes estimation of ash, carbon, hydrogen, nitrogen and oxygen. Although several attempts have been made to classify coal on the basis of elemental classification, it has been discovered that, elemental composition and coal behaviour do not necessarily exist in simple relationship and hence classification by means of elemental composition alone is extremely difficult (Spheight, 1983).

2.6.1 CLASSIFICATION OF COAL BY RANK

Different international countries, have also ranked coal basing on proximate analysis, more specifically the calorific value or fixed carbon. These include the British coal ranking systems, the South African coal ranking system, the American coal ranking system and the international classification number system. (Spheight, 1983, Barbaras, 1991, Dara, 2004) The South African coal ranking 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.

Table 2.6 1a: SOUTH AFRICAN COAL RANKING SYSTEM

| | | | |
|------------|------|---|------------|
| C/shales | 1000 | - | 2000 Cal/g |
| Peat | 2000 | - | 3599 Cal/g |
| Lignite | 3600 | - | 4599 Cal/g |
| Bituminous | 4600 | - | 5600 Cal/g |

Anthracite A >6572.5 Cal/g

Anthracite B 6333.5 – 6548.6cal/g

Anthracite C 6094.5-6309.6 Cal/g

Anthracite D 5855.5-6070.6 cal/g

Anthracite E 5616.5-5831.6 cal/g

Source: South African Coal Processing Society

Table 2.6 1b: CLASSIFICATION OF COALS BY RANK (ASTM RANKING SYSTEM)

| Class | Group | Fixed carbon limits (%) (dry, mineral-matter-free basis) | | Volatile matter limits %(dry-mineral-matter-free basis) | | Gross calorific value limits Btu/lb (moist mineral-matter-free basis) | |
|----------------|---------------------|--|-----------|---|-----------------------|---|-------------|
| | | Equal to or greater than | less than | greater than | Equal to or less than | Equal o or greater than | less than * |
| Antracite | 1. Meta-antracite | 98 | - | - | 2 | - | - a |
| | 2. Antracite | 92 | 98 | 2 | - | - | - a |
| | 3. Semi antracite | 86 | 92 | 8 | 14 | - | - a |
| Bituminous | 1. Low volatile | 78 | 86 | 14 | 22 | - | - c |
| | 2. Medium volatile | 69 | 78 | 22 | 31 | 14,000 | - c |
| | 3. High volatile A | - | 69 | 31 | - | 13,000 | 14,000c |
| | 4. High volatile B | - | - | - | - | 11,500 | 13,000c |
| | 5. High volatile | - | - | - | - | 10,500 | 11,500a |
| Sub-bituminous | 1. Sub-bituminous A | - | - | - | - | 10,500 | 11,500n |
| | 2. Sub-bituminous B | - | - | - | - | 9,500 | 10,500n |
| | 3. Sub-bituminous C | - | - | - | - | 8,300 | 9,500 n |
| Lignite | 1. Lignite A | - | - | - | - | 6,300 | 8,300 n |
| | 2. Lignite b | - | - | - | - | - | 6,300 n |

Where * Agglomerating character

n = non agglomerating

c = commonly agglomerating

a = agglomerating

Source: American Society for testing and materials, McMullan 1976, Barbara 1991

Table 2.6 1c: BRITISH COAL RANKING SYSTEM

| | | | |
|------------|----------------------|---|--------------|
| C/shales | 1 | - | 2000 Kcal/Kg |
| Peat | 2000 | - | 5500Kcal/Kg |
| Lignite | 4000 | - | 5500 Kcal/Kg |
| Bituminous | 5500 | - | 7500 Kcal/Kg |
| Anthracite | ≥ 75000 Kcal/Kg | | |

Source: Starch 1975, ASTM 1991

Table 2.6 1d: TABLE OF COMPARISON OF CLASS NUMBERS OF THE INTERNATIONAL SYSTEM OF COAL CLASSIFICATION WITH COAL RANK FROM THE AMERICAN SOCIETY FOR TESTING AND MATERIALS SYSTEM OF COAL CLASSIFICATION

| ASTM Coal Rank | International classification number |
|---|-------------------------------------|
| Meta-anthracite | 0 |
| Anthracite | 1 |
| Semi-anthracite | 2 |
| Low volatile bituminous coal with VM ≤ 20 | 3 |
| low volatile bituminous coal with VM between ≥20-22% | 4 |
| Medium volatile bituminous coal A with VM between 22-31% | 5 |
| Medium volatile bituminous coal A with VM 31-37% and CV≥ 14000 btu | 6 |
| High volatile bituminous B coal with CV 1400 – 13000 and VM ≥37% | 7 |
| High volatile bituminous C and sub-bituminous A coal 13000-11000btu | 8 |
| Sub-bituminous B coal CV 11000-10000 btu | 9 |

Source ASTM 1991

Coal can either be ranked as anthracite, bituminous, lignite or peat. Anthracite is the highest quality while peat is the least quality. Coal occurs in a wide range of forms and qualities. Two broad categories of coal have been identified. These are hard coal and soft coal. Hard coal comprises of coking coal used to produce steel and other bituminous and anthracite coals used for steam and power generation. The soft coal (sub-bituminous and lignite) are used mainly as onsite fuel. (Barbaras, 1991; Fifield, 2002, Mc GrawHill, 1987). In analyzing coal from Mui basin according to specific use, the South African guideline was used.

Table 2.6.1e: CLASSIFICATION OF COAL SAMPLES IN REFERENCE TO SPECIFIC USE

| PROPERTIES | USE |
|--|---|
| Ash < 34%, Calorific value 3346 cal/g | Power generation |
| Volatile matter < 34%, Calorific value 20 – 32 Mj/kg | Metallurgical coke (steel industry) |
| Lignite and highly volatile bituminous coal | Domestic fuel, gaseous fuel or tar distillation |

Source: South African coal processing society

2.7 GENERAL REVIEW OF METHODS USED IN PROXIMATE ANALYSIS

Proximate analysis is the determination of overall composition of coal sample. It involves determination of:- Moisture content, Volatile matter content, Ash content and Fixed carbon content (Spheight, 1983; Barbaras, 1991).

2.7.1 Moisture content

Each constituent determined under proximate analysis has its own implication and importance in assessment of the coal sample. Moisture increases the transport costs. Excessive surface moisture may cause difficulties in handling the coal. Moisture reduces the calorific value. A considerable amount of heat is wasted in evaporating the moisture during combustion. Hence higher percentage of moisture is undesirable (Dara, 2004).

Several methods of moisture determination can be applied. They include: Thermal method, desicator method, chemical method, distillation method, extraction and solution method and electrical method. In this research, the desicator method was used. It involves a measure of weight loss of coal which occurs when coal is maintained in a desiccant or (in the presence of a desiccant) either at atmospheric pressure or at reduced pressure but at ambient temperature (Spheight, 1983).

2.7.2 Volatile matter:

The volatile matter content of a coal is related to the length of the flame smoke forming tendency and ignition characteristics. High volatile matter coals give long flames, high smoke and low heating values. Coals with low volatile content burns with a shorter flame, thus, the higher the volatile content, the larger is the combustion space required. Hence, the volatile matter content of coal influences the furnace design. Further, the percentage of volatile matter in coal denotes the proportion of coal which will be converted into gas and the

products by heat. Hence, high volatile matter content is preferable in coal gas manufacture and in carbonization plants, particularly when the main objective is the by product recovery. For the manufacture of metallurgical coke, coal with low volatile matter and high fixed carbon is preferred. The volatile matter content is more in bituminous coals than in anthracite coals. The volatile matter percentage gives some idea about coking properly of coal. The determination of volatile matter content is an important determination because volatile matter data are an integral part of certain classifications systems and also form the basis of evaluating coals for their suitability for combustion and carbonization. The methods for determining volatile matter content are based on the same principle and consist of heating a weighed sample of coal (usually approximately 1g) in a covered crucible to a predetermined temperature. The loss in weight (excluding losses due to water) is the volatile matter content (expressed as weight percent).

The temperatures are in the range 875-1050°C. The duration of heating is 3-20 minutes and the crucibles may be platinum, silica or ceramic material for German standards the temperature range in 875°C to be according to the industrial coking practice (Spheight, 1983).

One or two crucibles may be used. Two crucibles method is used in (Belgium, France) where coal is heated in a crucible which is enclosed in a larger crucible with the space between the two crucibles filled with carbon (charcoal). The advantages of using two crucibles in methods of this type is believed to arise from the prevention of partial oxidation and hence reduction of accrued errors. Also, the lower rate of heating (resulting from insulating effect of charcoal) assists in preventing the ejection of solid particles which can occur when lower rank coals in 10 to 20 ml platinum crucibles are heated at a higher rate as suggested by ASTM. D 189.

This is the residue derived from mineral matter during complete incineration of coal. The ash content is usually determined by heating (burning) a sample (1-2 g) of coal in an adequately ventilated muffle furnace at temperatures in the range 700-950 °C. The temperatures prescribed by the American society for testing and material is $725 \pm 25^{\circ}\text{C}$ for coal and up to but more than 950°C for coke (ASTM D3174). (Spheight, 1983; Barbaras, 1991).

2.7.4 Fixed Carbon

This is the material remaining after determination of moisture, volatile matter, and ash. It is a measure of solid combustible material of coal after expulsion of volatile matter. The fixed carbon content increases from low ranking coals such as lignite to high ranking coals such as anthracite. It is the fixed carbon which burns in solid state. Hence, information regarding the percentage of fixed carbon helps in designing of the furnace and the fire box (Dara, 2004).

Fixed carbon plus ash represent the approximate yield of coke from coal. It involves combustion of exact amount of coal in a closed system and the products of combustion (CO_2) determined by absorption (ASTM D 3178, ISO 609 and 625). The combustion is usually accomplished by placing the ground Coal (to pass through 60-mesh) in a stream of dry oxygen at a temperature of $850 - 900^{\circ}\text{C}$ ASTM D 3178). Complete conversion of combustion of gases to CO_2 and H_2O can be achieved by passing gases through heated cupric oxide. Other absorbents are magnesium perchlorate and soda-lime.

The carbon and hydrogen are calculated from the increase in weight of the absorbants used to collect the water and CO_2 . Oxides of sulphur, are removed by passing the products of combustion over heated lead chromate or Manganese dioxide (Spheight, 1983).

2.7.5 Sulfur

Sulphur present in coal contributes towards the heating value of the Coal but its combustion products (SO_2 and SO_3) have corrosive effects on the equipments, particularly in the presence of moisture. Further, the oxides of sulfur are undesirable from the atmospheric pollution point of view. Sulfur containing coal is not suitable for the preparation of metallurgical coke as it adversely affects the properties of the metal. Sulfur is either organically bound or inorganic sulfur (pyrite, marcasite or sulfate). Organic sulfur is less than 3% while inorganic sulfur is estimated to be around 11%. Iron content was determined as it shows the amount of sulfur present since half the amount of sulfur does exist as pyrite. The amount of iron oxide is very important since depending on its quantity, it can be extracted and used as a raw material in cement industry (Putnis, 1992).

Three methods are usually used in determination of sulfur. These are: Bomb combustion method, Eschka method and the high temperature combustion method. All the above three methods are based on combustion of sulfur containing matter to produce sulfate which can be measured either gravimetrically or volumetrically (Spheight, 1983).

The Eschka method is accepted as standard method for determination of sulfur in coal. The three methods of sulfur determination have all found application in the various national standards (ASTM D 3177, DIN 51724, BS 1016, ISO 334 and 351). The Eschka procedure has been favoured because of its relative simplicity. (Spheight, 1983). In the Eschka method, the sulfur compounds evolved as a result of combustion, react with sodium carbonate and under the oxidizing conditions, (the magnesium carbonate which serves to reduce the bulk density and thereby allows air into the mass), are retained as sodium sulfate which is determined gravimetrically as a barium sulfate. The Eschka mixture consists of

combusting coal with one part sodium carbonate and two parts calcined magnesium carbonate (Spheight, 1983; Barbaras, 1991).

2.7.6 The Calorific Value

The calorific value is determined using the bomb calorimeter, either by static (Isothermal method or adiabatic method. (Spheight, 1983; Barbaras, 1991).

The Isothermal method: ASTM D 3286.

The calorific value is determined by burning a weighed sample of coal in oxygen under controlled conditions and calorific value is computed from the temperature observation made before, during and after combustion with appropriate allowances made for heat contributed by other process.

The adiabatic method:

The Coal is burned in an adiabatic bomb under controlled conditions and the calorific value is determined from the corrected rise in temperature. The computed values of calorific value are expressed in either: Calories per gram cal/g, Btu/lb and Absolute joules. The calorific value measured is usually gross calorific value. The net calorific value is calculated from the gross calorific value by making suitable subtraction of $1030 \text{ Btu/lb} = 572 \text{ cal/g} = 2.395 \text{ kj}$. This allows for the water originally present as moisture as well as that moisture formed from coal during combustion (Dara, 2004; Comstock, 1982; Spheight, 1983).

2.8 PRECISION AND ACCURACY OF COAL ANALYSIS

The deviation from true or theoretical value is not ordinarily attempted in coal analysis. Precision is determined by means of cooperative test programmes. Both repeatability, the precision with which a test can be repeated in the same laboratory and the reproducibility; the precision expected from different laboratories are determined (Spheight, 1983).

2.9 ATOMIC ABSORPTION SPECTROSCOPY

Introduction

Atomic absorption spectroscopy (AAS), is a spectrophotometric technique based on the absorption of radiant energy by atoms. Approximately two elements can be determined by AAS in concentrations ranging from 10ppm for some of the more difficult rare earths to less than 1ppb for mercury by the graphite furnace method. The absorption of this specific radiation follows Beer's law and is directly proportional to the concentration of the atom in the flame. The electromagnetic spectrum is approximately 0.002 nanometers wide. Therefore a continuous radiation source, such as a tungsten lamp cannot provide sufficient energy. A source called a hollow cathode lamp is usually required since each element requires a different source. AAS is a poor qualitative tool but is extremely useful for quantitative determination (Vogel, 1960).

Principle

While a sample is being aspirated into a flame, a light beam is directed through the flame into a monochromator and into a detector that measures the amount of light absorbed by the atomized element. In the flame, a source lamp composed of the element of interest is used because each element has its own characteristic wavelength. This makes the element free from spectral or radiation interference. The amount of energy at the characteristic wavelength

absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range. Most atomic absorption instruments are also equipped for operation in an emission mode (Bartram *et al*, 1996).

2.10 THE BOMB CALORIMETER

Principle method

The heat of combustion of a compound is measured by burning it in oxygen in a bomb contained in a calorimeter. The substance to be burned is weighed and brought into intimate contact with the ignition wire. The substance is burned in a bomb-calorimeter in pure oxygen at 30kp/cm. The burning is started by an electrical impulse through the ignition wire. The heat evolved by burning raise the temperature of the calorimeter system. Around 10 - 15 minutes after the ignition, the heat exchange between the bomb and the surrounding inner vessel is complete. The temperature rise is measured and is used to calculate the heat of combustion. This is only possible when the thermal capacity of the calorimeter system has been evaluated by combustion of a reference substance under the same experimental conditions. The value of the heat of combustion of the reference must be known exactly (Jankel *et al*, 2000; Gerson *et al*, 1968).

The Calorimeter

The calorimeter consists of a reaction vessel that is surrounded by a large volume of water contained in a well insulated vessel. When the reaction takes place in the calorimeter, the temperature of the water reservoir either increases or decreases according to whether the reaction is exothermic or endothermic. The heat liberated or absorbed is calculated by measuring the change in temperature and multiplying the change in temperature by the heat capacity of the calorimeter. No calorimeter is perfectly insulated, and therefore all determinations are complicated by loss of heat from the calorimeter to its surrounding or by

absorbing heat by the calorimeter from its surrounding. Correction is usually made by taking a number of temperature measurements after the reaction has taken place and then extrapolating back to zero time on a temperature versus time graph for a calorimeter experiment (Gerson *et al*, 1968).

CHAPTER THREE

3.0 METHODOLOGY

3.1 CHEMICALS, INSTRUMENTS AND APPARATUS

3.1.1 Instruments

The following instruments were used in this research.

| Instrument | Model | Source |
|-------------------------------------|---------------------------|----------------------------------|
| Atomic absorption Spectrophotometer | Shimadzu AA 6300 | Japan |
| Bomb Calorimeter | ChadWell Health Essex BtT | Baird and Tatlock Ltd England |

3.1.2 Apparatus

- Muffle furnace
- Hot plate
- Oven

3.1.3 CHEMICALS AND REAGENTS

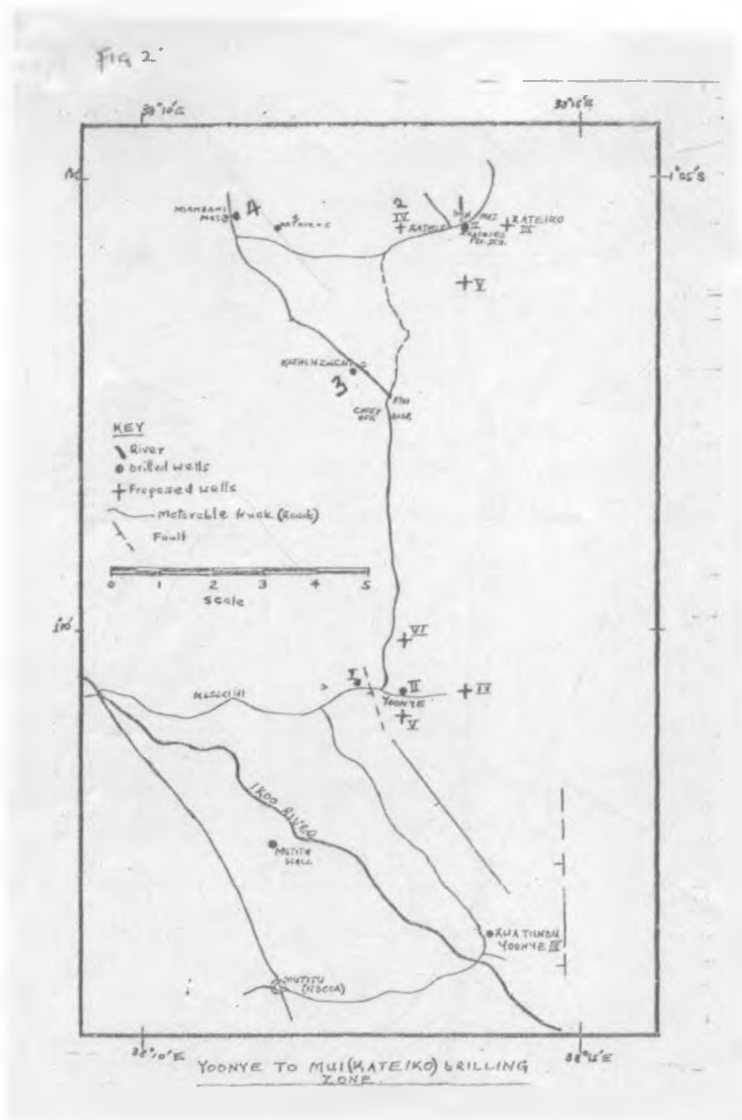
All the chemicals used in this work were of analytical grade. In addition to the common laboratory chemicals, the following were used.

| Chemicals / Reagents | % Purity | Source |
|-----------------------------|-----------------|------------------------------|
| Conc Hydrochloric acid | 98% | Fisher Scientific Ltd |
| Concentrated Nitric acid | 72% | Fisher Scientific Ltd |
| Concentrated Sulphuric acid | 98% | Fisher Scientific Ltd |
| Magnesium per chlorate | 86% | British Drug House (BDH) Ltd |
| Manganese dioxide | 70% | BDH Co. Ltd |
| Sodium hydroxide | 70% | BDH Co. Ltd |
| Sodium carbonate | 99% | BDH Co. Ltd |
| Magnesium oxide | 92% | BDH Co. Ltd |
| Barium Nitrate | 99% | Hopkins and Williams Ltd |
| Ferrous ammonium Sulphate | 99.75% | Fisher Scientific Ltd |

3.2 SAMPLING

Samples from each of the four already sunk borehole from Mui basin 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.

The figure below shows the site of the four drilled wells where the quality of the coal samples was determined



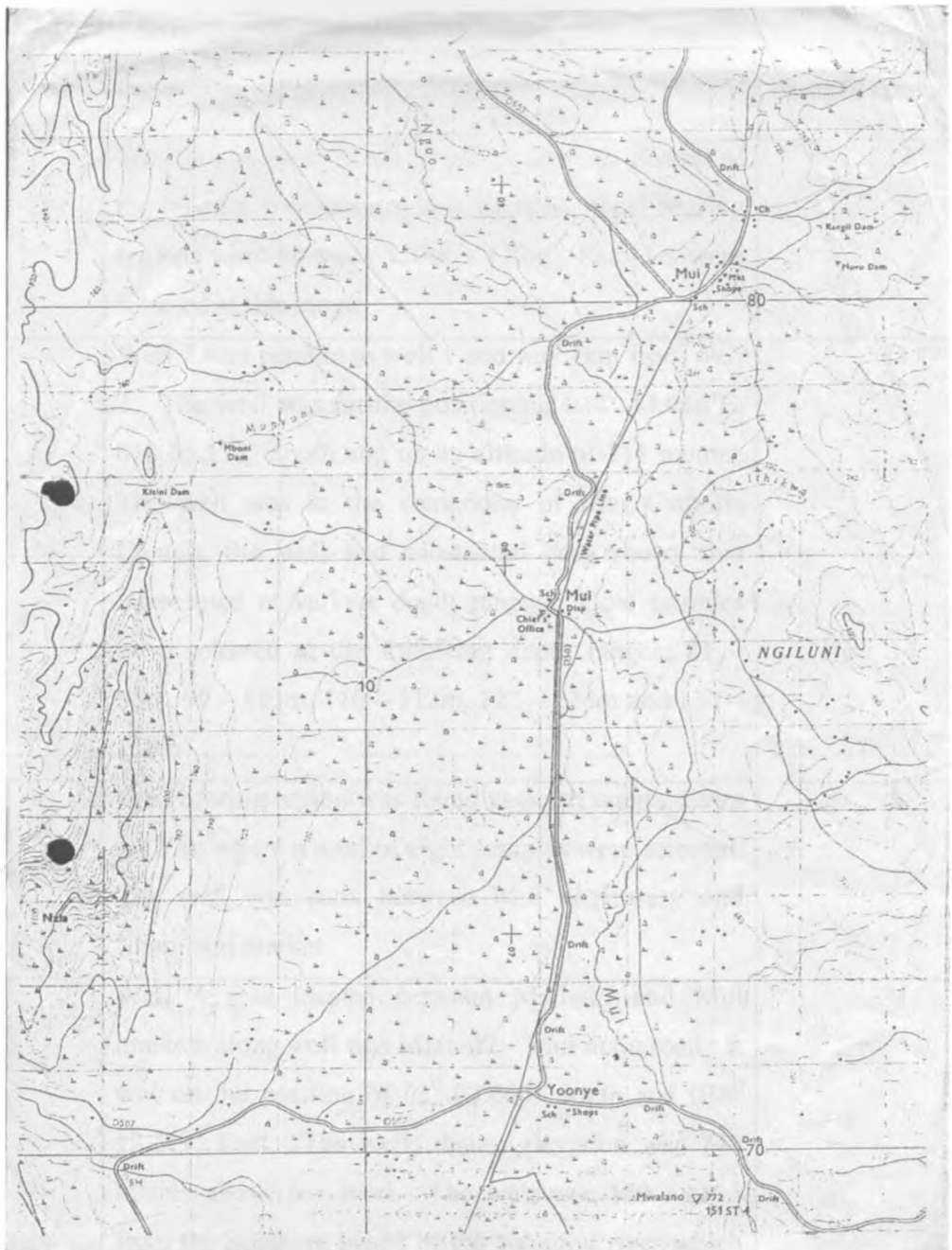


Fig 3.2b: Coal sampling sites

Table 3.2.1: Site stratification and sampling frame

| Well | Description of well | Sample size |
|------|---|-------------|
| 1 | Well 1 was sunk in the South of Mwingi district at the boarder 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 ⁰ 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 ⁰ 03.669' South and 038 ⁰ 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 upto 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 |

3.3 EXPERIMENTAL PROCEDURES

3.3.1 CALORIFIC VALUE DETERMINATION

The calorific value of coal samples was determined using the bomb calorimetric method.

About 0.5 grams of each sample was accurately weighed to the nearest 0.0001 gram. The sample was placed inside the sample holder and installed inside the stainless steel bomb. Pure oxygen gas was then added to the assembled bomb using the gas valve. The sealed bomb was then placed inside the calorimeter bucket that contained 1700 ml of water.

The bucket and bomb assembly was then installed inside the insulated calorimeter container. The thermometer and the stirrer mechanism were installed into the water bath surrounding the bomb. The water was stirred at a constant rate and the temperature allowed to reach equilibrium after ten minutes. The temperature were recorded after every thirty seconds.

The bomb mixture was then ignited after ten minutes by depressing the electrical ignition device. The rise in temperature was continuously recorded every thirty seconds until a constant maximum temperature was reached. The observed change in temperature was the algebraic difference between the initial temperature at firing time and the final calorimeter water temperature.

The corrected rise in temperature for each sample was then obtained by plotting the above recorded temperature versus time curve and extrapolating to zero time. This gave the accurate final temperature. Temperature change was obtained by determining the temperature difference between the final temperature and the initial temperature at firing time. [Gerson 1968, Ullmann's 1994]. This however, was found to be almost the same as the observed temperature change.

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.

Calibration of bomb calorimeter

(i) Determination of the quantity of water required in the inner vessel.

The calorimeter bomb was placed, closed in the inner vessel. The vessel was then filled with water until the bomb was submerged with the upper point of the ignition connector standing 6 mm above the water. The bomb was removed from the inner vessel and the volume of water determined by pouring it into a 2 litre measuring cylinder. The volume of water was 1700 cubic centimeters.

(ii) Calibration of the calorimeter

Knowing ΔT and the heat capacity, the heat of reaction of the calorimeter (w) was found

$$-q = w \cdot \Delta T$$

W consists of the heat capacity of the water of the calorimeter (1700cm^3), which was taken as 1700 cal/degree, plus the heat capacity of the bomb and other parts. To find the heat capacity of all these parts, a combustion experiment was carried out using benzoic acid with a known heat of combustion of 6318 cal/g. ΔT was determined after combustion and heat capacity calculated. [Ullmann's 1994, Hill 1991, Janke 2000]

The heat capacity (w) was 2335 cal/degree. The heat of combustion of the cotton thread and the different sources of error were also partly compensated for in this experiment. From $w = 1700 + w_b$ and $w_b = 635$ cal/degree.

3.3.2 FIXED CARBON

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

Drying of Manganese dioxide.

The manganese dioxide powder was placed in a pyrex beaker and then heated in an oven at a temperature of 110°C for 2 hours. The dried contents were then placed in a desiccator.

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. (Gerson: 1968).

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.

NB: Before the coal samples were analyzed using this technique, the percent efficiency of the technique was determined by analyzing the carbon content in a known sample - naphthalene ($C_{10}H_8$) and comparing the experimental value of carbon content with the exact value. Three tests were carried out with continued perfection of the method especially packaging of the absorbents. The weight of carbon dioxide was determined in each case. In the first test, 0.0730 g of naphthalene was accurately weighed and heated in a bomb calorimeter and the gas passed through the absorbents (Ullmann's 1994, Janke 2000, Findlay 1963).

The % carbon obtained was 82.07% instead of 93.618%. This gave a percent efficiency of 87.68%. In the second test, 0.0700 grams of naphthalene were accurately weighed and mass of carbon dioxide determined as above. The percent carbon obtained was 87.62 % instead of 93.618 % giving an efficiency of 93.60%. A third test was carried out using 0.0748 grams of naphthalene and increasing the number of second massing tube to three. The percent carbon content obtained was 89.26% giving an efficiency of 95.34%.

The coal samples were then analyzed using the technique at this percent efficiency. However, the second massing tubes containing sodium hydroxide were increased to four to ensure maximum absorption of carbon dioxide gas.

3.3.3 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 (NO₃)₂.

Preparation of 0.01M Ba (NO₃)₂

About 2.6 grams of Barium Nitrate was accurately weighed and then placed in one litre volumetric flask. This was dissolved by adding de-ionised water into the flask and shaking thoroughly. The dissolved solution was then filled to the mark.

Preparation of the Eschka mixture.

This 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 (Spheight 1983, Barbaras 1991).

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 (NO₃)₂. 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. The sulfur content as a percentage in each sample was determined by taking;

$$\frac{(\text{Mass of the precipitate} \times \text{gravimetric factor of sulfur when massed as Barium Sulphate})}{\text{Weight of the sample}} \times 100$$

3.3.4 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 (Spheight 1983). The crucible and the ash was weighed after cooling in a desicator. The nature and colour of ash was also noted. The results were expressed as percentage of the coal sample used.

3.3.5 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 (Spheight, 1983, Barbaras 1991).

3.3.6 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 (Spheight, 1983, Barbaras 1991).

3.3.7 IRON CONTENT

Iron content was analyzed using flame-acetylene (AAS) at 248.3 nm (Ullmann's , 1994, Gerson 1968)

Preparation of the Aqua regia

The Aqua regia was prepared by mixing concentrated HCL and conc. HNO_3 in the ratio 3:1. 900 ml of conc. HCL was mixed with 300 ml of conc. HNO_3 and kept in a plastic bottle. Mixing of all acids was done in a fume chamber. (Barbara, 1991)

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. (Bartram 1996). 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.

Calibration Curve

250 ml stock solution of 1000 ppm was prepared by accurately weighing 1.7597 g of $(\text{NH}_4)_2\text{SO}_4$, $\text{FeSO}_4 \cdot 6\text{H}_2\text{O}(\text{s})$ 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. (Gerson 1968, Bartram 1996).

(ii) 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.

(ii) Analysis of samples:

The nebuliser 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.

(iii) 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;

$$\frac{\text{Initial volume of the digested sample} \times \text{exact concentration in ppm} \times \text{dilution factor} \times 10^{-6}}{\text{Weight of the sample}}$$

Concentrations in mg/g or as a percentage were also determined by multiplying by a thousand and a hundred respectively.

3.3.8 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 carboneaceous shales, or rock. This was based on the South African coal ranking system (Table 2.6.1a and Table 2.6.1e). Ranking of the coal samples was first done per Well and overall rank established after critically analyzing the results for the four Wells. The results obtained were recorded in appendices 1,2,3, and 4. General discussion of the above results regarding coal ranking has been done in chapter 4.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

A total of seventy nine samples from four different wells were examined in order to establish the presence and quality 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.

The results obtained provided quick and valuable information regarding commercial classification and determination of the suitability of the coal from Mui basin identified for a particular industrial use (Dara, 2004).

In this chapter, the results obtained for each parameter analyzed have been discussed as presented below.

4.1.1 CALORIFIC VALUE

The calorific value for each sample for all the four wells was analysed using the bomb calorimetric method (section 3.3.1). The results below shows the average calorific value of coal samples obtained per well.

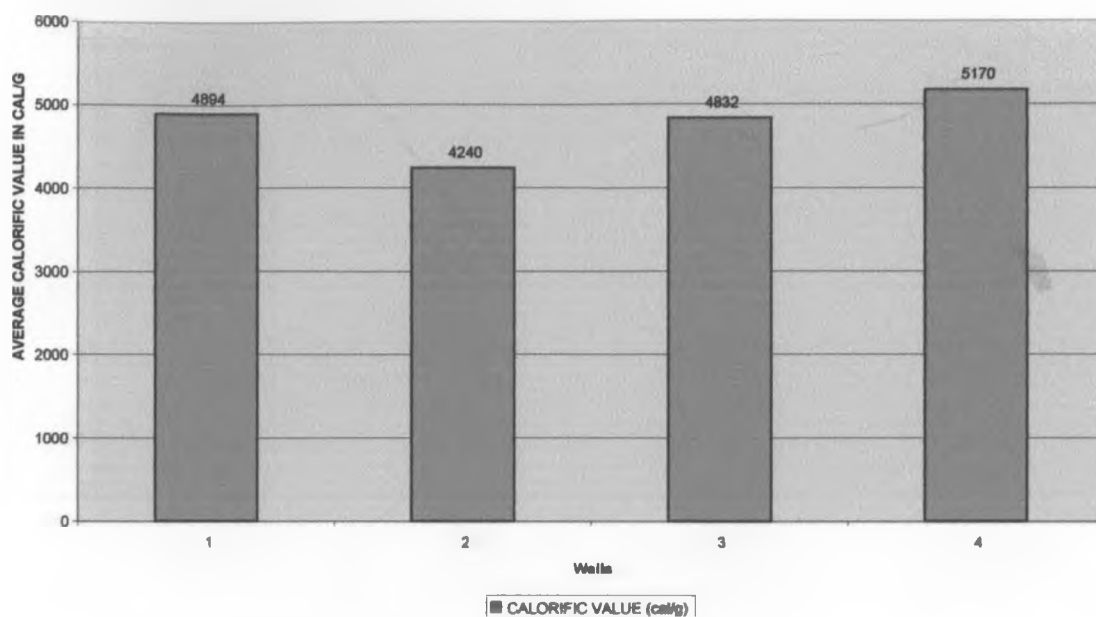


Figure 4.1.1 Average Calorific value of coal from the wells

On comparing the wells, well 4 had coal with the highest average calorific value compared to coal from other wells. Well 1 and well 3 had coal with similar calorific value. Well 2 had coal with the least calorific value compared to other wells. Thus, high quality coal was found in well 4.

4.1.2: FIXED CARBON

Fixed carbon for each carbon sample was determined using bomb calorimetric method as in procedure 3.3.2. From the results obtained, the average fixed carbon for all the samples per well was done and wells compared as shown below.

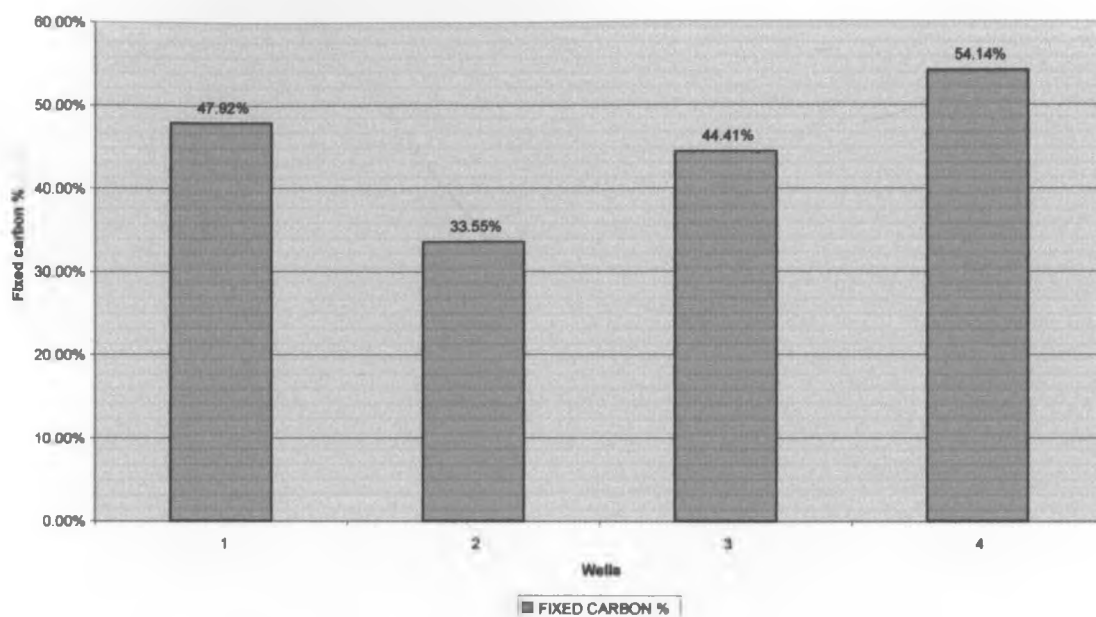


Figure 4.1.2 Average fixed carbon in coal

Well 4 had coal with the highest calorific value and fixed carbon. Generally, the fixed carbon in all the wells, increased with increasing calorific value of the samples, implying that fixed carbon plays a great role in determining the calorific value of coal samples.

4.1.3 SULPHUR

The sulphur content for each coal sample was determined following the experimental procedure 3.3.3. The average sulphur content in coal from each well was worked out basing on the results obtained. The figure below shows the sulphur content obtained from coal in Well 1,2,3 and 4.

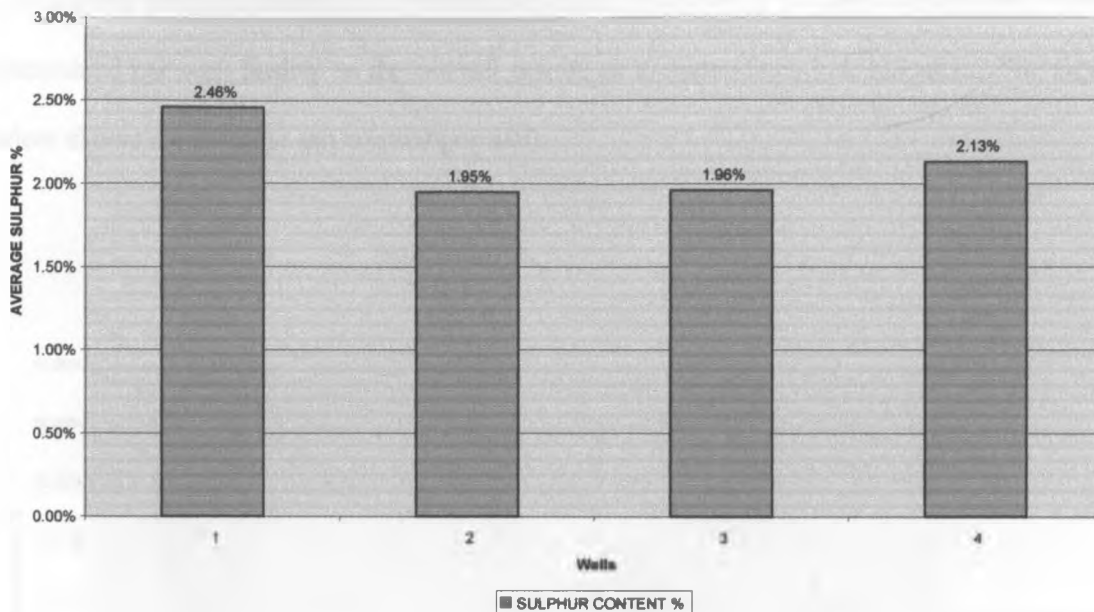


Figure 4.1.3 Average Sulphur content in coal from wells

The mean sulphur content in coal from all the wells is approximately 2.0%. High sulphur coal is that with sulphur content of 3 – 6% (Bailey, 2003). The range sulphur content in coal has been approximated as at (0.2 – 8%) (World Bank, 1996). The global required sulphur content into the environment is 0.05%. The sulphur content in coal from these wells is relatively high, and thus, if the coal will be used in boiler fuel or as domestic coal, then, there will be need for installations for desulphurization of flue gases in order to avoid emissions of SO_2 . In power plants, the reaction between sulphur and alkalis or alkaline metals will lead to formation of complex sulphate and contribute to corrosion. There will be need to reduce the sulphur content in coal from Mui basin before using it.

4.1.4 ASH

Ash content for each sample was determined as in procedure 3.3.4 and average ash content determined per well basing on the overall results as in appendices I, J, K and L. The figure below shows the average ash content per well

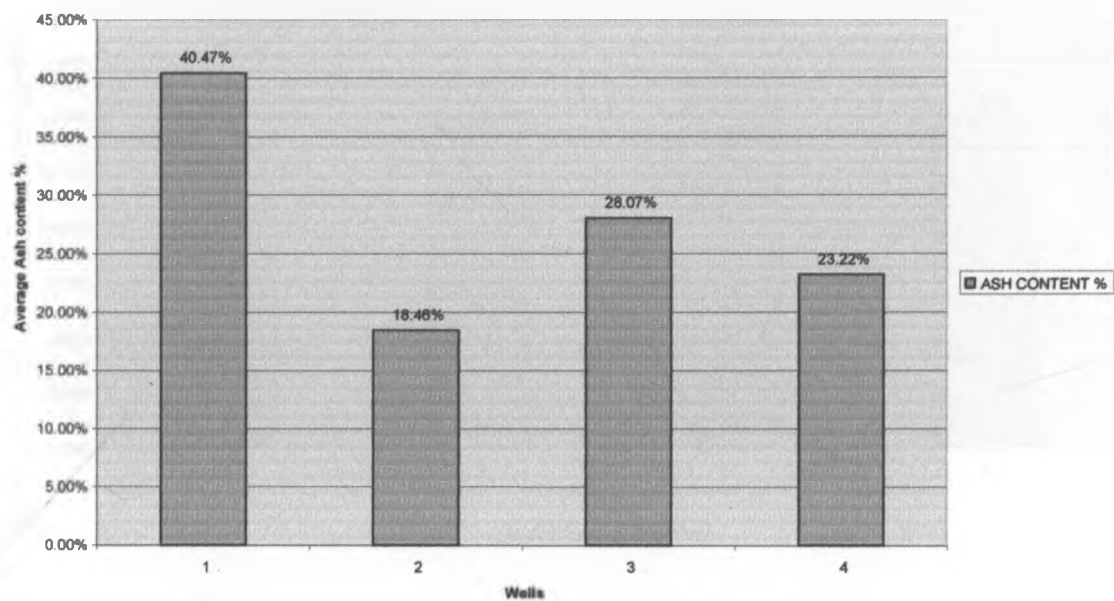


Figure 4.1.4 Average ash content in coal from the wells

Coal from well 1 had the highest ash content of approximately 40%. The ash content in coal has been approximated to be (5 – 40%) (McCloskey Group, 2002). The mean ash content of coal from well 2 and well 4 was almost the same where the ash content was approximately 20%. The high ash content in coal from well 1, may affect its use in power generation. In addition, coal from well 1 had also high sulphur content (fig. 4.1.3). High sulphur retention in coal ash of well 1 could have significantly contributed to the high ash content.

4.1.5 MOISTURE

Moisture content for each sample was determined basing on procedure 3.3.5 and average moisture content of coal per well calculated from the results obtained for all the samples in each well.

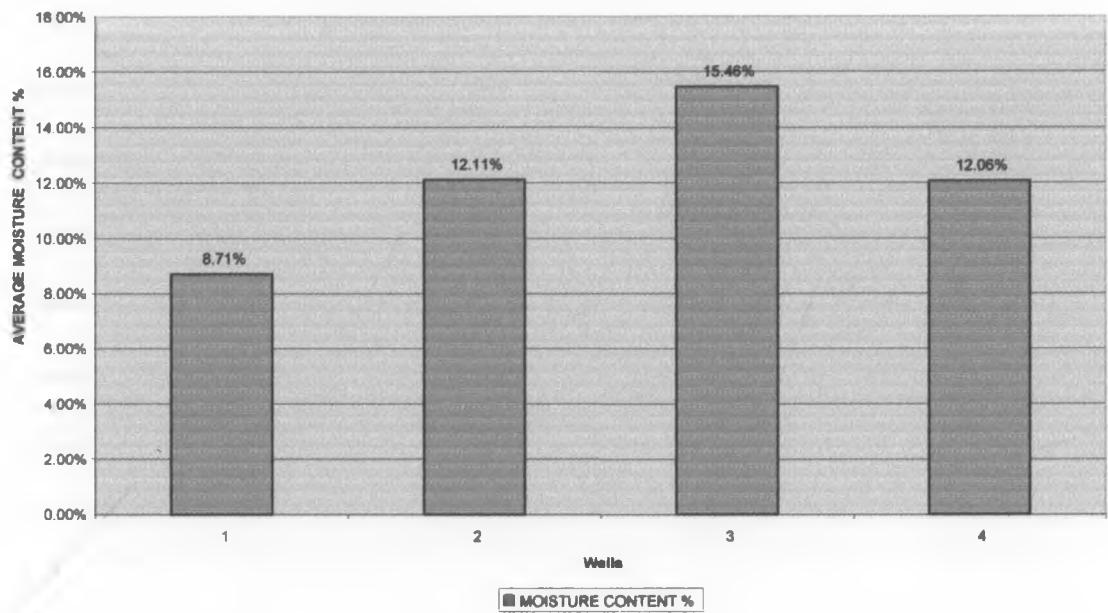


Figure 4.1.5 Average moisture content in coal from the wells

Well 2 and 4 had coal with similar moisture content of 12.11% and 12.06% respectively. The average moisture content of coal from well 3 was 15.5%. The moisture content in coal has been approximated to be between (2 - 40%) (World Bank, 1996). Well 1 had coal with the lowest average moisture content, thus, less heat will be used in evaporating this moisture from coal during combustion compared to coal from other wells. Also, the transportation cost of coal from well 1 will be lower.

4.1.6 VOLATILE MATTER

The average volatile matter was determined as per the results obtained per sample in each well after analysis in procedure 3.3.6. The graph showing average volatile matter in coal from the wells has been illustrated below.

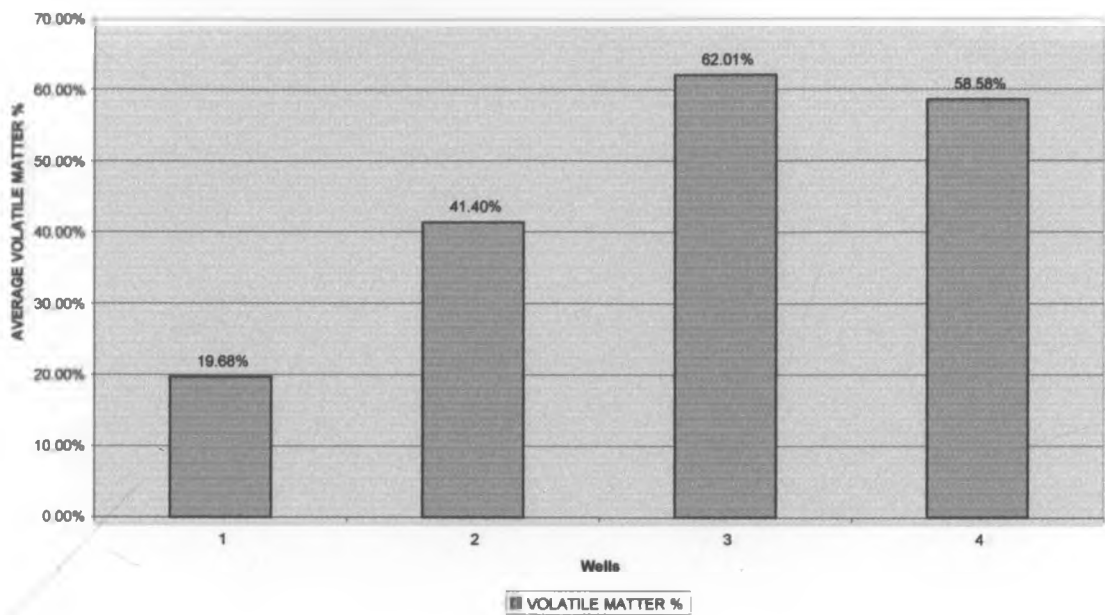


Figure 4.1.6 Average percent volatile matter in coal from Wells

Coal from well 1 had the lowest volatile matter content of 19.68%, while that from well 3 and 4 had the highest mean volatile matter content of approximately 60.00%, which may affect its suitability for use in metallurgical coking. In addition, the coal from wells 3 and 4 will burn with long flame and emitting high smoke, thus, the combustion space (furnace design) should be larger than that designed for combustion of coals from wells 1 and 2. However, the high volatile matter content in coal from wells 3 and 4 could be of an advantage, if this coal will be used in coal gas manufacture and in carbonization plants, where, the main objective is by – product recovery

4.1.7 IRON CONTENT

The amount of Iron content found in each of the coal sample was done using AAS (section 3.3.7) and the average iron content of all the samples per well determined from the results obtained as shown below.

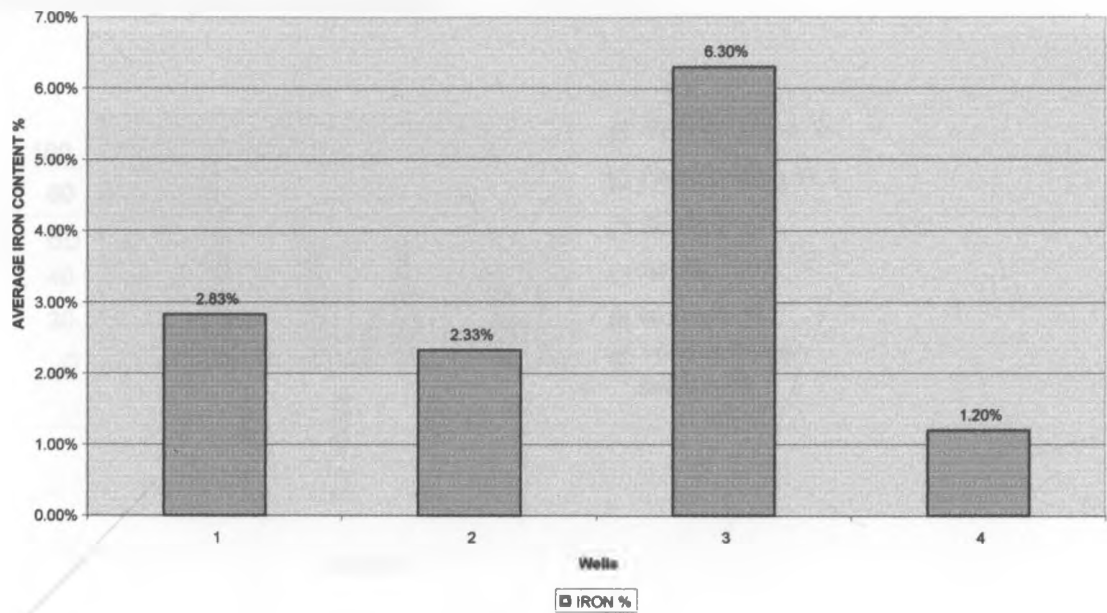


Figure 4.1.7 Average percent iron content in coal from Wells

The mean iron content was higher in well 3 with 6.3%, but lowest in Well 4 with 1.20%. Well 1 and well 2 had coal having almost the same iron content of 2.83% and 2.33% respectively. The high iron content will be of significant use, if it will be removed from the coal ash and be converted into other useful application such as steel industry. However, if it will be discharged as part of the affluent, then, there will be need to monitor the iron content before discharge, since the maximum amount of iron required in the liquid affluent should be 3.5 mg^l⁻¹ (World Bank, 1996). The presence of iron increases acidity of liquid affluent due to hydrolysis.

4.2 INTERRELATIONSHIP BETWEEN THE PARAMETERS ANALYZED PER WELL AND THEIR IMPLICATIONS

Results of four different samples from each well (as appendices 1, 2, 3 and 4) were selected and numbered as S1 – S4 with decreasing calorific value. The parameters for each sample as a percentage were plotted against the sample number, and their interrelationship assessed. The following figures were obtained.

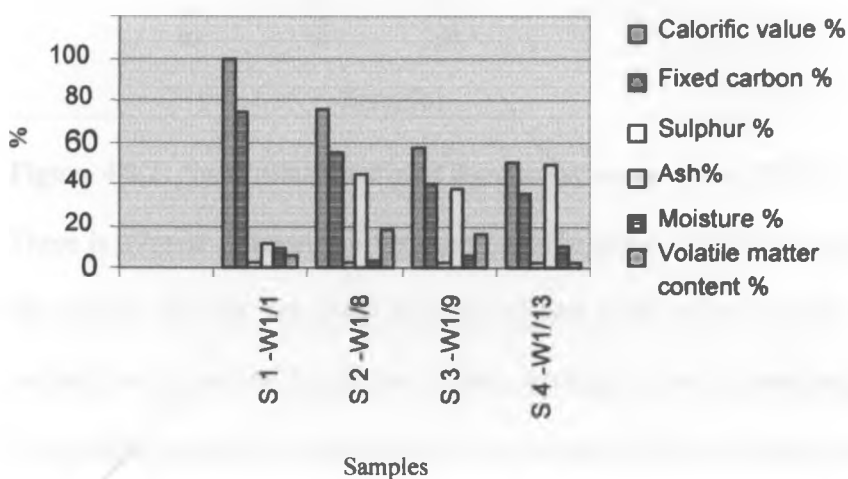


Figure 4.2.1: Interrelationship of parameter value from Well 1

S1-W1/1, S2-W1/8, S3-W1/9 and S4-W1/13 were samples number 1, 8, 9 and 13 respectively as in appendix I. In all the samples, the fixed carbon increased with increasing calorific value. The fixed carbon increases from low ranking coals with low calorific value to high ranking coal, (Dara, 2004). The ash in samples S1, S3 and S4 increased with decreased calorific value. Sample S1-W1/1 with a highest calorific value had the lowest sulphur, ash, moisture and volatile matter content. While sample S4-W1/13 with the least calorific value, was reported to have the highest ash content and moisture content. Low ash content has been reported in coal with the high calorific value (Barbara, 1991; Speight, 1983).

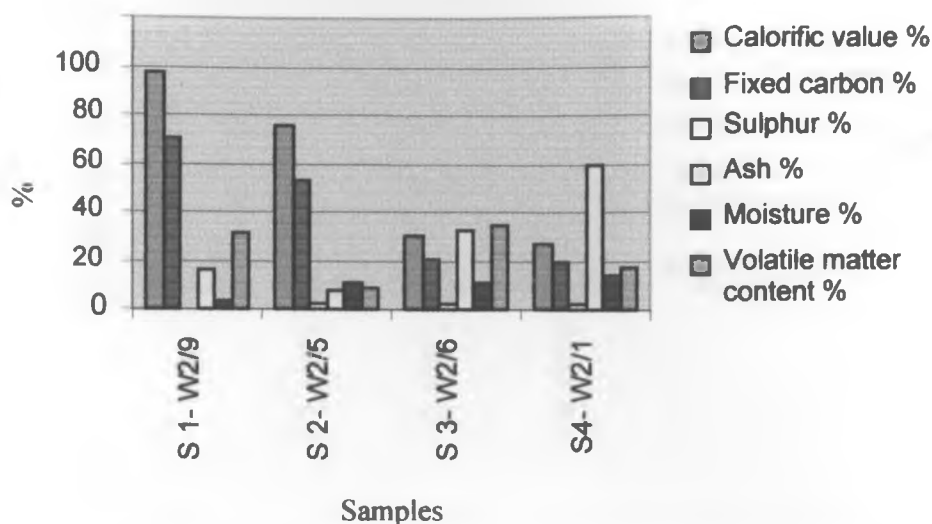


Figure 4.2.2: Interrelationship of parameter values from Well 2

There is a linear relationship between calorific value and fixed carbon only, sample S1 with the highest calorific value had also the highest fixed carbon, while sample S4 with the least calorific value had the least fixed carbon, but highest ash content compared to other samples. The moisture content was also reported to increase with decreasing calorific value. S1-W2/9, S2-W2/5, S3-W2/6 and S4-W2/1 were sample number 9, 5, 6 and 1 of appendix 2.

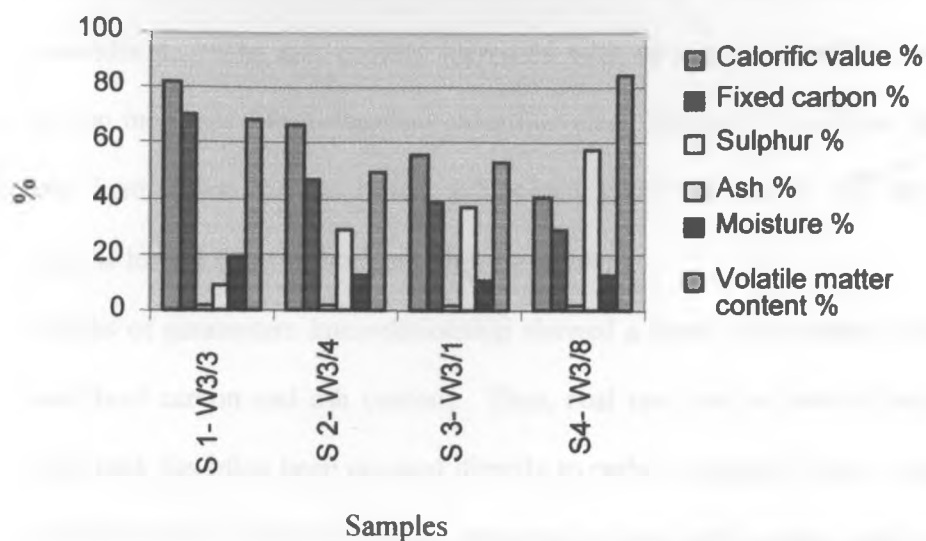


Figure 4.2.3: Interrelationship of parameter values from Well 3

S1-W3/3, S2-W4/4, S3-W3/1 and S4-W3/8 were sample number 3, 4, 1 and 8 of appendix 3

The ash content increased with decreasing calorific value. The moisture and sulphur content was similar in all the samples.

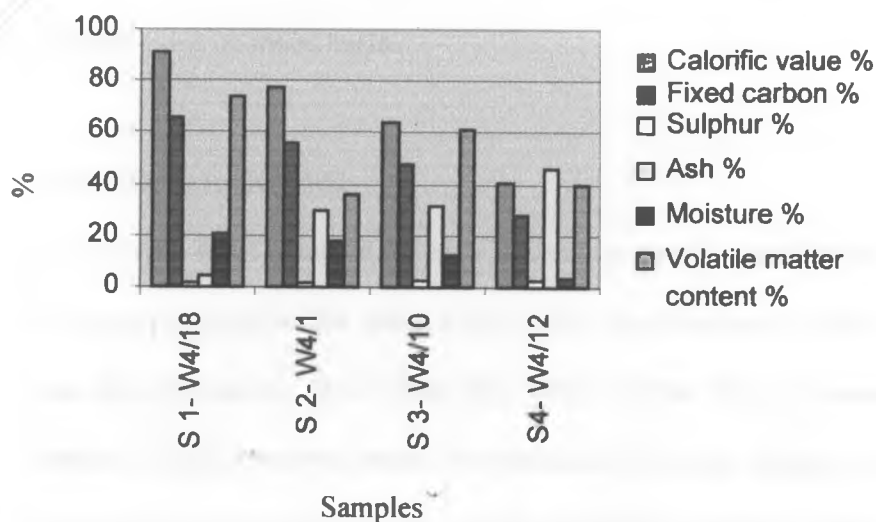


Figure 4.2.4: Interrelationship of parameter values from Well 4

S1-W4/18, S2-W4/1, S3-W4/10 and S4-W4/12 were sample number 16, 1, 10 and 12 of appendix 4. The ash content increases with decreasing calorific value, while the fixed carbon increases with increasing calorific value. Sample S1 with the highest calorific value and fixed carbon had the lowest ash content while sample S4 with the least calorific value had the lowest fixed carbon, but high ash content.

Graphs of parameters interrelationship showed a linear relationship between calorific value and fixed carbon and ash content. Thus, coal can also be ranked basing on fixed carbon. Coal rank has often been equated directly to carbon content, where, classification of coal by rank has been considered to be a progression from high carbon coal to low carbon coal in conjunction with other properties of coal (Spheight, 1983). The American Society for Testing and Materials has also evolved a method of coal classification over the years, that relies on the fixed carbon content as well as other physical properties such as ash content and volatile matter content. Similarly, according to McGraw Hill, 1987, high rank coals have always been classified with respect to fixed carbon on dry basis, and low rank coals according to calorific value on moist basis.

4.3 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. (MC Graw Hill, 1987, ASTM 1991, Comstock 1982, Barbara 1991). Ranking of coal from Mui basin was based on the South African coal ranking system, based on calorific value. (Table 2.6.1a). Coal can either be ranked as anthracite, bituminous, lignite or peat. Anthracite is the highest quality while peat is the lowest quality. Tables 4.3.1, 4.3.2, 4.3.3 and 4.3.4 below shows the coal rank established per each Well after critically reviewing the results recorded in appendices 1,2,3 and 4.

Table 4.3.1: 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 4.3.2: 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 is of high quality compared to Well 1 since it has the highest % anthracite coal compared to Well 1.

Table 4.3.3: 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 | 37.5% |
| Lignite | 3891 | 1 | 12.5% |
| Peat | 2829 | 1 | 12.5% |
| Rock | Did not ignite | 1 | 12.5% |
| 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 4.3.4: 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 |
| TOTAL | | 31 | 100 |

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).

4.3.5 OVERALL QUALITY OF COAL FROM MUI BASIN

The mean and range value per parameter for all the samples analyzed in all the 4 wells was established and recorded in table 4.3.5a.

Table 4.3.5a: Overall Quality of Coal from Mui basin

| Parameter | Range (%) | Mean % |
|-----------------------|---------------|--------|
| calorific value Mj/kg | 8.65 - 31.40 | 21.16 |
| Fixed carbon % | 20.00 - 80.12 | 52.16 |
| Volatile % | 4.98 - 85.90 | 45.89 |
| Ash % | 2.09 - 61.06 | 26.53 |
| Sulphur % | 0.45 - 3.98 | 2.01 |
| Iron % | 0.02 - 40.33 | 2.04 |
| Moisture % | 1.99 - 20.46 | 10.85 |

The mean sulphur content of coal from Mui basin was found to be 2.01% with 0.45% as the lowest sulphur content established and 3.98% as the highest. All coals contain sulphur and the amount depends on their type and origin. Studies done has shown that in the United States, the coals from the Eastern, mid Western and Southern States, are predominantly higher in sulphur, containing 2 – 4%, while those from Western States mostly contain less than 1%. The sulphur content of German ignite has been established as at 1 – 2% rarely > 5%, while that from the Ruhr has 0.5 – 2.5% and South African coals range from 0.3% to 2.8% (Ullmann's 1994). Recent studies have shown the sulphur content in South African coal from South Eskom general is 1% while that from South African coal from New Vaal is 0.5%. [South African coal processing society]. Elsewhere, sulphur content in coal has been established to be within the range of 0.2 – 8% (Dara, 2004), while in others, the range total sulphur content is 0.42% to 6.47% (Spheight, 1983). According to studies done by Fable (1982), sulphur content in coals range from 0.5 and 3%. In addition, analyses done on coals of different rank by McMullan in 1976, showed that, the sulphur content range from 0.23% to 5.69%. Thus, basing on these values, the sulphur content in coal from Mui basin is quite comparable. Several severe environmental problems may result from using greater amounts of coal in energy production. One major problem, is the release of oxides of sulphur when coal is burnt. The clean air act standards for emission of oxides of sulphur can only be made if the sulphur content is 1% or less. (Bailey, 2003). This is not a big problem because the above sulphur content in Kenyan coals can be reduced to just 50% (minimum required emission of 1% by just washing and drying (McCloskey Group, 2002)

In addition to the already mentioned uses of different ranks of coal, coal is also recognized as a source of valuable elements and inorganic materials such as uranium, germanium and other desired elements. Elsewhere, sulphur, which is also a valuable element has been obtained from coal by conventional gas – cleaning method (Spheight, 1983). It is of great interest to

note that world resources of sulphur has been estimated at 25×10^9 tonnes with 4.0% as elemental sulphur; 4.1% in sulphide ores; 3.0% in crude oil, 5.3% in natural gas while the rest 83.6% of sulphur is obtained from coal. (Ullmann's, 1994). Thus, availability of coal in Kenya will also be a main source of sulphur and other valuable elements. In addition, several methods of prevention of SO_x emission have been proved to be quite effective. These include flue gas desulphurization (99% efficient) and fluidized combustion 90% and use of super critical coal – fired plant especially for cement industry and other industries that use coal as process heat. (Roger, 2004, Bailey, 2003). The high sulphur coal which requires use of relatively expensive methods of removal of Sox, is that with sulphur content between 3 – 6%. (Bailey, 2003). However, of the samples analyzed, only two samples had sulphur content slightly above 3%. Thus, it is clear that sulphur content in coal from Mui basin will not be a great environmental threat, but economically viable, since, only washing will be enough to reduce it to the minimum required standard specification.

Similarly, coal from Mui basin had relatively high ash content of 26.53%. However, coal washing has been considered as an effective and cheap way of reducing the ash content by 50% (W.E.C, 2004). In addition, the ash coal is considered as a major source of mineral wealth such as germanium, uranium, iron among others (Ullman's 1994). Similarly, modern coal –fired power stations which have very effective ash – arresting equipments are available, which prevents serious pollution due to the harmful elements in ash after disposal.

The mean iron content in coal from Mui basin samples was found to be 2.04%, with 0.02% as the lowest, while 40.33% as the highest iron content. Iron metal is a very important component in the steel industry (Ullmann's, 1994). In addition, iron is used as a catalyst in many industrial processes. Manufacture of various alloys requires iron as the main raw

material. Thus, presence of iron content in the coal from Mui basin sample will be of economic importance. The use of coal in electricity generation and for heat production should not be a problem in terms of CO₂, since cleaner coal technologies, which ensure zero emission of CO₂ in to the atmosphere, such as carbon capture and carbon sequestration as discussed in chapter two, have been developed.

The mean values in table 4.3.5a above were used to establish the overall rank of coal from Mui basin basing on the South African coal ranking system. The following rank was established in the table below.

Table 4.3.5b: Overall coal rank

| Coal rank | No. of Coal Samples | % |
|--------------|---------------------|------------|
| 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 |
| TOTAL | 79 | 100 |

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.

The mean values in table 4.3.5a above were compared with coal from South Africa (Eskom general and coal from New Vaal) as indicated below.

Table 4.3.5c: Comparison of Coal from Mui Basin with South African Coal

| | Kenya | South Africa (Eskom general) | South Africa (New Vaal) |
|------------|-------|------------------------------|-------------------------|
| Cv Mj/Kg | 21.16 | 21 | 16 |
| Vm % | 45.89 | 23 | 16 |
| Fc % | 52.16 | 44 | 36 |
| Ash % | 26.53 | 30 | 40 |
| Sulphur % | 2.01 | 1 | 0.5 |
| Moisture % | 10.85 | 4 | 6 |

The mean calorific value of coal from Mui basin was slightly higher than that of South African coal. This was also the same with fixed carbon. This showed direct correlation between calorific value and fixed carbon. The sulphur content in coal from Mui basin was however higher than that of South Africa but the ash content was lower than that from South African coal. The moisture content and volatile matter content in coal from Mui basin were found to be relatively higher compared to coal from South Africa.

4.3.6 CLASSIFICATION OF COAL FROM MUI BASIN IN REFERENCE TO SPECIFIC USE

The classification of the coal from Mui basin with reference to specific use, was done using the guided table from South African coal processing society, (table 2.6.1a) and other literature sources. In tables 4.3.6a, 4.3.6b and 4.3.6c below, the coal samples from Mui basin have been classified with reference to either as industrial fuel, domestic fuel and according to specific use in terms of power generation, domestic fuel, gaseous fuel and metallurgical coke, after assessing the calorific value, ash and volatile matter content per coal sample. Samples found to be mere rock was excluded

Table 4.3.6a: Overall Classification as Hard Coal or Soft Coal

| Coal Type | No. of Coal Samples | Percent (%) |
|--------------|---------------------|-------------|
| Hard coal | 42 | 67 |
| Soft Coal | 21 | 33 |
| TOTAL | 63 | 100 |

The hard coal comprised of anthracite and bituminous coal samples, and the rest were soft coal as in table 4.3.5 b

Classifying the above samples as hard coal and soft coal the hard coal comprised of 42 samples (67%). 21 samples (33%) was soft coal. Rock samples were excluded. Studies done as indicated in table 2.3.1, shows that, coal resources in most African countries are mainly hard coal (W.E.C, 2004).

Table 4.3.6b: Classification according to specific use

| Use | No. of Coal Samples | % |
|---|---------------------|-------|
| Power generations (ash < 34%, CV >3346 Cal/g) | 40 | 62.49 |
| Domestic fuel | 12 | 19.05 |
| Metallurgical coke (vol <34%, CV 20 -32 mj/kg) | 11 | 17.46 |
| TOTAL | 63 | 100 |

Similarly, when these samples were classified according to specific use, 40 samples (62.49%) were found to be suitable for power generation, 12 samples (19.05%) were found to be suitable for either domestic fuel or gaseous fuel, or tar distillation, and the rest 11 samples (17.46%) were found to be suitable when used as metallurgical coke. The above results showed that coal from Mui basin can basically be used for power generation while a small portion of approximately 18% can be used in metallurgical coking.

Table 4.3.6c: Classification as industrial fuel and domestic fuel

| Use | No. of Samples | % |
|-----------------|----------------|-------|
| Industrial fuel | 51 | 80.95 |
| Domestic fuel | 12 | 19.05 |

Classifying the above samples as industrial fuel or domestic fuel, 51 samples (80.95%) could be used as industrial fuel while 12 samples 19.05% could be used as domestic fuel.

4.3.7 WELL ANALYSIS AND THEIR ECONOMIC IMPLICATION

The mean values per parameter of coal analysed per well were critically reviewed and the economic implication of coal from each well was assessed basing on table 2.6.1e. The mean value for the samples analysed was done per well for each parameter and the results obtained are presented in 4.3.7.1 below.

Table 4.3.7.1

Average values obtained per well after analysis of calorific value, fixed carbon, sulphur content, ash content, moisture content, volatile matter and iron

| WELLS | CALORIFIC VALUE (cal/g) | FIXED CARBON % | SULPHUR CONTENT % | ASH CONTENT % | MOISTURE CONTENT % | VOLATILE MATTER % | IRON % |
|-------|-------------------------------|----------------------|-------------------------|---------------------|--------------------------|-------------------------|-----------|
| 1 | 4894 | 47.92 | 2.46 | 40.47 | 8.71 | 19.68 | 2.83 |
| 2 | 4240 | 33.55 | 1.95 | 18.46 | 12.11 | 41.40 | 2.33 |
| 3 | 4832 | 44.41 | 1.96 | 28.07 | 15.46 | 62.01 | 6.3 |
| 4 | 5170 | 54.14 | 2.13 | 23.22 | 12.06 | 58.58 | 1.20 |

The calorific value and fixed carbon of coal from well 1 was higher than that of South African coal (table 4.3.5c). However, coal from this well is mainly bituminous coal. Due to its relatively low volatile matter content, the coal from this Well was found to be both suitable when used as metallurgical coke and also for power generation. The coal from well 2 had high mean volatile matter content, hence not suitable for metallurgical coke. However, relatively low ash content and high mean calorific value, makes it suitable both for power generation and also as domestic fuel or gaseous fuel or for tar distillation. The mean calorific value also classifies this coal as mainly bituminous coal.

The volatile content in coal from well 3 was relatively high. Hence, coal from this Well may not be suitable for metallurgical coke. However, it can be used for power generation and production of gaseous fuels. The coal from this well can generally be classified as bituminous coal using South African coal ranking systems.

Well 4 had coal with the highest calorific value compared to other wells, although the coal is still mainly bituminous coal. The high volatile matter content makes this coal unsuitable to be used as metallurgical coke, however, this coal may be used for power generation, as gaseous fuels and for tar distillation.

CHAPTER 5

5.0 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.

The size of the coal deposits, and, they can be mined economically, could not be established at this initial stage because exploration in other parts of Mui basin and other areas in the country, such as Taru at the coast was yet to be done. The economic viability of coal mining will depend on the depth range of all the explored coal wells in Kenya and quantity of established recoverable coal in the country and its overall quality.

The results of the above study have shown that coal of high quality do exist in Kenya and also clean coal technologies are in use in other countries and that coal can reliably and securely be used as an alternative energy resource for sustainable development. It is with this in mind that the following recommendations are being made: Environmentally sound and cost effective clean coal technological options exist and should be made available and facilitated by developed countries to developing countries, as well as countries with economies in transition, with a view to making energy for sustainable development a reality.

The government of Kenya to support and encourage investment in coal mining and coal-fired power stations using existing cleaner coal technologies. Moreover, given the magnitude of future energy requirements in Kenya, it is urgent that the government of Kenya encourages and support the increase of research in energy which should be shared between the public and private sectors.

In addition, the government of Kenya should network with world wide major coal producing countries and other private companies, which are investing in collaborative research for clean coal technologies so that she can acquire and use the same technologies depending on tuheir viability. For example, forums such as carbon sequestration leadership through which countries such as Brazil, Canada, China, Columbia, the European Union, Italy, Mexico, Norway, Russia, UK and the US are attempting to stimulate research on how CO₂ produced through burning fossil fuels can be stored deep underground. Other agencies may include world coal institute and international energy agencies.

Should the government of Kenya approve the coal mining and use in Kenya, then, there will be need to carry out a comprehensive research on elemental analysis in Kenyan coal sample and also fly ash. Coal is a heterogeneous mixture of many minerals. It is important to measure the inorganic constituents accurately in order to be able to follow their path through various stages of coal production and utilization. The analysis will also provide important information regarding the possible conversion of coal to synthetic fuel, due to increased emphasis on the development of synthetic fuels to supplement the depleting natural petroleum resource, a viable alternative fuel source.

It is also with great interest to note that no analysis of the ash from coal used in cement industry in Mombasa has been done. There is future need also to analyze this coal ash from South Africa and compare it with the coal from Mui basin. There will also be need to carry out a comprehensive life cycle analysis of coal which include all other impact categories. Key industries that heavily rely on fuel oil or wood fuel to generate process heat that is used in boilers such as cement industry, Nzoia Sugar, Mumias Sugar, KTDA, East Africa breweries, Cement Industry, should consider carrying out both an economic and environmental survey of shifting to coal.

There is need for the people of Kenya to be sensitized about the role coal can play in sustainable development, so that they develop a positive attitude towards it and eradicate the old traditional myths about its vice. This can be done through publications on newspapers, TV's, public barazas and seminars. Upon completion of exploration of coal, there will be need to call upon expertise to establish the quantity of coal, both resources and reserves in Kenya.

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GLOSSARY OF ACRONYMS AND DEFINATIONS

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|---|---|
| Calorific value | The calorific value of a fuel is defined as the amount of heat obtainable by the complete combustion of a unit mass of the fuel. |
| Calories (cal) or gram calorie (gcal) | <p>The amount of heat required to raise the temperature of 1g of water through 1°C more precisely from (15°C to 16°C).</p> <p>1 calorie = 4.185 joules = 4.185×10^7 ergs</p> |
| Kilo calorie or kilo gram calorie or Kilogram centigrade unit (Kcal or Kgcal or K.C.U) | <p>This is equal to 1000 calories and is thus the amount of the heat required to raise the temperature of 1kg of water through 1°C more precisely from (15°C to 16°C) 1Kcal = 1000 cal.</p> |
| British thermal unit (B. Th. U or B. T. U) | <p>A British thermal unit is the amount of heat required to rise the temperature of 1 lb of water through 1°F (more precisely from (60°F to 61°F)).</p> <p>1 B. T. U = 1,054.6Joules = $1,054.6 \times 10^7$ ergs.</p> |

Gross calorific value

The gross calorific value or higher calorific value is the total heat generated when a unit quantity of fuel is completely burnt and the products of combustion are cooled from 60°F or 15°C (room temperature)

Thermal capacity or specific heat capacity

Is the quantity of heat required to produce unit change of temperature in a unit mass of a substance. Alternatively, specific heat of a substance is the ratio of the thermal capacity of the substance to that of water at 15.5°C (or 60°F), since the thermal capacity of water at 15.5°C (or 60°F) = 1.000. Units of specific heat are B. Th.U/lb/ $^{\circ}\text{F}$ and cal/g/ $^{\circ}\text{C}$.

Parts per million (PPM)

One part per million (PPM) is the unit weight of Solute per million unit weights of solution.

In dilute solutions of density = 1,

1PPM = 1mg/litre.

APPENDICES

APPENDIX 1: SAMPLES FROM WELL 1

| Sample No. | Sample code | calorific value cal/g | fixed carbon % | ash % | sulphur % | moisture content % | volatile matter % | iron mg/g | calorific value mj/kg |
|------------|-------------|--------------------------|----------------|-------|-----------|-----------------------|----------------------|-----------|--------------------------|
| 1 | W1/1 | 6964 | 71.84 | 10.95 | 2.01 | 9.63 | 5.98 | 17.7 | 29.14 |
| 2 | W1/2 | 6405 | 66.07 | 12.93 | 3.54 | 7.18 | 5.83 | 2.8 | 26.80 |
| 3 | W1/3 | 6915 | 73.84 | 3.91 | 2.03 | 7.75 | 4.96 | 34.8 | 28.93 |
| 4 | W1/4 | 6797 | 70.97 | 2.09 | 2.16 | 6.59 | 7.71 | 109.7 | 28.44 |
| 5 | W1/5 | 6289 | 64.88 | 13.15 | 2.01 | 6.61 | 14.59 | 17.6 | 26.31 |
| 6 | W1/6 | 6020 | 62.10 | 13.04 | 2.69 | 6.47 | 18.69 | 145.7 | 25.98 |
| 7 | W1/7 | 2956 | 29.45 | 59.80 | 1.80 | 2.90 | 5.09 | 3.2 | 12.37 |
| 8 | W1/8 | 5309 | 55.05 | 44.50 | 1.90 | 3.63 | 18.72 | 3.0 | 22.21 |
| 9 | W1/9 | 4007 | 39.92 | 38.27 | 2.03 | 6.01 | 16.53 | 2.2 | 16.77 |
| 10 | W1/10 | 4996 | 49.77 | 44.79 | 1.89 | 6.30 | 6.79 | 27.4 | 20.91 |
| 11 | W1/11 | D.I | N.D | 74.01 | 1.78 | 8.71 | 9.01 | 4.2 | N.D |
| 12 | W1/12 | D.I | N.D | 63.21 | 8.56 | 8.51 | 32.65 | 1.5 | N.D |
| 13 | W1/13 | 3499 | 34.86 | 48.62 | 1.95 | 10.50 | 2.61 | 4.8 | 14.64 |
| 14 | W1/14 | D.I | N.D | 60.55 | 2.26 | 11.10 | 10.02 | 5.7 | N.D |
| 15 | W1/15 | D.I | N.D | 76.01 | 2.01 | 7.58 | 13.74 | 0.5 | N.D |
| 16 | W1/16 | 4810 | 49.92 | 38.46 | 1.98 | 8.39 | 54.13 | 6.6 | 20.13 |
| 17 | W1/17 | D.I | N.D | 70.68 | 1.65 | 7.20 | 8.68 | 0.5 | ND |
| 18 | W1/18 | DI | ND | 80.02 | 2.03 | 8.77 | 14.07 | 0.8 | ND |
| 19 | W1/19 | DI | ND | 80.00 | 2.01 | 8.90 | 12.59 | 4.9 | ND |

| | | | | | | | | | |
|----|-------|------|-------|-------|------|-------|-------|------|-------|
| 20 | W1/20 | DI | ND | 75.04 | 1.95 | 8.73 | 20.14 | 0.9 | ND |
| 21 | W1/21 | DI | ND | 77.23 | 2.11 | 7.47 | 19.14 | 0.2 | ND |
| 22 | W1/22 | DI | ND | 66.80 | 1.99 | 6.80 | 26.92 | 5.1 | ND |
| 23 | W1/23 | 3105 | 30.93 | 59.98 | 2.03 | 1.99 | 4.10 | 10.9 | 12.99 |
| 24 | W1/24 | DI | ND | 64.01 | 2.00 | 9.98 | 22.78 | 5.6 | ND |
| 25 | W1/25 | 2821 | 28.10 | 60.37 | 2.07 | 7.77 | 5.51 | 5.5 | 11.80 |
| 26 | W1/26 | DI | ND | 66.12 | 1.91 | 8.40 | 22.91 | 17.1 | ND |
| 27 | W1/27 | DI | ND | 68.11 | 2.24 | 5.02 | 24.13 | 3.0 | ND |
| 28 | W1/28 | 2005 | 20.00 | 61.06 | 2.36 | 10.02 | 27.85 | 1.9 | 8.39 |
| 29 | W1/29 | 5400 | 53.80 | 10.74 | 1.95 | 7.87 | 81.99 | 1.92 | 22.59 |

| TABLE I | | TABLE II | |
|---------|-------|----------|-------|
| Year | Value | Year | Value |
| 1950 | 100 | 1955 | 150 |
| 1951 | 110 | 1956 | 160 |
| 1952 | 120 | 1957 | 170 |
| 1953 | 130 | 1958 | 180 |
| 1954 | 140 | 1959 | 190 |

APPENDIX 3: SAMPLES FROM WELL 3

| Sample No | Sample code | calorific value cal/g | fixed carbon % | ash % | sulphur % | moisture content % | volatile matter % | iron mg/g | calorific value mj/kg |
|-----------|-------------|--------------------------|-------------------|-------|-----------|-----------------------|----------------------|-----------|--------------------------|
| 1 | W3/1 | 3891 | 38.76 | 36.64 | 2.15 | 11.10 | 53.09 | 7.2 | 16.28 |
| 2 | W3/2 | 5350 | 55.48 | 11.27 | 1.99 | 15.60 | 72.06 | 403.3 | 22.38 |
| 3 | W3/3 | 5756 | 70.20 | 9.18 | 1.93 | 18.98 | 68.79 | 9.5 | 24.08 |
| 4 | W3/4 | 4677 | 46.59 | 29.22 | 2.04 | 12.32 | 49.74 | 2.9 | 19.57 |
| 5 | W3/5 | 6468 | 66.72 | 16.74 | 1.75 | 18.96 | 64.46 | 11.4 | 27.06 |
| 6 | W3/6 | D.1 | N.D | 66.17 | 1.46 | 0.16 | 0.23 | 1.3 | N.D |
| 7 | W3/7 | 4851 | 48.33 | 36.11 | 2.01 | 19.01 | 40.97 | 0.9 | 20.30 |
| 8 | W3/8 | 2829 | 29.17 | 57.32 | 1.83 | 12.23 | 84.96 | 6.6 | 11.84 |

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Sample code | W4/1 | W4/2 | W4/3 | W4/4 | W4/5 | W4/6 | W4/7 | W4/8 | W4/9 | W4/10 | W4/11 | W4/12 | W4/13 | W4/14 | W4/15 | W4/16 | W4/17 | W4/18 |
| calorific value cal/g | 5417 | 5014 | 3304 | 5721 | 4489 | 427 | 6081 | 4234 | 3950 | 4475 | 3692 | 2821 | 5860 | 6125 | 5466 | 6110 | 5066 | 6395 |
| fixed carbon % | 56.17 | 49.95 | 32.91 | 59.32 | 44.72 | 4.25 | 62.73 | 42.18 | 39.35 | 47.75 | 36.78 | 28.10 | 60.76 | 63.18 | 56.68 | 63.03 | 50.47 | 6598 |
| ash % | 29.83 | 41.00 | 28.13 | 22.14 | 27.03 | 46.89 | 13.30 | 23.41 | 29.64 | 31.78 | 48.58 | 45.59 | 34.63 | 3.89 | 19.08 | 12.10 | 26.84 | 4.25 |
| sulphur % | 1.88 | 2.35 | 2.47 | 0.45 | 0.59 | 2.39 | 2.33 | 2.44 | 2.56 | 2.44 | 2.90 | 2.64 | 2.66 | 0.62 | 2.56 | 2.05 | 2.17 | 2.22 |
| moisture content % | 18.00 | 16.01 | 21.79 | 16.71 | 14.88 | 7.01 | 5.00 | 10.90 | 15.49 | 12.94 | 5.64 | 3.80 | 5.68 | 23.63 | 13.38 | 16.38 | 10.18 | 20.46 |
| volatile matter % | 36.38 | 31.44 | 43.20 | 58.59 | 52.83 | 31.53 | 85.90 | 55.61 | 49.05 | 61.60 | 53.34 | 39.62 | 61.32 | 73.42 | 65.25 | 69.78 | 67.98 | 73.46 |
| iron mg/g | 12.6 | 1.7 | 3.6 | 9.7 | 12.4 | 1.8 | 4.6 | 8.1 | 9.0 | 6.8 | 15.8 | 15.8 | 7.2 | 5.9 | 0.2 | 0.5 | 4.7 | 14.0 |
| calorific value mj/kg | 22.66 | 20.98 | 13.82 | 23.94 | 18.78 | 1.79 | 25.44 | 17.72 | 16.53 | 18.72 | 15.45 | 11.80 | 24.52 | 25.63 | 22.87 | 25.56 | 21.20 | 26.76 |

| | | | | | | | | | |
|----|-------|------|-------|-------|------|-------|-------|--------|-------|
| 10 | W4/19 | 5386 | 56.00 | 29.17 | 2.37 | 11.27 | 62.87 | 7.5 | 22.54 |
| 20 | W4/20 | 6270 | 64.68 | 9.99 | 2.00 | 15.63 | 75.97 | 2.1 | 26.23 |
| 21 | W4/21 | 6393 | 65.95 | 9.63 | 2.00 | 15.83 | 73.10 | 13.1 | 26.74 |
| 22 | W4/22 | 6263 | 64.61 | 5.58 | 2.27 | 17.42 | 17.73 | 17.3 | 26.21 |
| 23 | W4/23 | 6166 | 63.61 | 9.07 | 2.17 | 10.13 | 8.24 | 131.79 | 25.80 |
| 24 | W4/24 | 5567 | 57.73 | 28.87 | 1.21 | 10.96 | 78.18 | 0.68 | 23.29 |
| 25 | W4/25 | 5901 | 61.19 | 39.20 | 3.60 | 10.13 | 74.26 | 57.29 | 24.69 |
| 26 | W4/26 | 6161 | 63.55 | 19.60 | 1.78 | 8.45 | 73.71 | 0.03 | 25.78 |
| 27 | W4/27 | 5867 | 60.84 | 11.72 | 1.98 | 10.11 | 74.56 | 2.98 | 24.55 |
| 28 | W4/28 | 6116 | 63.09 | 17.83 | 3.98 | 10.92 | 85.53 | 2.89 | 25.59 |
| 29 | W4/29 | 4725 | 47.07 | 26.44 | 1.45 | 10.13 | 74.26 | 1.50 | 19.55 |
| 30 | W4/30 | 5754 | 59.66 | 27.39 | 2.01 | 9.23 | 81.88 | 0.95 | 24.08 |
| 31 | W4/31 | 3627 | 36.13 | 20.78 | 1.50 | 8.41 | 64.18 | 0.29 | 15.18 |