Characteristic Properties of Tanzanian Coal for High Temperature Gasification

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ABSTRACT

Tanzania has coal reserves amounting to over 180 million tons. The coal is of low quality due to the presence of high ash content of about 29%. The volatile matter of the coal is estimated at 27% and calorific value is in the range 20,093 kJ/kg to 29,501 kJ/kg. In order to contribute to national energy demand there is a need to utilize this coal reserve. However, the quality of the coal together with environmental concern associated with coal utilization, which includes the emission of SOx, NOx, CO2, and disposal of particulates (ash) is a drawback. The combustion of this feedstock is problematic due to poor ignition and burnout properties, high ash content and the production of pollutants such as SOx, NOx, which require expensive down-stream processing. This has called for a need for alternative clean route to obtain the energy. The high temperature gasification of coal particles has been shown to be a viable alternative to alleviate these problems for the specific coal in reference. An investigation was undertaken to determine the characteristics and properties of the coal for power production as well as gasification. This paper presents the results for this undertaking that used thermo-gravimetric analysis (TGA) to ascertain the quality of Tanzanian coal for the said uses.

Key worlds: Coal, Gasification, Heating Value, Thermogravimetric Analysis

1.0 INTRODUCTION

In the foreseeable future coal will continue to be the primary source of power generation globally and in developing countries. Tanzania as one of developing countries depends over 90% of its primary energy consumption on biomass whereas petroleum and electricity accounts for 8% and 1.2%, respectively (MEM, 2003). Other energy sources including coal, solar, biogas and wind account for less than 1% of the total primary energy consumption. Imported petroleum, whose importation per annum averages 850,000 metric tones, supplies over 90% of the commercial energy needs. Its importation per annum consumes more than 30% of the foreign exchange earned by country.

Coal reserves in Tanzania are estimated at about 1,200 million tones of which 304 million tones are proven. The vast Tanzania reserves of coal have and will continue to receive considerable attention as a source of energy generation. The thermal properties of coal play a significant role in revealing its specific properties, its most appropriate uses in industry, and impacts of coal combustion on environmental pollution (Wall *et al.,* 2003). Methods such as thermo-gravimetric analysis (TGA) and Differential Scanning Calorimetry (DSC) measurements have been used to investigate the thermal properties of coal.

Coal characterization involves numerous complex reactions in coal conversion process. As the temperature increase, considerable changes occur in the coal residue (char). Solids, moisture and gaseous products are formed during the pyrolysis reactions and some of these reactions are accompanied by weight loss, and temperature changes. TGA of coal samples have been extensively used to determine the characteristics of devolatilization and kinetic parameters.

The volatile matter release profile of fresh coal can be describe using three stages: stage I (250 – 475°C), in which mainly light species are liberated; Stage II (475 – 575°C), characteristic of bituminous coal in which high molecular weight species (tar) and hydrocarbons (primary gases) are evolved, which may lead to melting (metaplast); and stage III (>575°C) in which secondary gases are produced while undergoing ring condensation leading the formation of char. The purpose of this paper was to investigate the kinetics of the pyrolysis of Tanzanian coal and their changes during the thermal characteristics

2.0 METHODS

Bituminous coal sample was collected from Kiwira Coal Mining Company Northern highlands of Tanzania. This sample was grinded to a size of 45µm, and then was oven dried at 105°C for 2hrs in VECSTAR 174799 FURNACE: Model-F/L. Table 1 shows the results of proximate and ultimate analyses of the coals used in the study. The coal samples with a particle size of 45µm were used for TGA and DSC analyses. For experimental parameters, 100mg coal samples a nitrogen atmosphere 50ml/min and heating rate of 10°C/min were used. The experiment was performed over a temperature range of 35°C to 1000°C using platinum crucibles. The weight loss (TGA signal) and the calorimetry (DSC signal) as a function of time and/or temperature were recorded, while the coals were subjected to a programmed computer-controlled temperature environment.

Table 1: Characterizations of Kiwira Coal Samples (dry base)

S/NO	**Proximate Analyses**	**(Wt%)**
1	Ash	53.802
2	VM	18.848
3	Fixed Carbon	27.686
S/NO	**Ultimate Analyses**	
1	C	85
2	H	5.3
3	N	0.507
4	O	5.27
5	S	0.692
6	CV	33.28

2.1 Thermal Decomposition

There are a number of approaches for modeling the complex pyroysis process. One of them is the empirical model, which employs global kinetics, where the Arrhenius expression is used to correlate the rates of mass with temperature (Wall *et al.,* 2007). The thermal degradation of coals particles in the pyrolysis zone can be represented by the first order called pyrolysis reactions:

$$Coal \xrightarrow{k} Colatile + char \qquad (1)$$

Alternatively, the kinetics is studied for TG/DSC data. Here it is assumed that the rates of weight loss of the total sample is dependent only on the rate constant, the remaining weight of the sample and its temperature with a reaction order of unity. The kinetics parameters of the thermal decomposition reactions were calculated by using an Arrhenius type kinetics model assuming that there is a first order reaction (Kok and Pamir, 2000). Kinetic analysis of non-isothermal pyrolysis, and is based on the following equations:

$$\frac{dW}{dt} = kW^{n} \tag{2}$$

$$k = A \exp\left(\frac{-E}{RT}\right) \tag{3}$$

Assuming first order kinetics $(n = 1)$,

$$\frac{dW}{dt} = A \exp\left(\frac{-E}{RT}\right).W \tag{4}$$

Taking the logarithm of both sides,

$$\log\left[\left(\frac{dW}{dt}\right) * \left(\frac{1}{W}\right)\right] = \log A_r - \frac{E}{2.303RT} \tag{5}$$

Where dW/dt is the rate of weight (W) change of the reacting material in % min^{-1}, A is the Arrhenius constant or pre-exponential factor in (min^{-1}), E is the activation energy in kJ mol^{-1} , T is the temperature in C, n is the reaction order and R is constant in 8.314 Jmol^{-1} . The plot of $\log[(dW/dt) * 1/W]$ against $1/T$ is a straight line with a slope of $-E/2.303R$.

The magnitude of the slope can be used to calculate the activation energy (E). The pre-exponential factor (A) can be calculated from the intercept.

Table 2: The Thermal degradation stages for Tanzanian coal determined from TG-DTG data

S/NO	Stages	Temperature	Thermal Degradation
1	I	>200°C	Maximum moisture released
2	II	400-600°C	The region for active decomposition(main volatiles evolution)
3	III	600°C-1000°C	The region where the combustion takes places

3.0 RESULT AND DISCUSSION

3.1 Pyrolysis

The TGA and DSC curves (Figure 1) of the Tanzanian coals indicates the pyrolysis of coal occur in three main temperature regions. DTG curves show the same trends in thermal behavior in 2 peaks. After the loss of moisture, in the temperature region of 200 to 400°C, a particle starts to lose mass from decomposing phenolic structures and oxides of carbon from carboxylic and carbonyl groups (Harries *et al.*, 2007). At temperatures below 400°C different processes takes place prior to primary pyrolysis to primary pyrolysis, disruption of hydrogen bonds, evaporation and transport of the non-covalently bonded molecular phase (Fletcher *et al.,* 2000). The second peak, where essential weight loss occurs in the range of 400-800°C is related to devolatilization, during which carbon, hydrogen and oxygen released. At 350°C primary carbonization starts, initially with the increase in temperature, methane and other lower aliphatics are evolved together with hydrogen, carbon monoxide, and alkyl aromatics (Harris and Elder, 1984; Yakar *et al.,* 2003). Primary devolatilization leads to the generation of tars and light oils between decomposition temperatures (T_d). Secondary devolatilization or decomposition results in the evolution of a variety of hydrocarbon gases, elemental hydrogen and oxides of carbon over an extended temperature range beyond 600 – 700°C (Qingzhao Li *et al.*, 2008; Yakar *et al.,* 2003). At temperature higher than 700°C the reactions takes place with condensation of the carbon matrix with the evolution of H_2. It can be seen that the maximum devolatilization temperatures are about 400 – 600°C for the higher temperature region as seen in Figure 1. Arenillas *et al.*, 2001, reported that the maximum devolatilization temperature is between 400°C to 500°C. The temperature maximum rate of weight loss in the higher temperature region may be used as an indicator of coal reactivity in devolatilization.

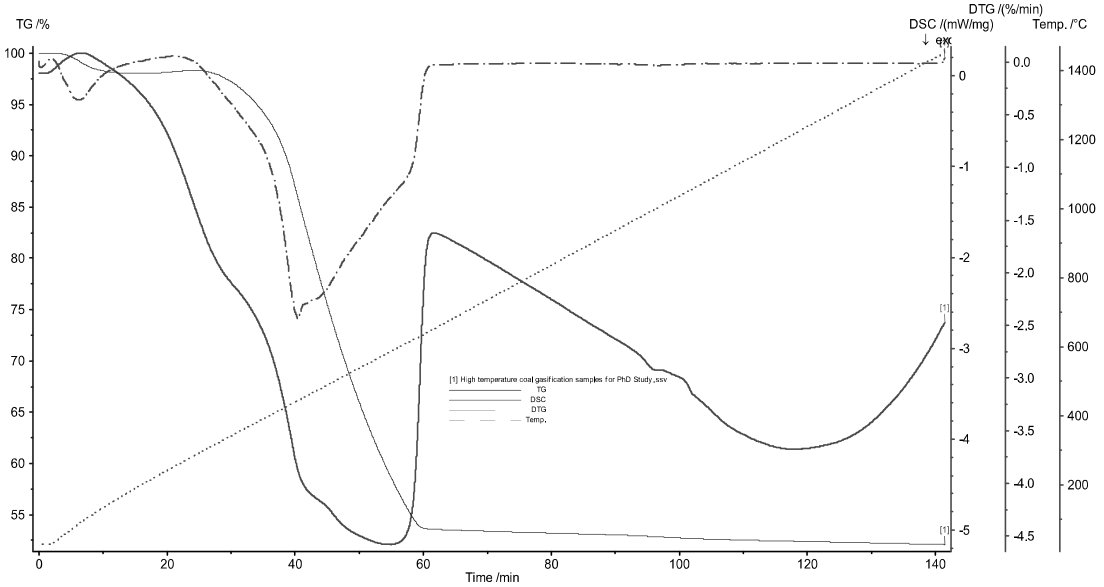

Figure 1: TGA-DSC Curves for Kiwira Coal

3.1.1 Activation Energy

Results of kinetic parameters analysis to the coal sample showed that the coal was highly correlated to the first order reaction (R^2=0.9956). The activation energy (A) was established to be 562.03 kJ/mol where the pre-exponential factor was 1.42 x 10^4 min

4.0 CONCLUSIONS

The thermal degradation characteristics of Tanzania coal depicted three common distinct TG regions that represent moisture release, devolatilization, and char degradation. The TG curves indicate that as temperature increases, the coal particles reactions take place with condensation of the carbon matrix and with highly the evolution of volatile matters. Rate of mass loss as represented by the DTG curve resulted in a devolatilization peak that occurred at 443°C. After the devolatilization DTG peak the rate of mass loss decreases sharply indicating that the coal is less reactive thereafter. This is due to the high ash content of the Tanzania coal. Activation energy value of from Tanzanian bituminous coal was established to be 562.03 kJ/mol.

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