Abstract—The biomass is experiencing a market increase in development, leading to research and development interest focusing on determining optimal biofuel combustion behavior as alternative energy source. The major focus of this paper is to describe the combustion behavior and kinetics parameters of cashew nut shells. Combustion behavior was studied by characterization and thermogravimetric analysis (TGA) at 10 °C/min heating rate under non-isothermal environment. The weight loss (WL) and weight loss rate (WLR) profiles were used to simulate the combustion behavior and kinetic parameters of the sampled material. It is observed that WL is attributed to main three regions drying, devolatilisation, and finally residues. Kinetic parameters activation energy (E) and pre-exponential factor (A) were determined at peak of WLR as function of temperature. Overall results show that cashew nut shells can be a useful candidate in thermal conversion system.

Keywords—Cashew nut shells, combustion behaviors, kinetics.

I. INTRODUCTION

Energy is a basic necessity for human activity, economic and social development, but the issues of energy on a global scale are about to face a major turning point. The population growth and the boom in energy consumption due to the improvement of living standards indicate that the progress of human civilization must face challenges in the near future [1]-[2], if it continues to depend on fossil resource, hence there is an urgent need for the development of an alternative energy source that will support a wide range of daily activities based on environmental conservation.

Biomass is renewable energy resources that continue to play a vital role in meeting local energy demand in many regions of the developing world. It is reported that about 2.4 billion people in developing countries use biomass; as their primary source of energy [3]. When this biomass is subjected to a combustion process, the contained components decompose. On the other hand, combustion is a complex process, which manifests through a series of reactions. In order to understand the biomass combustion, it is essential to study kinetics and combustion behavior which is useful in formulation of simple design and scaling rules to optimize thermal conversion process [4]. The reaction kinetic parameters are activation energy (E_a) and pre-exponential factor (A). They are obtained through measurement of sample weight loss as a function of time and temperature by using thermo-gravimetric analyzer, but this technique does not provide the capability to collect the combustion products and also the temperature variation during sample heating up period is neglected and the final temperature is taken as the reaction temperature [5]. Kissinger’s method is most accurate and simple method to estimate the reaction kinetic parameters when the analysis of the sample considered is to undergo a non-isothermal process [6]. The objectives of this paper are to investigate combustion behavior and reactivity under non-isothermal environments so that to allow self reactivity of biomass species.

The study employed autobomb calorimetry to determine energy contained in the material, and thermogravimetric analysis (TGA) to determine thermal/combustion characteristics [7]-[8]. During thermal decomposition, the contained xylene are likely to react independently. However most of the studies simplify and lump biomass as a single reactant as in [6] and shown in Figure 1. The kinetic study takes into account the decomposition rate to describe the properties of components contained in the biomass material.

II. METHODS

A. Material and Experiment

Cashew nut shells biomass material was selected for this study. The feedstocks were obtained from southern regions of Tanzania, the sample were processed based on two physical steps namely: chipping/shredding, and thereafter, ground to 1±0.5 mm particle size prior for characterization. Standard test methods based on proximate and ultimate analyses together with the Higher Heating Values (HHV) were obtained.

The reactivity and thermal behavior were performed using a thermogravimetric analyzer type Netzsch STA 409 PC.
It is observed that, the average moisture content (M) is 3.83 \%, and this is within acceptable limit to ensure free flow and good quality gas production [9]. The average of volatile matter content (VM) in cashew nut shell was found to be 73.41 \%. The higher amount of VM revealed the suitability of the fuel for gasification/pyrolysis.

### Table I

<table>
<thead>
<tr>
<th>Proximate analysis</th>
<th>M (% wt)</th>
<th>VM (% wt)</th>
<th>A (% wt)</th>
<th>FC (% wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.83</td>
<td>73.41</td>
<td>7.53</td>
<td>15.04</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ultimate analysis</th>
<th>C (% wt)</th>
<th>H (% wt)</th>
<th>O (% wt)</th>
<th>N (% wt)</th>
<th>S (% wt)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>63.20</td>
<td>6.74</td>
<td>21.9</td>
<td>0.63</td>
<td>0.16</td>
</tr>
</tbody>
</table>

| HHV (MJ/kg) | 24.2 |

Also the data indicated that, the average ash content (A) of the cashew nut shell was found to be 7.53 \% which revealed their suitability for the gasification. The most desirable component, which governs the suitability of the fuel for gasification is the average fixed carbon (FC). In this study after carbonization, the FC for cashew nut shell was found to be 15.4 \%. On the other hand carbon (C) and hydrogen (H) content are the drive factor for reactivity during combustion process. The high oxygen (O) content results from the lignocellulosic structure of plant, which is the principal reason for the low heating values of biomass as compared with hydrocarbon fuels [10]. The heating value of fuel is the major factor determining the suitability of fuel for gasification. The results obtained showed that the average HHV of the cashew nut shell was found to be 24.2 MJ/Kg.

### B. Thermal Gravimetric Analysis

Figure 2 shows the WL and WLR of cashew nut shell as function of temperature under inert (N₂) environment, that distributed to main three regions drying, devolatilisation, and finally residues (char and ash). The first weight loss below 110 °C, corresponds to the moisture loss, at this temperature the moisture content was reduced by 3.76 \% wt of the sample. The second weight reduction correspond to increase of temperature to 730 °C which is attributed to devolatilisation of xylene materials mainly hemicelluloses, cellulose and lignin [11]. All the xylene was evolved at 730 °C, and only the char remained. In this step, the yields of the xylene material were up to 94.07 \% of the initial weight of sample. Finally there was no extreme weight loss this means residues (char) were left distorting to ash at 1000 °C, where 2.17 \% wt encountered.

The WLR curve has four peaks for weight loss rate steps. The first step accounts for moisture removal with peak at 110 °C. The second major weight loss rate step represents the decomposition of hemicellulose and that occurred between 120 and 320 °C, the temperature at which hemicellulose removal was at its maximum is 280 °C as observed by the inflection point of the WLR curve. The third weight loss rate step happened between 320 and 375 °C with peak at 330 °C, this step is for cellulose decomposition. At above 375 °C, the lignin started to break and released with peak at 450 °C.
Beyond 730 °C, the decomposition rate was almost negligible corresponding to the deformation of char components to ash.

![Graph: WL and WLR curves of Cashew Nut Shell at 10 °C/min]

**C. Kinetics Analysis**

Determination of kinetics parameters (of $E$ and $A$) was done by using the kinetics was Kissinger’s method, since the thermo-gravimetric analysis was non-isothermal process. The activation energy was 291.82 kJ/mole and pre-exponential factor was 3.51E2 s$^{-1}$. This is influenced by volatile and ash, materials with lower activation energy are easily thermally degradable, and hence, more reactive compared to the other materials [12]-[13].

**IV. CONCLUSION**

The ultimate analysis shows cashew nut shells has small composition of nitrogen (N) and sulphur (S) elements less than 2%, which will result into low emission of NO$\text{X}$ and SO$\text{X}$ when combusted. The xylenes are of major fraction as observed in the WL profile during the devolatilisation of sample when subjected in heat. The realized xylene amount was 94.07 % with major composition of hemicelluloses, cellulose and lignin which are the ones usually converted to synthesis gas upon gasification process. The small composition of ash and moisture provides evidence of suitability for gasification process. But for pyrolysis process these xylenes are converted to bio-oil product. With this regard cashew nut shells can be a useful candidate in thermal conversion systems.

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**REFERENCES**


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