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Temporal Evaluation of Bagasse from Sugar Mills in Western Kenya

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Abstract*—Sugarcane bagasse from legacy dumpsites was analysed to determine its suitability for energy conversion, material applications, and environmental impact. Through a partnership between Kibabii University, Carbon Footprint Limited, Kenya and Craig Anderson PWE Heat and Power UK, bagasse samples dumped 0-15 years ago were subjected to proximate and ultimate analysis at Alfred H Knight Energy Services Ltd (20-Jun-2025 to 04-Jul-2025). Removed ash contributors and elemental ash content fell within the typical range for most biomass feedstock. Moisture content and volatile matter declined by 1.4% and 24.2% respectively while ash content and fixed carbon increased through time. All elemental oxides dropped through time except SiO_2 and Al_2O_3 that increased by 14.8 % and 57.9 % respectively. This data was essential in determining the heating values, air requirements for combustion, and potential yields in gasification or pyrolysis equipment and operating conditions for biochar production. Biochar is known to improve soil fertility, and sequester carbon. Recycling ash into soil reduces waste and supports circular economy practices, aligning with Kenya's green growth agenda.

Index Terms—**Sugarcane bagasse, proximate & ultimate analysis, biochar, circular economy**

I. INTRODUCTION

Landfilling or open dumping of sugarcane bagasse creates serious environmental and health challenges, including methane emissions, groundwater contamination, pest breeding, and wasted resource potential. Instead of disposal, bagasse can be recycled into bioenergy, paper, packaging, or building materials, offering sustainable alternatives (Atieno, 2022). Biomass characterization studies by Singh (2023) point out that both proximate and ultimate analysis are critical for material evaluation, serving different purposes. Ultimate analysis identifies what elements the material is made of while proximate analysis identifies how those elements are grouped into compounds by measuring fixed carbon, volatile matter, moisture, and ash. For testing services, specialized commercial laboratories such as Alfred H Knight Energy Services Ltd, and SGS, perform ultimate analyses to deliver independent chemical compositions of fuel and biomass samples.

Proximate analysis is a crucial method for characterizing biofuels, as it provides detailed information on moisture, volatile matter, ash, and fixed carbon content. This analysis is essential for evaluating the viability of biomass and optimizing its applications, particularly in renewable energy production. Understanding these parameters helps in comparing different biomass types and determining the best methods for their utilization or pre-treatment to enhance efficiency (Racero-Galaraga et al., 2024).

Ultimate analysis of biomass determines the elemental composition—specifically carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and sulphur (S)—by weight percentage, usually on a dry basis. It is essential for calculating heating values, air requirements for combustion, and potential yields in gasification or pyrolysis, identifying major components like carbon and oxygen (Smith & Lee, 2018; Kumar & Zhao, 2019). Elemental ash analysis of sugarcane bagasse is carried out to determine the inorganic mineral content, which directly affects its suitability for energy conversion efficiency (high ash content lowers calorific value and reduces efficiency in combustion or gasification. Elemental composition (e.g., silica, potassium, calcium) influences slagging and fouling in boilers, which can damage equipment (Wang et al., 2021; Li et al., 2023; Zhao et al., 2023). In material applications, bagasse ash rich in silica can be used in cement, concrete, and ceramics. Elemental analysis ensures consistency and suitability for industrial applications. For environmental considerations, bagasse analysis helps the identification of heavy metals or harmful elements that may cause pollution if ash is disposed of improperly. It also helps in designing safe disposal or recycling strategies (Raj, Chauhan & Pal, 2022). For agricultural use, ash contains minerals like potassium and calcium that can be recycled as soil amendments. Elemental analysis ensures safe and beneficial use in farming (Singh, Kumar, & Rai, 2016). Typical bagasse analysis targets Silicon (SiO_2), a major component, useful for construction materials; Potassium (K), and Sodium (Na) which affect slagging/fouling in boilers, Calcium (Ca), and Magnesium (Mg) that influence ash melting behaviour, and Iron (Fe), Aluminium (Al) that contribute to ash fusion characteristics. Trace metals (Cu, Pb, Zn) may be analysed as important for environmental monitoring (Zhang & Wang, 2023).

In material science and industrial chemistry, removed ash contributors refers to the inorganic impurities, mineral residues, or trace metallic compounds that are intentionally extracted or reduced from a raw material (such as coal, biomass, activated carbon, or fuels) to improve its quality, performance, and purity. These inorganic components, when left in the material, typically convert into inorganic ash after combustion, which causes issues like slagging, fouling in boilers, or reduced adsorption capacity in carbon materials (Schollbach, Vollpracht & Snellings, 2018; Izquierdo & Querol, 2023; Raval, 2026).

According to Li et al., 2017, thermochemical techniques like pyrolysis could be a more effective approach for biomass processing. Their study demonstrated that ash removal improves the purity and performance of biomass-derived fuels. This could be related to the inherent benefits of pyrolysis such as its ability to use a variety of feedstock; minimize environmental effects; and the co-production of bio-oil, biochar, and syngas (Osman et al., 2023). Studies by Thomas, Hosur, Pasquini, & Chirayil, 2023 document verified ranges for biomass fuel composition (Table 1).

Table 1: Biomass Fuel Composition – Verified Ranges

Property	Typical Range	Notes
Total Ash Content	0.2 – 6 %	Depends on species; wood is lower, agricultural residues higher
Volatile Matter	70 – 86 %	High volatility makes biomass reactive in combustion
Fixed Carbon	12 – 20 %	Provides char for longer burning
Total Sulphur	< 0.2 %	Very low compared to coal, reduces SO_2 emissions
Chlorine	< 0.1 %	Higher in straw/agricultural residues; can cause corrosion
Carbon (C)	45 – 55 %	Main contributor to energy content
Hydrogen (H)	5 – 7 %	Increases flame temperature
Nitrogen (N)	0.1 – 1 %	Low, but can form NOx during combustion
Oxygen (O_2 by difference)	35 – 45 %	High oxygen lowers energy density compared to fossil fuels
Gross Calorific Value	17 – 21 MJ/kg	Comparable to low-rank coal, but cleaner

Handbook of Biomass (Springer, 2023)

II. MATERIALS AND METHODS

(a) Collection of Bagasse

Sugarcane bagasse was collected from legacy dump sites of West Kenya Sugar Company Limited (0.3796868 N, 34.831342E) (WGS 84). The material was sampled at 0-60 cm depth in three batches of 10 Kg each based on time taken after dumping, specifically 0-1 year, 3-4 years, and 10-15 years.

(b) Analysis of Bagasse

The collected bagasse samples were freighted to Craig Anderson, PWE Heat and Power, 6 Arundel Place, Scarborough, North Yorkshire, YO11 1TX. They were subsequently delivered to Alfred H Knight Energy Services Ltd Unit 1 Palmermount Industrial Estate, Bypass Road, Dundonald Kilmarnock, Ayrshire, KA2 9BL for analysis. Elemental ash and removed ash contributors were determined through United Kingdom Accreditation Service, UKAS-accredited analysis procedures ensuring technical competence and reliability, primarily under ISO/IEC 17025 standards for testing and calibration laboratories (https://www.ukas.com/). The Certificate of Analysis Doc Id: DB/427096/3 was issued.

(c) Analysis Result

Total moisture content (%), volatile matter (%), Carbon (%) and Calorific value (MJ/Kg) declined through time. Total ash content (%) and Fixed Carbon (%) increased with ageing bagasse from 1.8 -14.0% when the samples were analysed on as is basis (Table 2). The trend in removed ash contributors was repeated but with incremental values in the parameters when the material was analysed on dry basis and dry ash free basis (Table 3 & 4).

Table 2: Removed Ash Contributors (As Received Basis)

Period after dumping (years)	Total MC %	Total Ash Cont. (%)	Volatile matter (%)	Fixed C (%)	Total S (%)	Cl (%)	C (%)	H (%)	N (%)	O_2 by Diff. (%)	Gross Cal Value (MJ/Kg)	Net Cal Value (MJ/Kg)
0-1	10.7	1.8	75.4	12.1	<0.01	0.02	42,3	5.44	0.22	39.5	17.055	15.140
3-4	10.7	6.9	69.7	12.8	0.02	<0.01	39.6	5.08	0.53	37.1	16.174	14.798
10-15	9.3	14.0	60.7	16.1	0.02	<0.01	37.7	4.59	0.55	33.8	15.358	14.033
Typical	-	0.2-6	70-86	12-20	<0.2	<0.1	45-55	5-7	0.1-1	35-45	17-21	

Source: Alfred H Knight Energy Services Ltd

Table 3: Removed Ash Contributors (Dry Basis)

Period after dumping	Total Ash Content (%)	Volatile matter (%	Fixed C (%)	Total S (%)	Cl (%)	C (%)	H (%)	N (%)	O_2 by Diff. (%)	Gross Calorific Value (MJ/Kg)
0-1 year	2.0	84.4	13.6	< 0.01	0.02	47.4	6.09	0.25	44.2	19.098
3-4 years	7.7	78.0	14.3	0.02	< 0.01	44.4	5.69	0.59	41.6	18.112
10-15 years	15.4	66.9	17.7	0.03	< 0.01	41.6	5.06	0.61	37.3	16.823
Typical range	0.2-6	70-86	12-20	<0.2	<0.1	45-55	5-7	0.1-1	35-45	17-21

Source: Alfred H Knight Energy Services Ltd

Table 4: Removed Ash Contributors (Dry Ash-Free Basis)

Period after dumping	Total Ash Content (%)	Volatile matter (%	Fixed C (%)	Total S (%)	Cl (%)	C (%)	H (%)	N (%)	O_2 by Difference (%)	Gross Calorific Value (MJ/Kg)
0-1 year	-	-	-	< 0.01	0.02	48.4	6.21	0.26	45.1	19.488
3-4 years	-	84.5	15.5	0.02	< 0.01	48.1	6.16	0.64	45.1	19.623
10-15 years	-	79.1	20.9	0.04	< 0.01	49.2	5.98	0.72	44.1	19.885
Typical range	0.2-6	70-86	12-20	<0.2	<0.1	45-55	5-7	0.1-1	35-45	17-21

Source: Alfred H Knight Energy Services Ltd

Elemental ash analysis (Wt. % db.) revealed a declining trend in all oxides through time except SiO_2 and Al_2O_3 that generally increased from 68.53-78.70% and 7.01-11.15% respectively (Table 5).

Table 5: Elemental Ash Analysis (Weight % Dry Basis.)

Period	SiO_2 (%)	Al_2O_3 (%	Fe_2O_3 (%)	TiO_2 (%)	Mn_3O_4 (%)	CaO (%)	MgO (%)	Na_2O (%)	K_2O (%)	$P_2O_{5(}$ (%)	SO_3 (%)	BaO (%)
0-1 year	68.53	7.01	8.27	1.04	0.52	4.25	1.99	1.32	5.15	1.19	0.66	0.07
3-4 years	73.72	11.15	5.97	0.65	0.26	2.88	1.25	0.88	2.16	0.78	0.20	0.10
10-15 years	78.70	11.12	4.42	0.60	0.11	1.30	0.61	0.63	2.00	0.35	0.06	0.10
Typical range	55-70	4-8	2-6	0.1-0.5	0.05-0.5	5-12	1-4	0.5-2	3-8	1-6	0.5-3	0.1-0.3

Source: Alfred H Knight Energy Services Ltd

The accumulation of SiO_2 and Al_2O_3 in the bagasse dumpsites poses a risk to the environment and biodiversity through reduced soil pH and nutrient availability, affecting agricultural productivity.

III. CONCLUSION

This study confirmed that the quality of bagasse in legacy dumpsites in western Kenya meets the physico-chemical standards and is suitable for biochar production. Storage-related degradation (loss of cellulose/hemicellulose and increase in ash/extractives) enhanced its pyrolysis behaviour, making aged bagasse a viable feedstock for biochar used in soil amendment, and carbon sequestration.

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Appendices

Table 1: Removed Ash Contributors

Parameter	0-1 year			3-4 years			10-15 years		
	As received	Dry Basis	Dry Ash-Free	As received	Dry Basis	Dry Ash-Free	As received	Dry Basis	Dry Ash-Free
Total moisture (%)	10.7			10.7			9.3		
Total Ash Content (%)	1.8	2.0		6.9	7.7		14.0	15.4	
Volatile matter (%)	75.4	84.4		69.7	78.0	84.5	60.7	66.9	79.1
Fixed Carbon (%)	12.1	13.6		12.8	14.3	15.5	16.1	17.7	20.9
Total Sulphur (%)	< 0.01	< 0.01	< 0.01	0.02	0.02	0.02	0.03	0.03	0.04
Chlorine (%)	0.02	0.02	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Carbon (%)	42.3	47.4	48.4	39.6	44.4	48.1	37.7	41.6	49.2
Hydrogen (%)	5.44	6.09	6.21	5.08	5.69	6.16	4.59	5.06	5.98
Nitrogen (%)	0.22	0.25	0.26	0.53	0.59	0.64	0.55	0.61	0.72
Oxygen By Difference (%)	39.5	44.2	45.1	37.1	41.6	45.1	33.8	37.3	44.1
Gross Calorific Value MJ/Kg)	17.055	19.098	19.488	16.174	18.112	19.623	15.258	16.823	19.885
Net Calorific Value (MJ/Kg)	15.14			14.798			14.033		

Source: Alfred H Knight Energy Services Ltd