Nigerian Journal of Engineering,Vol. 30, No. 3, December 2023,ISSN (print): 0794 – 4756, ISSN(online):2705-3954.

Nigerian Journal of Engineering,
Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria
journal homepage: www.njeabu.com.ng

Evaluation of Typha Grass as Potential Feedstock for the Production of Fuel Briquette

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Research Article

Abstract

This study established that a minimum of 2, 738.61 metric tons of fresh typha grass (TG) could be obtained from some of the Kano River Irrigation Scheme's facilities per perennial cycle of the TG. Some sample of fresh TG was randomly harvested and sun dried without any treatment. The dried TG was subjected to some physico-chemical characterizations (moisture content (%), ash content (%), char content (%), and calorific value (MJ/kg)). The results recorded suggested TG as a potential material for fuel briquette production. Furthermore, the dried TG was carbonized and used to produce typha grass fuel briquettes (TB) using five (5) tons hydraulic press machine, three different binding materials (arabic gum (AG), starch (S), and cement (C) at three different dosages (4, 9, and 12% (wt/wt)). The results achieved reveals that the TB produced with starch binding material at 12% dosage exhibited superior properties, including, 97.5 ± 2.00%, 1970±170 (kg/m^3), 68.22%, 26.45±0.22 MJ/kg, 140 ± 0.22 min, 0.42 ± 0.21 g/min, and 277± 0.06 ppm recorded for mechanical durability, bulk density, char content, calorific value, water boiling test, specific fuel consumption rate, and carbon monoxide emission, respectively. Overall, the TG was found to be abundant enough to be adopted as a feedstock for the production of fuel briquette. Its properties and the produced TB properties have shown that TG is a suitable candidate for the fuel briquettes production.

doi: 10.5455/nje.2023.30.03.01

Keywords

Solid fuel, briquette, typha grass, KRIS.

Article History

Received: – , September 2023 **Accepted: –** , October 2023
Reviewed: – , September 2023 **Published: –**, December 2023

1. Introduction

The utilization of wood as a solid fuel in Nigeria for domestic and commercial purposes is a very common phenomenon, especially in rural areas, and that has significantly increased the demand for firewood which has consequently increased the rate of deforestation (Omobolaji, 2018). Earlier report reveals that the utilization of firewood and other solid fuels is perhaps what exposes over 120 million Nigerians to serious health risk due to exposure to smoke(Eleri *et al*., 2012). These challenges underscore the need for a cleaner and more sustainable source of solid fuel especially for the rural population considering their limited access to conventional energy sources. Biomass materials in form of agricultural and agro-industrial waste are also combustible and sustainable energy resources with minimal green house gas emissions and their production is increasing due to the significant increase in agricultural activities. However, their utilization in the original form having low bulk density results in huge transportation and storage costs, and cannot be used as an effective combustible fuel. Densifying biomass makes it a more effective combustible fuel(Suhartini *et al*., 2011). Different groups have reported their independent studies on the successful utilization of various lignocelluloses base materials in the production of fuel briquettes(Avelar *et al*., 2016; Gendek *et al*., 2018; Lubwama and Yiga, 2017; Mendoza *et al*., 2019; Parthasarathy and Narayanan, 2014). However, findings by Mendoza *et al*.,(2019) have opined that more than 200 million tons of agro-industry waste in Brazil are not utilized energetically in spite their technological advancement. This suggests that similar finding could be found in Nigeria, therefore the importance of exploring agro-industrial waste for the production of fuel cannot be over-emphasized.

In another development, a study by Kataki and Kataki (2022) suggested that the utilization of weeds that grow in agricultural fields for bioenergy and bio-fuels production will not only offer sustainable and renewable feedstock, but can also help in conserving the environment. Typha grass (TG) otherwise called Cattail, and locally as Kachalla by people living around Hadejia-Nguru wetland area (Zungum *et al*., 2019), with *typha latifolia* and *typha angustifolia* being the most predominant species in the African Region (Bansal *et al*., 2019). It is a very serious threat to communities depending on the wetland either for farming or fishing, as finding has shown that it has caused 80% reductions in both the land available for farming and caught fishes, thereby significantly diminishing the livelihood of the depending communities (Salako *et al*., 2016). TG has been practically investigated as a sustainable feedstock in the production of bioethanol (Bala *et al*., 2020) and biogas *(*Hartung *et al*.,

2023) and yields recorded revealed that its chemical composition favours the production of liquid bio-fuel with some pre-treatments. But hitherto, relevant information related to its abundance per unit area, physicochemical properties, and practical suitability in the production of solid bio-fuel (briquettes) using some common binding materials receives little or no attention from the research community to the best of our knowledge.

Therefore, in this study the following objectives are achieved; Global Positioning System (GPS) technology was employed to establish an estimated quantity of the TG in the Kano River Irrigation Scheme (KRIS), study the physicochemical properties of the TG, and production of typha grass fuel briquettes (TB) using some common binding materials. The information established in this study has no doubt provided some fundamental information related to the utilization of TG as a feedstock in the production of TB. The widespread adoption of TG as a feedstock in the production of fuel briquettes will go a long way in providing a sustainable and renewable energy source, and also provide a systematic solution to its wetland's invasion.

2. Materials and Methods

2.1 Materials Used

Starch, arabic gum and Dangote portland cement (42.5R Grade) available in Kano Metropolitant Market were obtained and used without further treatment.

2.2 Methods

2.2.1 Quantitative evaluation of Typha Grass

Garmin GPS device with was used to used to capture the coordinates and map of the KRIS, while MapSource software was employed to view the captured map on the google map. The ArcGIS 10.8 was then used to identify the the presence and dimensions of hydraulic structures (reservoirs and canals) available at the KRIS. Furthermore, site visitations were carried out to establish the existence of such structures, the presence of the typha grass (TG) in the structures, and the estimated population density of the TG was determined with equation 1 as described in GCSE (2023)using a quadrant method.This evaluation was carried out in March 2023 which is three months after dredging of the hydraulic structures carried out by the Federal Government of Nigeria.

$$EPS = \frac{TAF}{TA_{SQ}} \times ATG_{EQs} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Physicochemical characterization of TG The TG obtained from the KRIS was subjected to some phyisico-chemical characterizations that involved the determination of parameters such as; width (cm), height(cm), linear mass density (g/cm), moisture content (MC), ash content (AC), char content (CC), and calorific value (CV) of the dried TG sample were measured. Firstly, a fresh TG (Fig. 1 (a)) harvested manually using sickle 5 was dispersed on a platform for seven (7) days, sun dried, and the dried TG obtained (Fig. 1 (b)) was used for the aforementioned parameters evaluation. Ten (10) different TG were sampled randomly in each facility, therefore ten (10) measurements carried out in each facility to determine the average and standard deviation of the with (cm), height (cm), and linear mass density (g/cm) of TG found at every facility, and later, the overall average and standard deviation of the TG at the KRIS was computed. A calibrated steel tape was used to directly measure the width (cm) and the height (cm), while the mass per unit length was measured using a 0.5 grams sensitive weighing balance as the linear density (g/cm). The MC (%) of the TG was determined by drying five different samples at 100°C in a ventilated oven and the percentage MC was calculated using equation 2 as reported by Rezania et al., (2016). The TG was used as an initial sample and samples obtained after ventilated oven drying as dried sample. WC+S is the weight of the crucible and sample, WC+DS represented the weight of crucible and dried sample, and WC denoted the weight of the crucible.

$$M_C = \frac{(W_{C+S} - W_{C+DS})}{(W_{C+S} - W_C)} \times 100 \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

(a)

(b)

(c)

(d)

Fig. 1 Typha Grass (TG): (a) Fresh TG, (b) Dried TG, (c) TG Carbonization set-up, (d) Carbonized TG.

The ash content of the TG was determined using equation 3 as used previously (Rezania et al., 2016), TG was used as an initial sample and it was heated using a box-type furnace (Barnstead Thermolyne 48000) at 800°C for an hour to obtain a heated sample. WC+HS; weight of crucible and heated sample, and WC; weight of crucible. The char content (CC) (%) of the TG and the binders (arabic gum, cement, and starch) were determined using a thermogravimetric analyzer (Mettler-Toledo GC10) at a heating rate of 5 o C/min from temperature of 25 to 800 o C, and nitrogen rate of 50 mL/min.

$$A_C = \frac{(W_{C+HS} - W_C)}{(W_{C+S} - W_C)} \times 10 \ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3)$$

The calorific value (CV) (MJ/kg) of the TG samples and the binding materials were obtained using GDY-1A oxygen bomb calorimeter (Fig. 2 (b) according to the standard guide (GB/T 213-2008 Standard, 2008).

(a)

(b)

(c)

Fig. 2 Five Tons Press Type Briqueting Machine (a), Oxygen Bomb Calorimeter (GDY-1A) Set-up (b), Carbon Monoxide Meter (GCO-2008) (c). Production of typha grass fuel briquettes

2.2.2 Production of typha grass fuel briquettes

The typha grass briquettes (TB) were produced using a four-piston five-ton press briquetting machine (Fig. 2(a)) that has a piston capacity of 27g feedstock. The feedstock was prepared by putting the required quantity of the dried TG in a drum and carbonized it with the drum closed as shown in Fig. 1(c). The carbonized TG (Fig. 1(d)) was smashed against a platform to produced a carbonized TG powder. To evaluate the efficacy of different binding agents on the TG, the required carbonized TG powder and three different binding agents (arabic gum, cement, and starch) at 4%, 9%, and 12% were mixed differently with clean water to produce a paste. The pastes were placed inside different pistons of the machine Fig. 2(a)) and the hydraulic load was released to produced the arabic gum-binded TB (AG-TB), cement-binded TB(C-TB), and starch-binded TB (S-TB) categories at 4%, 9%, and 12% doses.

2.2.3 Characterization of the TG fuel briquettes

To characterize the produced TB, parameters such as; mechanical durability, bulk density, char content, calorific value, water boiling test, specific fuel consumption, and carbon monoxide (CO) emission were determined. The mechanical durability experiment was conducted as reported by Yank et al., (2016). Each sample of the TB was subjected to shocks and collisions against each other and the walls of the container of the soil laboratory sieve test vibrating machine. After which, the mechanical durability was calculated by determining the ratio of the mass of the sample remaining after the separation of abraded and fine broken particles to the initial mass of the sample. The bulk density was determined by geometric method using equation 4 as reported by Deshannavar et al. (2018). A geometric dimension of cylindrical briquette was measured using a vernier caliper and the volume of the briquette was determined using a formula $(\boldsymbol{V = \pi \times diameter\ of\ cylindrical\ briquette \times height\ of\ the\ briquette})$. The briquette was weighed and briquette density was calculated using equation 4.

$$\rho_b = \frac{M}{V} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where; ρ_b = briquette density, M and V are mass of briquette and volume of briquette respectively. The char content and calorific value were determined using the thermogravimetric analyzer and GDY-1A oxygen bomb calorimeter as reported earlier. Water boiling test experiment was carried out to determine the cooking efficiency of the TB. The time taken to boil 1 L of water with a known quantity of TB using a traditional tripod stove. Furthermore, the specific fuel consumption of the TB was determined by recording the weight of the briquettes burnt per unit time (g/min.) during the water boiling test. The CO emission was measured from the emission of the TB during the water boiling test experiment with a CO meter (GCO-2008) (Fig. 2 (c)).

3. Results and Discussion

3.1 Estimated Quantity of Typha Grass at the KRIS

Fig. 3 depicts the GIS map of the KRIS. Therein, it could be seen that a lot of facilities could be seen to be available at the KRIS. However, hydraulic structures that includes reservoirs (RS), primary canals (PC), secondary canals (SC) and tertiary canals (TC) are the main focus of the study because they are traditionally known to be the major TG habitat due to their water-containing nature.

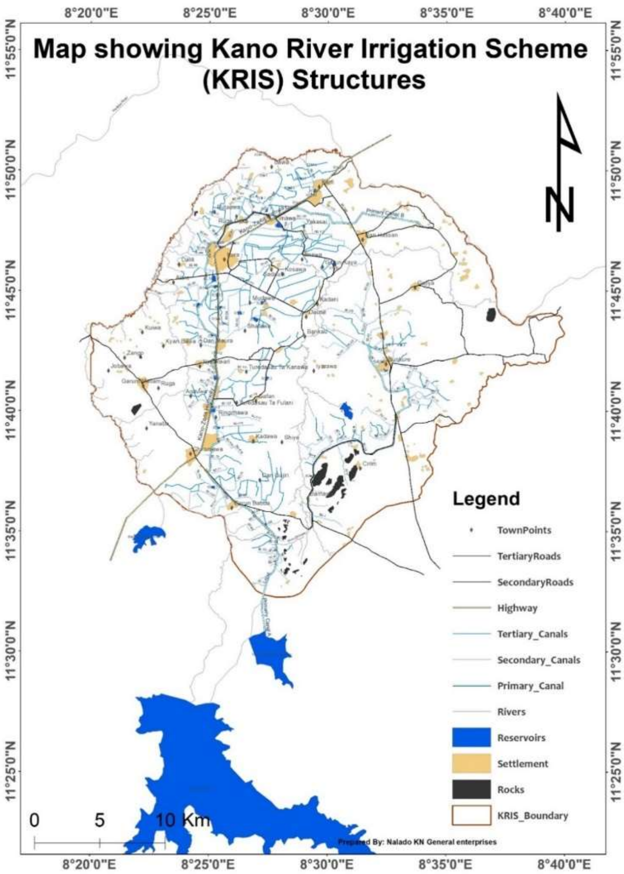

Fig. 3 GIS Map of the KRIS

A total of sixty-one (61) reservoirs (11607.2 ha), three (3) primary (78.16 km), one hundred and twenty-one (121) secondary (297.77 km) and one hundred and thirty-six (136) tertiary (254.98 km) canals were found at the KRIS. Among the aforementioned facilities, twenty-five (25) reservoirs (RS) and the three (3) primary canals (PC) (Table 1) were found to be occupying the TG, while the remaining of the aforementioned facilities were found to be occupying insignificant amounts of TG which could be due to the facilities were maintained recently (around three months prior to this study), cement or/ and concrete linings present on the facilities, or/and efforts of the individual farmers and water user association (WUA) in dredging the facilities. Thus, it could concluded that the 100% of the primary canals and 25% of the water storage reservors of the KRIS were occupied by the TG. Of course, some variations in the population size of the TG were observed, and that has been presented in Table 1. Overall, the RS contains the highest TG, as 210,240 and 1.29E+08, and 1,303971 and 9,644144 populations of TG were recorded as the minimum and maximum EPS of the TG at the RS and PC, respectively. Perhaps, the variation within and between the hydraulic facilities could be attributed to the swimming, car washing and laundry activities observed to be carried out using the facilities by the neighbouring communities. Detergents, spilt engine oil, and other wastes generated by the activities are detrimental to plant growth. Totalling the EPS of the various facilities indicated that 1, 70,118,65.6 population (Table 1) was recorded as the estimated quantity of the TG in an area of 9,860695 m2 (~986.07 ha).

Table 1: Estimated Population Size of the TG

Hydraulic Facility	*TAF* (m^2)	ATG_{EAQs}	*EPS*
PC- A	64553	202	1303971
PC- B	1161945	83	9644144
PC- C	543374	154	8367960
RS-1	14600	144	210240
RS-2	8384	185	155104
RS-5	142400	186	2648640
RS-6	43045	152	654284
RS-7	11516	174	200378.4
RS-8	73678	106	780986.8
RS-13	43669	174	759840.6
RS-14	29769	111	330435.9
RS-15	6973	74	51600.2
RS-19	9223	175	161402.5
RS-21	43482	78	339159.6
RS-22	15916	96	152793.6
RS-25	19462	182	354208.4
RS-26	15451	94	145239.4
RS-30	650759	188	12234269
RS-34	18419	140	257866
RS-35	30859	185	570891.5
RS-36	12049	192	231340.8
RS-41	7556	156	117873.6
RS-42	10501	100	105010
RS-44	22464	161	361670.4
RS-46	20169	194	391278.6
RS-55	44753	152	680245.6
RS-57	14801	178	263457.8
RS-Ruwan Kanya	6780925	190	1.29E+08
Total	**9,860,695**	**4,206**	**1,703,118,65.6**

PC: Primary canal, RS: Reservoir, *EPS*; estimated population size of the TG, *TAF*; total area of the facility, and ATG_{EQs}; average TG enumerated across the quadrants

3.2 Physico-Chemical Properties of TG

Physicochemical data of the dried TG (Fig. 1(b)) is presented in Table 2. Therein, the average width shows that the TG is a narrow-leaf plant, while the average height suggests that it is a tall growing plant. The average linear mass density of the TG (Table 2) was found to be 0.06 g/cm. Thus, a simple analysis (linear mass density (g/cm) × dried TG height (cm) × total EPS) using the data (Table 2) and total EPS (Table 1) shows that a minimum of 2,738,614,798.85 grams (2,738.61 metric tons) of freshly harvested TG could be obtained at the KRIP for each of its perennial life cycle. This shows that the population density of TG (2,738.61 metric tons divided by the ~986.07 ha which equals to 2.78 metric tons/ha) is much lower than the 27.97 kg/m2 (~279.7 metric tons/ha) estimated for water hyacinth as reported previously (Adamon et al., 2023). Nevertheless, the 2.78 metric tons/ha recorded for the TG is a significant amount. The obtained average MC (%) of the dried TG (Fig. 1 (b)) has shown that the open sun drying process described in sub-section 2.2.2 has adequately dried the TG to a MC (%) suitable for the production of fuel briquette, because the value of the MC (%) recorded is significantly less than the 18.29%, 12.04%, 9.8%, and 10.85% recorded against willow chips, rape straw, rape straw, rapeseed oilcake, and pine sawdust, respectively used in the production of fuel briquttes (Stolarski et al., 2013). Also, the AC (%) of the TG is lower compared to 6.27% and 6.90% recorded against green pea pods and water hyacinth as reported by Srivastava et al. (2014) and Rezania et al. (2016), respectively. Therefore, the relatively lower AC (%) of TG makes it a good candidate for the production of fuel briquettes considering the fact that lower AC (%) results were obtained against the lower generation of harmful environmental waste and higher heating value (Rezania et al., 2016).

The C_C also known as pyrolitic char contains some amounts of volatiles, ash, and largely fixed carbon (F_C). Therefore, the higher the C_C (%) value for any biomass material to be used as a candidate for the production of fuel briquettes will have a better, because it contains higher FC value. Therefore, the 22.59% (Table 2) CC recorded for the TG compares favourably to the 15.6%, 18.1%, 7.6%, and 18.7% of banana leaf, banana pseudostem, rice husk, and tea waste reported in the literature (De Oliveira Maia et al., 2018). The CV value (Table 2) of the TG is high enough, for instance, the value recorded is significantly higher than the 14.58 MJ/kg recorded with the water hyacinth (Rezania et al., 2016). Overall, the aforementioned physicochemical properties of the TG have shown that the TG is an excellent candidate for the production of fuel briquettes.

Table 2: Physicochemical Properties of the TG

Physico-chemical Parameter	Data
Width (cm)	2.67±0.9
Height (cm)	268±64
Linear mass density (g/cm)	0.06±0.02
Moisture content(M_C)(%)	5.67±0.2
Ash content (A_C)(%)	4.8±2.2
Char content (C_C) (%)	22.59
Calorific value (C_V) (MJ/kg)	16.25±0.0

3.3 Produced Typha Grass Fuel Briquettes

Fig. 4 depicts the produced TBs, as can be seen, the uniformly sized and densified TBs aresimilar.Also, the findings from the mechanical durability test conducted revealed that the TBs are excellently bound with the binding materials used at 4%, 9% and 12% dosages as evident by the data recorded (Table 3). A slight increase in the mechanical durability of the samples in the order; S@12%-TB> C@12%-TB > AG@12%-TB was obtained. Comparing the mechanical durability (%) with the 91.8% durability achieved with the (15% w/w) cassava starch wastewater on rice husk/bran fuel briquettes (Yank *et al*., 2016) reveals that the carbonized TG with S, C, or AG as binding materials resulted in the production of TBs with superior durability.

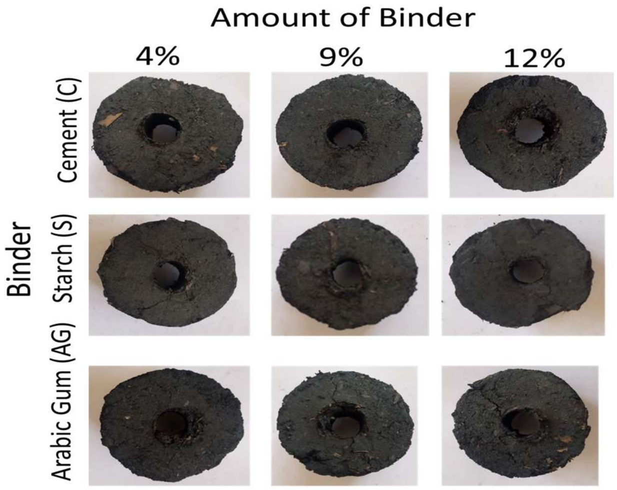

Fig. 4: Samples of the TB Produced with Different Binders at Different Dosages

Also, a range of 1970 to 2230 kg/m^3 in bulk density of TBs was recorded (Table 3), with AG@12%-TB exhibiting the highest bulk density. Perhaps, the variation in bulk density of the samples could be attributed the differences in the densities of the binding materials used.

Table 3:Properties of the TB

Parameter	Data		
	C@12%-TB	**S@12%-TB**	**AG@12%-TB**
Mechanical durability (%)	96.6 ± 1.55	97.5 ± 2.00	93.0 ± 2.56
Bulk density (kg/m^3)	2070± 190	1970± 170	2230± 200
Char content (C_C) (%)	66.87	68.22	55.86
Calorific value (C_V) (MJ/kg)	26.45±0.00	26.45±0.22	26.45±0.18
Water boiling test (L/hr.)	0.38 ± 0.00	0.43 ± 0.003	0.4 ± 0.002
Specific fuel consumption rate (g/min)	0.48 ± 0.01	0.42 ± 0.21	0.66 ± 0.05
Carbon monoxide emission (ppm)	189± 0.01	277± 0.06	185± 0.04

Fig. 5 shows a trend of the thermogravimetric of the TB samples. It could be observed that the carbonization treatment done on the TG (Fig. 1(d)) and the binding materials used in the production of the TB samples have significantly increased the CC of the TB. Also, a significant variation in the CC is obvious between the samples, which are in the order of C@12%-TB > S@12%- TB>AG@12%-TB, showing that after using the TB, the AG@12%-TB generated the least waste. Perhaps, this variation could be attributed to the differences in the pyrolitic properties of the binding materials used.

Also, comparing the CV values of the TB samples (Table 3) reveals that CV values are almost the same, and comparing the values with the 12.39, 13.70, 16.60, and 10.26 MJ/kg recorded against cabbage leaves, coriander stalk and leaves, field beans, and green pea pods, respectively (Srivastava et al., 2014) and 14.58 MJ/kg recorded for water hyacinth (Rezania et al., 2016) have shown the CV of the TB is relatively high. However, considering the average weights of the TB samples (19.5 g, 18.5 g, and 21 g for the C@12%-TB, S@12%-TB, and AG@12%-TB, respectively), it implied that the specific heat value of the TB samples stands around; 1.36 MJ, 1.42 MJ, and 1.26 MJ respectively, suggesting that the heat energy content of the S@12%-TB is relatively higher, and this could be attributted to the differences in the calorific value of the binding materials used. The results recorded in the water boiling tests where S@12%-TB (Table 3) boils more quantity of water in one hour corroborate the above explained result. Also, the specific fuel consumption rate (g/min) of the TB samples, where AG@12%-TB was found to have the highest has been explicitly corroborated by the significant differences in the pyrolitic properties of the samples shown by the thermogravimetry (Fig. 5), where AG@12%-TB could be seen to have lower degradation temperature and char content among the TB samples.

Strikingly, the S@12%-TB that exhibited higher mechanical durability, higher char content, higher cooking efficiency, and lower specific fuel consumption (Table 3) was found to have higher carbon monoxide emission. Thus, it could be concluded that the TG can be used in the production of TB using various binding materials, with the binding materials impacting both desirable and undesirable properties of the TB. Thus, there is a need for the exploration of the binding materials that will impacts greater desirable and lesser undesirable properties.

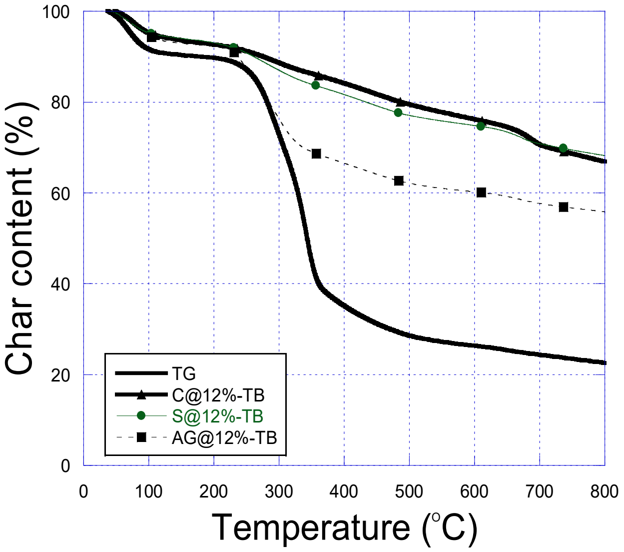

Fig. 5 Thermogravimetry of the TG and TB Samples

4.0 Conclusıons

Based on the experiments carried out, results obtained, and the discussions made. The following conclusions could be drawn;

i. The typha grass found to be occupying the hydraulic facilities within and around their irrigation scheme is significant enough to provide a sustainable feedstock that could employed in the production of fuel briquette. For instance, it has been established that a minimum of 2,738.61 metric tons of fresh TG could be obtained at the KRIP for each of its perennial life cycle (minimum of two years). This amount could be used to produce TB thereby making provision for a sustainable, renewable, and a cleaner fuel source.

ii. The fundamental physicochemical properties of the TG evaluated have shown that the TG is an excellent candidate for the production of fuel briquettes.

iii. Characterization of the TB produced using cement, starch, and arabic gum as binding materials has practically shown that the TB compared favourably with some fuel briquettes produced using agricultural and industrial wastes as feedstock.

iv. Overall, TG is an available, suitable and viable candidate that could be used with little or no pre-treatment in the production of an alternative solid fuel. Its adoption and adaption as a canditate could not only provide a sustainable material for solid fuel production but also help minimize or eradicate maintainance cost caused by its emergence within or/and around hydraulic facilities of irrigation schemes.

Acknowledgement

The authors acknowledged and appreciated the Institutinal-based research (IBR) funding received from the Tertiary Education Trust Fund of the Federal Government of Nigeria (TETFund, FGN) through the Directorate of Research, Innovation and Partnership(DRIP) of Bayero University, Kano, Nigeria.

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