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Proximate Analysis of Alternatives Cooking Solides Fuels in Sub Saharan by Using Astm Standards

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Abstract

A number of persistent problems have been associated with the supply of traditional domestic fuels in developing countries and particularly in rural areas, including deforestation, scarcity of fuel wood and the high cost of fossil fuels. The use of biomass fuels derived from agricultural waste biomass, generally available in large quantities, has been advocated. This article, therefore, presents some bio-fuels in use or in acceptability test phase in some countries of West Africa and particularly in Senegal but also their characteristics, compared to those of wood or wood charcoal. Samples were prepared and analyzed for moisture content, ash content, volatiles mater, fixed carbon and calorific value. The results indicate that charcoal and bio-charcoal (not mixed with clay) have the best calorific value, while pellets and typha briquettes have the best results in volatile matter and fixed carbon. The results of moisture are generally satisfactory against the use of clay as a binder detrimental to fuel performance. These results suggest that pellets and bio-fuels are used as an energy source for domestic purposes; that the binder is changed in others; pelletizing and briquetting transformations are expanded in other residues such as rice husks, peanut shells.

Keywords

Biomass, Proximate Analysis, Calorific Values

1. Introduction

Most of Sub-Saharan Africa continues to rely overwhelmingly on traditional fuels and cooking technologies, both of which are a major cause of death and illness as well as a range of socio-economic and environmental problems. In sub-Saharan Africa, about 50% of primary energy comes from biomass; Senegal's share is 47% [1]. Wood and charcoal are the principal sources of cooking energy of Senegal country and they constitute about 85% of household energy consumption [1]. With the speed of urbanization, wood becomes scarce and overexploitation sets up desert, erosion and loss of soil fertility in areas such as the Sahel. In Senegal, 40,000 hectares of forest are lost every year, mainly due to the cutting down of trees for firewood, as well as to forest fires and desertification [2]. Exposure to harmful emissions can have a strong negative impact on education and gender, particularly when women and children are predominantly involved in the collection of fuels and cooking. More than 8000 people die annually from diseases caused by indoor air pollution [2]. Therefore to fight against this phenomenon, the Government of Senegal set up the policy called "Lettre de Politique de Sous-Secteur des Combustibles Domestiques 2010 (LPSSCD)". This policy aims at ensuring the long-term supply of household cooking energy for urban and rural households while protecting forest resources and the environment. Specifically, it seeks to manage forest exploitation; promote alternative energies; adapt institutional, regulatory and fiscal frameworks; and circulate good practices [2]. It is in this logic that we propose to valorize certain biomass which is plentiful in Senegal and in Saharan areas. Biomass is an organic material that is available on a renewable basis and includes all plants (trees, agricultural crops, wood and wood residues, grasses and aquatic plants) and plant-derived materials (animal fertilizers and municipal residues). Biomass is the main energy resource (stored by plants through photosynthesis during growth) of local populations in many regions of developing countries. It is used by 2.4 billion people in developing countries. In many parts of the world, biomass is readily accessible to people living in poverty and gives them vital energy at a reasonable cost for cooking and heating. Of this biomass, wood is the most consumed directly or indirectly. Direct consumption is the traditional consumption of biomass energy and involves the combustion process such as cooking, heating of premises and industrial processes. Indirect consumption and/or modern consumption are the most advanced processes of converting biomass into secondary energy [3].

Our study consists to do proximate analysis and determine calorific value of several types of biomass, transformed into alternative fuels in order to substitute them with wood or wood charcoal for domestic use (cooking or heating). The fuels studied are: wood pellets (from Aprovecho in the USA), typha pellets, typha briquettes, typha lump charcoal (charcoal powder + clay), rice husks (produced at CNT of Rosso in Saint Luis, Senegal), Shea butter meal pellets (from Burkina Faso), bamboo charcoal and bamboo lump charcoal (from Ghana), mixture (typha + rice) ball charcoal (from Rosso Mauritania), jatropha seed press oil residues (CERER). Among these fuels, others are already in use in some areas of

Senegal through NGOs, women's groups and others are being studied in laboratories. The proximate analysis is the determination of moisture, ash content, volatile matter and fixed carbon. There are determined by using the muffle furnace and drying cabinet. These different characteristics have a very important effect on the thermal conversion of biomass [4] and are useful to classifier them rapidly in the general typology [5]. The comparison of these characteristics with those of wood or wood charcoal will allow us to know their level of performance and see which of them will be the best substitute for wood and charcoal but also appropriate equipment for the combustion of each of them. The calorific value (CV) is the most important of these characteristics and represents the amount of energy contained in the unit of mass of fuel. The CV is determined experimentally using a calorimetric bomb under the conditions specified by raising the temperature gap obtained during the combustion of the sample and using an equation given in the literature by "Parr Instrument Company" [6]. The standard of testing we apply is the ASTM (American Society for Testing Materials) whose purpose is the establishment. In accordance with ASTM D3175-11 in insert atmosphere, the moisture of the biomass is determined at a temperature of 105˚C in drying cabinet until further loss of the mass will not occur, the ash is usually determined by oxidizing drying sample fuel at 710˚C in the muffle furnace according to ASTM D3174-11, the volatiles matter (VM) are determined by heating fuel sample at 950˚C in the muffle furnace and the fixed carbon (FC) (ASTM D3172-07a) is obtained from 100 − (ash + VM).

2. Materials and Methods

2.1. Materials

The biomass that is converted into alternative fuels comes from agricultural and forestry residues. The most used is typha and rice husks. Typha is an aquatic grass that develops on the coast of the Senegal river and limits cultivable and fishing areas. Rice husks come from rice cultivation in northern Senegal (Saint Louis and Matam) and southern Mauritania. After harvesting and shelling, rice shells become an environmental problem. So the valorization of this biomass can at the same time solve environmental problems. Twelve (12) types of fuels (**Figure 1**) are collected for testing and finding the best characteristics for use by the population. These fuels are among others wood pellets (from Aprovecho in the USA), Shea butter meal pellets (from Burkina Faso), bamboo charcoal and bamboo lump charcoal (from Ghana), typha briquettes, typha pellets, typha lump charcoal powder + clay, rice husks (produced at CNT of Rosso in Saint Louis, Senegal), peanut shell + clay or "bioterre" (from Fatik, Senegal), lump charcoal (typha + rice husks) (from Rosso, Mauritania), jatropha seed press oil residues (CERER, Senegal) and peanut shell (from local market in Dakar, Senegal).

Some of these fuels are already in use in Senegal. Typha pellets, carbonized typha + clay, biochar (typha + rice husks) and typha briquettes are used in

Figure 1. Alternatives fuels presentation.

northern Senegal (Saint Louis and Matam) and in southern Mauritania (Rosso Mauritania) which are desert areas and where wood and charcoal are scarce and very expensive. The peanut shell + clay or bioterre is processed and used in central Senegal in the groundnut basin (in Ndèm at Diourbel, Senegal), bamboo charcoal and bamboo biochar (in Ghana).

The materials used to make proximate analysis are a 0.00001 precision balance, an oven (to dry the fuel and evaluate the humidity), desiccators, a muffle furnace (ashes, volatile materials…), and a calorimetric bomb (for calorific value).

2.2. Method

2.2.1. Proximate Analysis Process

The method used in this study is the American Society for Testing Materials (ASTM) standard.

The proximate analysis of fuels consists of knowing the composition of fuels in moisture, volatile matter, ash, fixed carbon and their calorific value. The limit of our laboratory equipment does not allow us to make an elementary analysis (composition in carbon, hydrogen, sulfur, …) of the fuels. The stages taken by a sample to get there are summarized in the diagram of Figure 2 below.

1) Moisture

The moisture content of solid fuel is expressed as the quantity of water per unit mass of the dry solid. But there are two different ways of specifying the moisture content of biomass; on a "wet" or "dry" basis. The wet basis moisture content of a biomass sample is given by the mass of water contained in the biomass divided by the total mass of the biomass sample as found. The dry basis moisture content is the mass of water divided by the mass of the biomass only, *i.e.* excluding the water.

The moisture content was determined in accordance with ASTM Standard D 3173-87 (1998). The conventional determination of moisture is drying in an oven in air to constant weight at 105˚C [7]. Three silica capsules without covers, air-dried and numbered are used in which 1 g of the sample is introduced to determine moisture. The capsules are then weighed and placed in an oven-dried set at (105˚C ± 2˚C) according to EN 14774 standard (temperature at which the water will evaporate from the fuel) for 18 hours [8]. After this time, they are removed and cooled in a desiccators at room temperature before being weighed again [9] [10]. The determination of the value of the humidity is carried out using Equation (1) below.

2) Ash

Ash is the solid mineral matter remaining from the combustion of a solid fuel under specific conditions [11]. It comes in the form of a powder from gray to black depending on the content of unburned and iron oxide (darker than cement) and soft to the touch. The ash is mainly composed of silica (SiO_2), alumina (Al_2O_3), iron oxides (FeO, Fe_2O_3), calcium oxide (CaO) of magnesium oxide (MgO) [12]. Several standards can be used to determine the ash rate of a biomass. The one used in our work is ASTM D1762-84 [11]. In order to ascertain the reliability of the tests, three capsules are dried and weighed, and in each capsule, 1 g of dry fuel is introduced and the whole in a muffle furnace at 750˚C for 2 hours. After this time, a drop in temperature is expected and the capsules

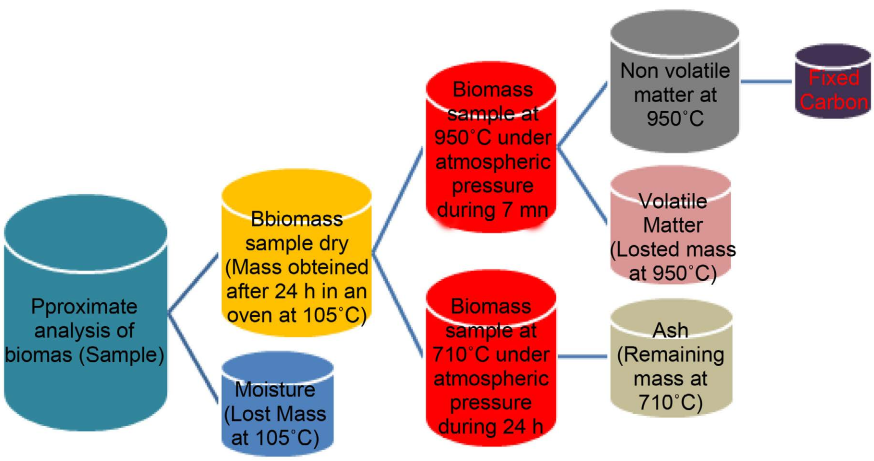

Figure 2. Proximate analysis process diagram.

are removed and cooled in desiccators before being weighed with the residue. A simple calculation using Equation (2) allows us to know the percentage ash contained in the biomass being tested.

3) Volatile Matter

The volatile matter (V.M) of solid fuel is the set of products (moisture not taken into account) which escape as a gas when heated. It is determined by considering the mass loss of the sample during its heating.

The V.M rate is of great practical interest because, in addition to its simplicity, it constitutes an important parameter for the qualification of fuels. It plays an important role in direct combustion because volatile matter promotes ignition of fuel, development and stabilization of fuel flame [13].

We determine volatile matter according to the American standard method. According to this standard, the sample, in a platinum crucible, is introduced directly into the furnace at (950˚C) for exactly 7 minutes, thus obtaining a rapid rate of heating: ASTM D120-30 [10] [14] or CEN's EN 15148 [9].

In this work, three capsules are dried and weighed, and in each capsule, 1 g of dry fuel is introduced and the whole in a muffle furnace at 950˚C for 7 mn. After this time, a drop in temperature is expected and the capsules are removed and cooled in desiccators before being weighed with the residue. A simple calculation using Equation (3) allows us to know the percentage of volatile matter contained in the fuel being tested.

4) Fixed Carbon

The fixed carbon is the solid residue of the fuel remaining after the determination of the volatiles matter by heating the sample to about 950˚C for a period of 7 minutes. The fixed carbon is determined according to ASTMD3172-07a [15] and ASTMD1762-84 [16]. Its determination is not a process of analysis but of calculation using two equations depending on whether the fuel is wet or dry based. In our study, the fixed carbon is calculated by using the dry sample fuel with Equation (4).

2.2.2. Calorific Value

The calorific value of a fuel is the expression of the energy content of the fuel or the amount of heat released during its combustion in the air. It's usually measured in terms of energy per unit mass or volume, either MJ/kg for solids, MJ/L for liquids or MJ/Nm^3 for gases [13] [17]. The calorific value is determined in the laboratory using an adiabatic bomb calorimeter [18] or by resolving equation using elementary analysis parameters. A sample mass unit in a crucible, all in a bomb calorimeter where the sample is subjected to combustion under specific conditions according to ASTM D2015-96 (ASTMD standard D2015-96, 1998). The difference between the maximum and minimum temperatures obtained was used to calculate the calorific value of the sample according to Equation (5).

2.3. Equations Used

After experimental test, the different parameters are calculated by equations below:

- Moisture:

$$M = \frac{M_0 - M_1}{M_0} \times 100 \tag{1}$$

where:

M is the moisture content (%);

M_0: Initial masse of the sample before drying (g);

M_1: Masse of the sample after drying at 105˚C (g).

- Ash:

$$\text{Ash} = \frac{M_2}{M_1} \times 100 \tag{2}$$

where

M_2: Ash mass (masse of the residue after incineration at 750˚C (g)).

M_1: Masse of the dry sample (g).

- Volatile Mater (VM):

$$\text{V.M} = \frac{M_1 - M_3}{M_1} \times 100 \tag{3}$$

where:

M_1: Masse of dry solid fuel (g) before heating;

M_3: Masse of residues (g) after heating at 950˚C.

- Fixed Carbon (FC):

$$\text{FC}(\text{Dry}) = 100 - ([\text{Volatile Dry}] + [\text{Ash Dry}]) \tag{4}$$

- Calorific Value (CV):

$$Q = \frac{\Delta\theta * W - e_1 - e_2 - e_3}{M_o} (\text{MJ/kg}) \tag{5}$$

$$W = \frac{H * m_{ac} + e_1 + e_3}{\Delta\theta} \tag{6}$$

where:

Q: Calorific value of biomass study (kJ/kg);

W: Water equivalent of the calorimeter (J/K) or (cal/˚C) or equivalent energy of the calorimeter (cal/˚C);

H: Combustion heat of benzoic acid (kJ/kg or cal/g) = 26448 kJ/kg;

mac: Mass of the benzoic acid sample (g);

$\Delta\theta$: Temperature variation during combustion (˚C);

e_2: Correction due to formation of sulfuric acid (negligible);

e_3: Correction of the heat of combustion of nikeline wire (J or cal) (e_3 = 2.3 * Lf);

2,3: Correction value during combustion of chromium nickel wire of 45C10 parr (in cal/cm) and Lf: length of wire burned during combustion (cm);

e_1: Correction due to the formation of Nitric acid (negligible);

M_o: Mass of fuel sample tested (g).

3. Results and Discussion

3.1. Results

Results of proximate analysis for different biomass samples were given in Table 1. Overall moisture content varies between 2.69% and 10.92% with minimum for Bamboo charcoal and maximum for typha briquettes. This shows that all the samples were well dried and stored well before being collected outside typha briquettes that come out of the zone of good humidity according to EN 14961-2 and −6 standards [19] which must be less than 10%. Carbonized biomass has the lowest moisture content (less than 5%).

Ash content varies more than moisture content. Its value ranges between 0.07% and 55.27%. Bioterre (peanut shell mixed with clay) give maximum (55.27%) ash while the wood pellets have minimum (0.07%). Both biomasses (bioterre and typha biochar) with very high ash content have as binder the clay. The rice husk has also a high ash rate while it is in the raw state.

The volatile matter (VM) content of the biomass samples tested ranged from 25.38% (Bamboo coal) to 87.89% (Typha pellets). These results show that the carbonized samples (charcoal, bamboo, bamboo biochar, typha biochar) and bioterre have the lowest VM levels (less than 55%). The samples that are not carbonized and especially those that are densified have the best rates of VM (typha pellets, wood pellets, typha briquettes) (greater than 80%).

Content of fixed carbon vary widely between four samples. Bioterre have lowest 2.73% and bamboo charcoal had maximum 69.39% fixed carbon. We can note that three biomass samples (53.01% charcoal, 61.65% bamboo biocharbon, 69.39% bamboo charcoal) have fixed carbon content higher than 20%. The particularity is that these samples are only coals.

Table 2 shows the calorific values of the different biomass samples tested. The

Table 1. Proximate analysis results.

Fuels	Moisture (%)	Volatil Mater (%)	Ash (%)	Fixed Carbon (%)
Wood charcoal (W.C)	5.05	39.94	7.05	53.01
Bamboo charcoal (B.C)	2.69	25.38	5.23	69.39
Bamboo biocharcoal (B.Bc)	4.66	30.36	7.99	61.65
Typha biocharcoal	5.66	52.95	43.22	3.83
Bioterre (peanut shell + clay)	3.00	42.00	55.27	2.73
Jatropha Residues (J.R)	8.84	77.73	5.25	17.02
Shea butter cake pellets (S.B.C.P)	9.27	74.22	10.36	15.42
Typha pellets	8.61	87.89	6.33	5.78
Wood Pellets	7.44	84.89	0.07	15.04
Typha Briquettes	10.92	82.21	5.61	12.18
peanut shell	7.01	80.55	3.32	16.13
Rice husk	5.88	63.92	22.90	13.18

Table 2. Calorific values results.

Fuels	Bioterre	Rice husk	Typha bio-charcoal	Wood pellets	Sénégal wood	USA wood	S.B.C. Pellets	Typha pellets	peanut shell	J. R	B. C	B.Bc	W.C
Calorific Value (kJ/kg)	8789.48	14,625.17	15,479.13	17,268.56	17,894.02	17,996.42	18,919.53	18,964.36	20,694.04	21,918.65	27,156.33	27,344.66	27,509.59
Ecarttype	3228.57	386.94	472.84	154.08	193.09	131.28	516.71	178.04	106.18	781.4381001	330.7676102	1355.739266	3367.56

With: S.B.C: Shea butter cake; J.R: Jatropha Residues; B.C: Bamboo charcoal; B.Bc: Bamboo biocharcoal; W.C: Wood charcoal.

calorific values (CV) obtained ranged from 8789.48 kJ/kg (bioterre) to 27,509.59 kJ/kg (charcoal) with an overall average of 19,914.25 kJ/kg. It is found that the majority of samples have the CV between 15,000 kJ/kg and 20,000 kJ/kg. The three coals (bamboo charcoal, wood and bamboo biochar) have the higher (CV) (about 27,000 kJ/kg). On the other hand, the CV of bioterre is the lowest (8789 kJ/kg). All denser biomass are a good CV because the densication increase the heat per unit volume [20].

3.2. Discussion

The moisture results are satisfactory but nevertheless require clarification. The low humidity of carbonized biomass is due to the fact that during carbonization, the biomass sample is released from intrinsic moisture (bound water) and that the moisture found is extrinsic (bound only to weather conditions and conservations). This is not the case for non-carbonized biomass (which has both types of moisture).

Previous research has shown that humidity limits local temperature in biomass, the fuel will require additional energy to be heated [21]. The energy required to vaporize the water in the biomass will lower the temperature in the combustion chamber, thus slowing the rate of combustion. Moisture in the biomass will also reduce the temperature of the adiabatic flame and increase the amount of air required for complete combustion. A biomass with high moisture content will have a reduced rate of volatile production during pyrolysis and an increased char formation [22].

The high ash values in the biomass samples (bioterre: 55.27% and typha biochar 43.22%) tested are due to the presence of clay. Clay is a mineral material and does not carbonize. So, the residue found when determining the ash content is not just ash but there is clay. The high ash value of the rice husk (22.9%) is normal because previous studies by Pierre Delot (2014) [23] showed that this product contains the most silica compared to other plants whereas the ash is mostly composed of silica. The advantages to be gained when using these biomass for cooking or heating are the lack of corrosion often caused by the massive presence of ash, the ease in the maintenance, the easy obtaining of a fire, the non shutter shutters of ventilation of the cookstove by ashes…High ash content significantly reduces energy yield from a specific biomass source [16] and cookstove efficiency too [20].

The low volatility mater rate of charcoals and bio-charcoals is due to carbonization. During this chemical transformation, a large quantity of volatiles mater escapes from the biomass leaving only carbon. On the other hand, pelletizing or briquetting is a physical process that does not alter the nature of the biomass but increases its density. During this process, there is no loss of volatiles mater but the denser biomass tends to burn for long periods of time [20].

High volatile mater content gives a coal less friable than charcoal and produces less dust during transportation and handling but burns with a smoky flame. This requires a large amount of secondary air and high pressure to ensure efficient combustion [12]. Biomass with a high content of volatile matter is easier to gasify but produces high tar content [24].

A low volatile mater fuel is difficult to ignite but will burn with a clear flame [25].

The VM rate is proportional to the fixed carbon (CF) rate. The fact is that when the VM level of a biomass is high; the FC level is low. The lower the fixed carbon content of a biomass, it is of good quality since it contains a large amount of volatile matter. So it will be able to provide more heat when burned with a suitable cookstove and pyrolyze volatile matter.

Bamboo charcoal and its biochar have the best PCS values (at the same height as wood charcoal, see **Table 2**). These values are in agreement with those of J.-C. GOUDEAU who said that: "coal (whatever its nature) has the highest ICP of solid biomass and which is generally between 25,000 and 35,000 kJ/kg [26]." On the other hand, the weakness of bioterre and typha biochar is due to the presence of clay in the composition of this biomass. Of the biomasses that have carbonized, only the rice husk has a low PCS (less than 17,000 kJ/kg). The other biomasses show satisfactory results compared to wood PCS. The good PCS values of Jatropha residues, peanut shell, typha pellets, typha briquettes and shea butter cake pellets (higher than PCS of wood = 17,894.02 kJ/kg) encourage them to be selected as a substitute for wood. These results are generally satisfactory, since they are for the most part greater than the minimum value of PCS recommended by the German and Austrian standards for pellet and briquette fuels (Austria ÖNORM M7135, Calorific value ≥ 18,000 kJ/kg, Germany DIN 51,731/ DIN plus, Calorific value 17,500 - 19,500 kJ/kg) [20].

4. Conclusion

The increased demand for energy, particularly in developing countries, can be filled by the use of biomass, which is a source of renewable energy available in abundance in these countries. The inefficient and unprocessed use of biomass residues is a pollution hazard to the environment and causes lung and eye diseases for the population. This requires quantification, characterization and efficient conversion of these easily available by-products for energy production. This study shows that the biomass (fuels) that is already in use or in use in some parts of the country or sub-region can be improved in calorific value by reducing its moisture content, controlling nature and quality binder and using suitable cookstove for good thermal conversion. At the same time, other fuels have good characteristics (wood pellets, typha pellets, peanut hulls, typha briquettes and bamboo biochar) and are apt for substituting wood or charcoal. So the government has to motivate actions to be taken to spread its large fuels, to create productions and sales units. The study can be extended to the elementary analysis in order to know the percentage mass composition in elements of each type of fuel.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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