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RESEARCH ARTICLE

Prediction of Cotton Shell from Sodecoton Behavior in Thermal Conversion and Theoretical Energy Potential

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ABSTRACT

This work focuses on the evaluation of the energy potential of cotton shells from SODECOTON and to predict suitable thermal conversion conditions. To achieve this goal, structural and proximate analyses were performed, while ultimate analysis, flue gas and higher heating value were calculated from models. This study reveals that cotton shells highly contain cellulose, volatile matter, lignin and carbon, which make it suitable for bioethanol, bio-oil/syngas and biochar production via biochemical and thermochemical technologies as well as fuel briquette. Heating value from cotton shell ranging from 17 MJ/kg to 19 MJ/kg, is set in the interval to be used as fuel. From the results, the value of flue gas is within acceptable limits and the pollutant emissions are less than the values of regulated threshold set. The energy potential released is around 1.30 GJ per year, 1.58×10^7 Nm^3/year, 1.62×10^4 m^3/year, $15.21 \times E^6$ L and $26 \times E^6$ L for annual combustion energy, syngas, methane, bioethanol and bio oil, respectively. Amongst them combustion via fuel briquette is suitable for less developing country such as Cameroon thus, it could supply 40% of cooking energy consumption in Garoua center town and can improve environmental sustainability in company.

Keywords: Cotton shell, energy potential, fuel briquette, SODECOTON.

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HIGHLIGHTS

- Ultimate, proximate and structural analyses of cotton shell from SODECOTON
- Efficient conversion in combustion, biogas, bio-oil and biochar
- Efficient process parameters
- Design of conversion plant
- Prediction of theoretical energy potential

1. INTRODUCTION

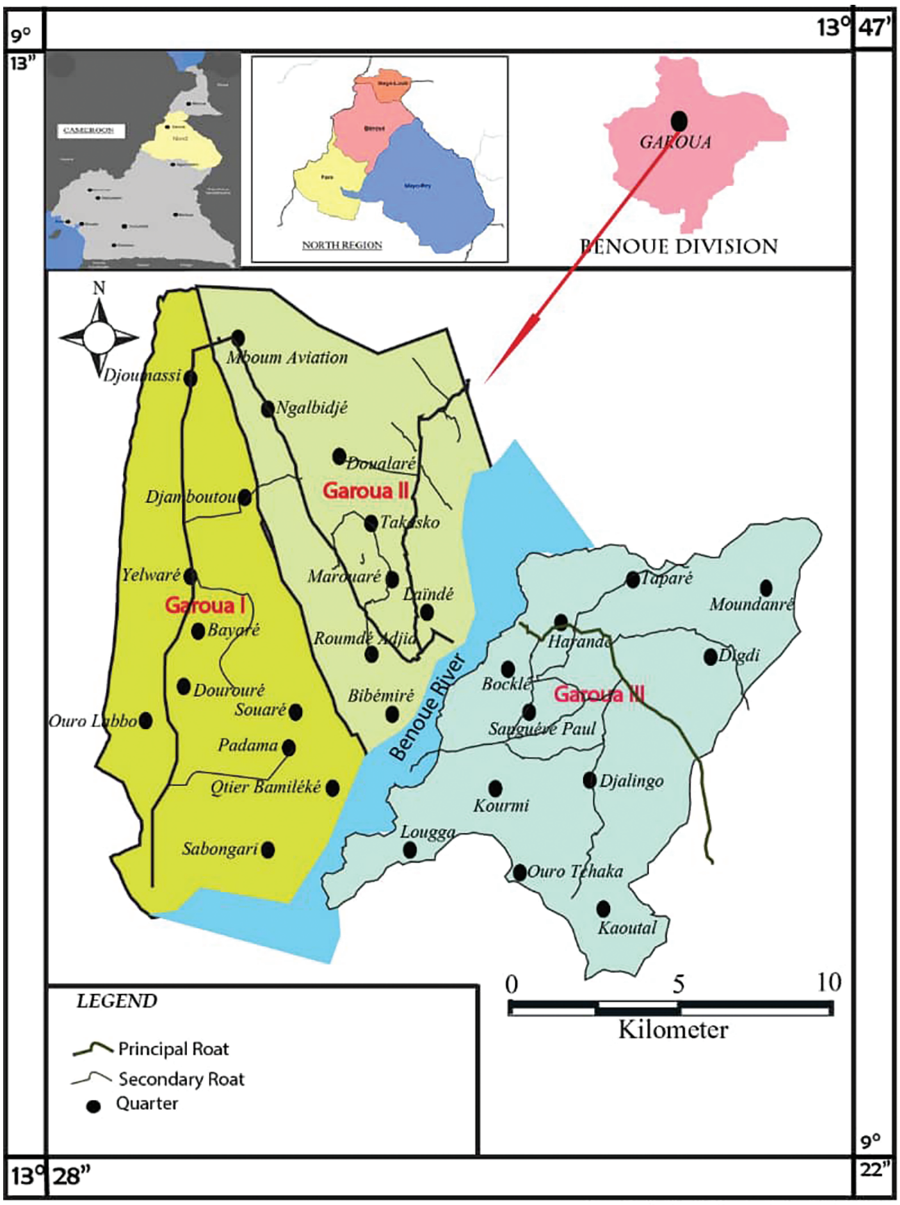
SODECOTON is a Cameroon company located in the northern part of the country, particularly in the Garoua region and the Benue division. Its activities are agricultural, industrial, and commercial. In industrial activities, oil named "Diamaor" is extracted from cotton seed. This process has many steps and generates a huge amount of waste. These steps involve shelling, extraction, refining and packaging. The generated wastes from this transformation are cotton shell, cotton seed, bleaching lands and plastic wastes, respectively. Among them, the company is always looking for the best route to manage cotton shells in order to be in rule with environmental law. In fact, around 64,500 dry bons tons of cotton shell is generated per year, and just a few amount is used to heat the boiler during the extraction process and ninety percent (90%) is stored and takes up a lot of space and causing fires, soil, air and water pollution and leads to additional expenses in the payment of taxes.

However, cotton shell is a degradable waste, and many methods in literature exist to valorize them. These methods are classified into three domains, namely thermal, chemical through the adsorption process and biochemical by extracting macromolecule for various transformations [1]–[3]. Thermal valorization seems to be a suitable and promising method looking at the energetic deficit observed in the northern part of the country, particularly in the

Garoua division, and it could be a local and cheaper source of energy. However, there are many biomass conversion processes to prepare energy-efficient biofuels [4], [5]. These methods are physical, agrochemical, thermochemical and biochemical [6], [7]. For efficient use of the feedstock as renewable energy, the knowledge of raw material properties plays a vital role in the choice of thermal conversion technologies [8] as well as thermal conversion condition [9], [7].

In fact, in the briquetting process, there are three methods to pretreat biomass before densification, namely drying, AFEX and carbonization [4]. In the thermochemical process of conversion, the choice of some parameters such as temperature, time, and mass influence production yield [10]–[12], whereas, in the biochemical route, the choice of pretreatment and hydrolysis processes also affects yield [13]. These different pretreatments can be classified into five groups: physical (grinding, ultrasound, microwaves, and hydro thermolysis), chemical (acid or alkaline hydrolysis, solvents, and ozone), physicochemical (fiber explosion with ammonium or with CO_2), biological (fungi, bacteria, and microbes) and combined [13]. Meanwhile, there are two hydrolysis processes, mainly chemical (acid, alkaline) and enzymatic, where cellulose and hemicellulose are transformed into sugars by enzymes secreted by microorganisms such as bacteria and fungi [13]. Hence, the understanding of cotton shell properties can help to design the suitable pretreatment and process parameters [8]. These properties are compositional characteristics, namely proximate, ultimate, and structural analyses [14], [15].

Proximate analysis includes ash, volatile matter, fixed carbon, and moisture content. The high value of ash content decreases heating value, and the low melting point of ash in biomass causes sintering, agglomeration, deposition, erosion, and corrosion problems [16]–[18]. Volatile matter determines the ease of ignition and burning of the solids fuel and together with the VM/FC ratio, determines



Map Made by Talba Dalatou Nov 2022.

Fig. 1. Map of Garoua subdivision.

Fig. 2. Dried cotton shell.

the flame stability during combustion [19]. Fixed carbon increases with heating value, whereas moisture content decreases heating value due to the latent heat of water evaporation [17], [18]. The ultimate analysis gives information on the amount of gases released during thermochemical processes as well as water evaporation. These gases are CO_2, CO, CH_4, H_2 and can be further used as an energy source for heat and power generation [20]. The structural composition, which is cellulose, hemicellulose, lignin and extractible, influences the choice of pretreatment in different conversion processes [21], [22]. Thus, the knowledge of these compositional characteristics is a main feature for an economical and efficient route for the thermal conversion condition as well as in the design of the conversion plant.

The composition of cotton shell from the literature varying from one area to another [8], [23]–[27] may be due to climate, soil, and fertilizer. As far as cotton shell from SODECOTON is concerned, there is no study on fuel properties. The goal of the present paper is the assessment of fuel properties of cotton shell from SODECOTON and to predict appropriate pretreatment and process parameters.

2. MATERIALS AND METHODS

2.1. *Presentation of Studied Area*

SODECOTON is located in Benue division of Garoua region of Cameroon. This division has 12 subdivisions, namely Bascheo, Bibmi, Dembo, Demsa, Garoua I, Garoua II, Garoua III, Lagdo, Mayo-Hourna, Pitoa, Tcheba, and Touroua. Amongst them, only three subdivisions are situated in Garoua center town. The three subdivisions are Garoua I, Garoua II and Garoua III and contain 568 593 populations. Garoua center town is lied along the right bank of benue river. Fig. 1 represents the general view of Garoua center town.

2.2. *Sampling*

Cotton shell was collected in SODECOTON and was dried at 50 °C until constant mass. Dried sample was characterized to evaluate its thermal properties. The picture of the dried sample is presented in Fig. 2.

2.3. *Structural Analysis Determination*

2.3.1. *Cellulose Content Experiment*

Cellulose content was determined by the mean of Kurschner Hoffer nitric acid method. This method was described by Samomssa *et al*. [8] and is based on extraction of white paste of cellulose using 20 ml of ethanol at 95%, 5 ml of concentred nitric acid and 1g of dried cotton shell.

2.3.2 *Lignin Content Experiment*

It was determined using Tappi T 222 om-88 method described by Samomssa *et al*. [8]. This method is based on the use of 5 ml of 72% H_2SO_4. Thus, a volume of 5 ml of 72% H_2SO_4 solution was slowly added to 1g (w_1) of cotton shell and was maintained at 30 °C for 2 h. After, adding 300 ml of distilled water the whole mixture was boiled for 1 h at 90 °C. The obtained solid was filtered on a Buchner, washed several times with 150 ml of distilled water so as to eliminate sulfate ions. The residue was dried at 105 °C until constant mass (w_2) then placed in a muffle furnace at 800 °C then weighed (w_3). The lignin content was determined from (1):

$$\%Lignin = \frac{w_2 - w_3}{w_1} \times 100 \tag{1}$$

where:
w_1 – initial weight of sample,
w_2 – weight of sample after oven,
w_3 – weight of sample after furnace.

2.3.3 *Hemicellulose Content Experiment*

The experiment to determine hemicellulose content was done according to alkaline extraction method by mixing 1 g (m_1) of sample with 0.5 M NaOH. The mixture was boiled for 4 h, filtered and washed with distilled water until pH 7. Residues were dried at 105 °C until constant mass (m_2) and this represents hemicellulose.

2.4. *Proximate Analysis Determination*

2.4.1. *Moisture Content (MC) Determination*

ASTM E871-82 (2006) method was used to determine moisture content [28]. For this 1 g of the sample was weighed into pre-weighed crucible (w_1). Then the whole was weighed (w_2) and was dried in an oven at 105 °C for 24 h. The dried sample was cooled in a desiccator and re-weighed (w_3), and moisture loss was reported. The moisture content was calculated by using the (2)

$$MC = \frac{w_2 - w_3}{w_2 - w_1} \times 100 \tag{2}$$

where:
w_1 – initial weight of the empty crucible,
w_2 – weight of the crucible + sample,
w_3 – final weight of the crucible + sample after drying.

2.4.2. *Ash Content (AC) Determination*

The ash content was performed according to ASTM D1102-84 (2007) [29] method. 1 g (w_1) of sample was placed in a pre-weighed crucible in an oven at 105 °C until constant mass and then weighed (w_2) after which was incinerated in a muffle furnace at 550 °C for 4 h until white ashes were obtained. The crucible was then transferred into a desiccator for cooling. The cooled sample is then weighed (w_3). The ash content was calculated by using the (3):

$$\text{Ash content }(\%) = \frac{w_3 - w_1}{w_2 - w_1} \times 100 \quad (3)$$

where:
w_1 – weight of the crucible,
w_2 – weight of the crucible + sample before incineration,
w_3 – weight of the crucible + sample after incineration.

2.4.3. *Volatile Matter (VM) Determination*

The volatile matter was investigated according to ASTM E872-82 (2006) [30]. 1 g (m_i) of sample was placed in a pre-weighted crucible in an oven at 105 °C until constant mass and weighed (m_1). The dry sample was incinerated in a muffle furnace at 550 °C for 10 minutes then weighed (m_2). The VM was obtained from (4):

$$\%VM = \frac{m_1 - m_2}{m_1} \times 100 \quad (4)$$

where:
m_1 – weight of crucible + sample after oven,
m_2 – weight of crucible + sample after incineration.

2.4.4. *Fixed Carbon (FC) Estimation*

Fixed carbon was obtained as shown in (5):

$$FC = 100 - (VM + AC) \quad (5)$$

where:
VM – Volatile matter,
AC – Ash content.

2.5. *Estimation of Ultimate Analysis, Higher Heating Value, Flue Gas Composition and Energy Potential*

2.5.1. *Ultimate Analysis*

Elemental composition is calculating from proximate analysis of cotton shell [31], [32] using (6) to (10):

$$Carbon = 0.637FC + 0.455VM \quad (6)$$

$$Hydrogen = 0.052FC + 0.062VM \quad (7)$$

$$Oxygen = 0.304FC + 0.476VM \quad (8)$$

$$Sulfur = H + C + O - 100 \quad (9)$$

$$Nitrogen = 2.10 - 0.020VM \quad (10)$$

2.5.2. *High Heating Value (HHV)*

Vargas-Moreno *et al.* [14] and Demirbas' [33] mathematical models were used to estimate high heating value from biochemical, proximate and ultimate analyses. These models are given in the (11) to (14):

$$HHV = 0.0877\,(Lignin) + 16.4951 \quad (11)$$

$$HHV = 27.239 - 0.306 \times [ash] - 0.089 \times [VM] \quad (12)$$

$$\text{HHV} = -3.393 + 0.507[\text{C}] - 0.341[\text{H}] + 0.067[\text{N}] \quad (13)$$

$$\begin{aligned}\text{HHV} \;=\; & 0.3491[\text{C}] + 1.1783[\text{H}] + 0.1005[\text{S}] - 0.1034[\text{O}] \\ & -0.0151[\text{N}] - 0.0211[\text{ash}] \quad (14)\end{aligned}$$

2.5.3. *Flue gases*

The composition of fumes (Flue gases) is calculated according to Yves Jeannot *et al.* [34]. The equations used for determining flue gases are given in the (15) to (20):

$$\text{VX} = \%\text{X} \times \frac{22.4}{MX} \quad (15)$$

$$Va = \frac{1}{\psi}\left(\text{VCO}_2 + \text{V}_{\text{SO}_2} + \frac{1}{2}V\text{H}_2\text{O} - \text{V}_{\text{O}_2}\right) \quad (16)$$

$$\text{V}_{\text{FS}} = \text{V}_{CO_2} + \text{V}_{\text{SO}_2} + \text{V}_{\text{N}_2} + (1 - \psi) \times \text{V}_\text{a} \quad (17)$$

$$\text{V}_{\text{FH}} = \text{V}_{\text{FS}} + \text{V}_{\text{H}_2\text{O}} \quad (18)$$

$$\text{Wt} = 11,5 \times \text{C} + 34,5 \times \left(\text{H} - \frac{\text{O}}{8}\right) + 4,3 \times \text{S} \quad (19)$$

$$\text{Wdfg} = \frac{28}{12} \times \text{C} + \frac{44}{12} \times \text{C} + \frac{64}{32} \times \text{S} + 0,768 \times \text{WT} + \text{N} \quad (20)$$

where:
X – represents either C, S, N, O and H,
MX – molar mass of X,
Ψ – oxygen content,
Va – comburivorous power,
V_{CO2}, V_{H2O}, V_{SO2}, V_{O2}, and V_{N2} are volumes of carbon dioxide, the volume of water, the volume of Sulfur dioxide, the volume of Oxygen, and the volume of the Nitrogen, respectively,
V_{FS} – dry smoking power,
V_{FH} – wet smoking power,
Wt – theoretical oxygen index,
Wdfg – theoretical mass of chimney.

2.5.4. *Energy Potential by Combustion*

The energy potential of cotton shell by combustion was calculated using (21):

$$EP = \sum_{i}^{n} MiHHVi \quad (21)$$

where EP (GJ/year) is the energy potential in tons per year, Mi (tons/year) is the amount of cotton shell per year and HHVi (GJ/ton) is the higher heating value per unit.

2.5.5. *Energy Potential in Syngas Production*

The gasification process chemical reaction is expressed by (22):

$$\begin{aligned}& \text{x}\,(\text{C}_\text{n}\text{H}_\text{a}\text{O}_\text{b}\text{S}_\text{c}\text{N}_\text{d} + \text{MC}) + \text{y}\,(\text{O}_2 + 3.77\text{N}_2) + \text{z}\,(\text{H}_2\text{O}) \\ & - \rightarrow (\text{CO} + \text{CO}_2 + \text{CH}_4 + \text{H}_2 + \text{N}_2 + \text{S}_2) \quad (22)\end{aligned}$$

The empirical formula $C_nH_aO_bS_cN_d$ was determined owing to the contents of chemical elements. Exponents n, a, b, c, and d were obtained using (22) to (27). The energy conversion of gasifying was evaluated according to Wang *et al.* model [16] illustrated by (28):

$$\text{n} = \frac{\%\text{C}}{\text{M}_\text{C}} \times \frac{1}{\text{R}_\text{C}} \quad (23)$$

$$a = \frac{\%H}{M_H} \times \frac{1}{R_C} \quad (24)$$

$$b = \frac{\%O}{M_O} \times \frac{1}{R_C} \quad (25)$$

$$c = \frac{\%S}{M_S} \times \frac{1}{R_C} \quad (26)$$

$$d = \frac{\%N}{M_N} \times \frac{1}{R_C} \quad (27)$$

$$S_y = \frac{22.4}{(12n + a + 16b + 32c + 14d) \cdot x} \quad (28)$$

where:
MC – moisture content,
M_C, M_H, M_O, M_S and M_N: represent molar masses of carbon, hydrogen, oxygen, sulfur, and Nitrogen, respectively,
R_C – ratio molar mass.

2.5.6. Energy Potential in Methane Production

The CH_4 production Bu (Nl/kg VM) given by (29), was calculated from the model [16] described by (30):

$$C_nH_aO_b + \left(n - \frac{a}{4} - \frac{b}{2}\right) H_2O \rightarrow \left(\frac{n}{2} - \frac{a}{8} + \frac{b}{4}\right) CO_2 + \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) CH_4 \quad (29)$$

$$B_u = \left(\frac{n}{2} + \frac{a}{8} - \frac{b}{4}\right) \times \frac{22.4}{(12n + a + 16b)} \quad (30)$$

2.5.7. Energy Potential in Bioethanol and Bio-oil Production

Equations (31) and (32) cited by Sigüencia *et al*. [35] and Edward [36] are used to estimate the volume of bioethanol and bio-oil percentage, respectively:

$$\text{Bioetanol (l/year)} = \frac{Cellulose_{an} \times Rtp \times E^6}{\rho} \quad (31)$$

$$\text{Bio oil (L/Ton)} = 9.245 \times C - 3.218 \quad (32)$$

where:
ρ – bioethanol density (790g/l),
$1E^6$ – conversion factor from grams to tons,
$Cellulose_{an}$ – annual cellulose in t/year from cotton shell,
C – organique carbon content in ton per year,
Rtp – represent 0.49 g ethanol/g.

$$Cellulose_{an}(t/year) = cellulose\ content(\%) \times Amount\ of\ residues\ (t/year) \quad (33)$$

3. RESULTS AND DISCUSION

3.1. Analysing of Structural Composition

The structural analysis is given in Table I revealing that cellulose is higher followed by hemicellulose while lignin is lower. Furthermore, literature reported that, feedstock highly content in cellulose and hemicellulose increases bioethanol, biogas, bio-oil yields while those rich in lignin content increases coal or biochar and fuel briquette yields [1], [23], [35], [36]. For bioethanol production, cellulose and hemicellulose are proportionaly hydrolysed into glucose and xylose, respectively; while during biogas production these biomolecules slow down the release of NH_4NO_3 and are hydrolysed to methane [36] but, lignin is not recommended due to its slow anaerobic decomposition. This can be justified by the fact that; the lignin biodegradation occurs in an aerobic environment. Concerning pyrolysis process, cellulose and hemicellulose contents are converted to bio-oil [8], [23], [35] while lignin which presents tensile strength is transformed into coal [1]. According to obtained results, cotton shell could present high yields during bioethanol and bio-oil/syngas processes due to high cellulose and hemicellulose contents. Lignin content displays that cotton shell could be also transformed to coal and then to fuel briquette.

In bioethanol process, pretreatment is one of the most important steps which permit to enhance solids digestibility, sugar yields, to avoid the sugars degradation and to minimize the inhibitors formation [37], [38]. Thus, lignin is a recalcitrant part in the fermentation process and must be remove. Regarding the value of lignin in cotton shell (12%), alkaline or biological pretreatments are suitable to remove it, thus, to enhance the porosity, and surface area of biomass and therefore improves hydrolysis. Organosolv pretreatment also has the ability to fractionate biomass into cellulose, hemicellulose and lignin with high efficiency [39] and then to remove lignin. Nevertheless, these pretreatments could be combined with acid pretreatment due to high hemicellulose content (23%), which leads to the hydrolysis of hemicellulose to fermentable sugars and amorphous cellulose conversion to crystalline. Concerning the biogas process, Li *et al*. [40] observed that cellulose to methane reveals a higher yield than hemicellulose; however, hemicellulose is easier to hydrolyze than cellulose, while the digestion of lignin is very difficult. Thus, for efficient conversion of cotton shell to methane, alkaline pretreatment using sodium hydroxide to remove lignin and increase the crystallinity of cellulose is required. Comminution pretreatment is also recommended to reduce particle size, as shown in Fig. 2. Zheng *et al*. [41] mentioned that comminution pretreatment can alter feedstock ultrastructure, increase surface area accessibility, reduce cellulose crystallinity, and decrease cellulose polymerisation, thus improving digestibility.

During bio-oil production, cellulose and hemicellulose contents in cotton shells produce a higher bio-oil yield. Nevertheless, Raquel *et al*. [42] reported that hemicellulose is less volatile than cellulose; hence, a cotton shell, which reveals high cellulose content, could lead to a higher bio-oil

TABLE I: STRUCTURAL ANALYSIS OF COTTON SHELL (% ON DRY BASIS)

Parameters	Values
Cellulose	38.03 ± 0.50
Lignin	12.51 ± 0.09
Hemicellulose	23.09 ± 0.04

TABLE II: Proximate Analysis of Cotton Shell (% on Dry Basis)

Analyse	Cotton shell
Moisture content, %	7.25 ± 0.15
Ash, %	3.63 ± 0.07
Volatile matter (MV), %	70.00 ± 1.00
Fixed carbon (CF), %	26.33 ± 1.06

TABLE III: Ultimate Analysis (% on Dry Basis)

Analyse	Cotton shell
Carbon (C), %	48.62 ± 0.22
Hydrogen (H), %	5.70 ± 0.01
Oxygen (O), %	41.32 ± 0.15
Nitrogen (N), %	0.70 ± 0.02
Sulfur (S), %	3.64 ± 0.08
C/H, %	8.52 ± 0,05

yield. According to Raquel *et al*. [42], lignin decomposition is difficult and leads to a small bio-oil yield. However, Casoni *et al*. [43] observed that the decomposition of lignin in studied biomass occurs at temperatures and high heating rates and then, resulting in higher yield of liquid. Also, the treatment of this material with fungus enhanced yield due to the activity of enzyme which leads to a degradation of the lignin biomolecule, makes it more accessible to heat attack. In this way, bio-oil yield will be improved during the conversion of the cotton shell to bio-oil.

3.2. Analysing of Proximate Composition

The results of proximate analysis are presented in Table II. This table reveals that volatile matter is the highest value followed by fixed carbon. Moisture content and ash are lower. These analyses play a vital role in the selection of efficient thermal conversion technologies. Moreso, Samomssa *et al*. [8] reported that moisture content less than 10% is appropriate in thermochemical conversion such as combustion, gasification, pyrolysis and physical conversion as densification into solid fuel briquette [4], [8]. Regarding the obtained moisture content of cotton shell from Table II, it can be concluded that thermochemical and physical route are the best conversion technologies. For biochemical processes, moisture content must be adjusted.

Volatile matter is defined as a quantity of volatile elements in the biomass, such as organic moieties like cellulose, hemicellulose, phenol, and moisture content. Thus, the biomass with high volatile matter produces high amounts of syngas and bio-oil [44]. The ash content is the inorganic and metal, mostly in the form of oxides in the biomass such as silisia, magnesium, lignin etc., for instance, a nutrient that the plant absorbs from the water or the soil during its growth or during harvesting [23], [8]. The fixed carbon is the amount of non-volatile organic matter present in the biomass and high heating value. The highest fixed carbon increases bio char production through thermochemical processes [45].

According to the value from Table II, the volatile matter is high and will increase bio-oil and syngas yield of the cotton shell during the pyrolysis process. Ash content is low in investigated biomass, whereas Lee *et al*. [46] found that high ash content contributes to decrease bio-oil yield, and it increases the char and pyrolytic gases such as CO_2, CO, CH_4, H_2. These gases can be directly used for energy applications. Fixed carbon is high; hence bio char yield will be increased during the pyrolysis process of the cotton shell. To optimize the pyrolysis process, energy from syngas must be recovered by the mean of the heat exchanger.

3.3. Analyzing of Ultimate Composition

Table III shows the ultimate analysis of cotton shell. This table displays that carbon is the highest amount followed by oxygen. Sulfur is the lowest value followed by nitrogen and hydrogen. This value is in accordance with the literature thus, the model used to calculate ultimate analysis is reliable. In bioethanol process, carbon and oxygen are the indicators of CO_2 formation during fermentation step, whereas, carbon and oxygen increase bioethanol yield. Oxygen content predict the amount of oxygen that cotton shell can provide during fermentation, while nitrogen acts as an activator. In biogas process, carbon and oxygen predict the volume of CO_2, while carbon and hydrogen reveal the volume of CH_4. Weiland [47] found that methanogenic bacteria are able to use hydrogen to form methane mostly at thermophilic step which making the process faster and more efficient.

The results from this analysis suggesting that pyrolytic gases such as CO_2, CO, CH_4, H_2 can certainly be present during pyrolysis and be further used as an energy source for heat and power generation, H_2 production, and synthesis of liquid fuels. Oxygen (0), Sulfur (S) and Nitrogen (N) contribute significantly to oil gravity. In fact, cleavage of heteroatomic bonds such as C-O and C-S is disproportionately greater than of the more stable C-C bonds. The lower oxygen content in biomass, the lower will be the possibility of forming H-bonds with the H_2O. Chen *et al*. [48] pointed out that oxygen in biomass was mainly removed in the form of CO_2, water, and acetic acid. C and H could also be lost during deoxygenation. The highest value of carbon and C/H increase heating value and biochar yield. Samomssa *et al*. [8] cited that hydrogen and sulfur content increase heating value while oxygen and nitrogen decrease heating value. Sulfur, Nitrogen and Oxygen predict pollutant gases emitted during combustion. The low fractions of Nitrogen and Sulfur reveal that cotton shell is environment friendly than the conventional fossil fuel. The Sulfur content is more than 0.2%, thus associated with H_2 lead to a formation of H_2S which is corrosive. The nitrogen content exceeds 0.6%, revealing that NOx emissions could be expected [8]. Hence the levels of S and N could be taken into account.

3.4. Analysing of Flue Gases

The flue gases of cotton shell are presented in Table IV. From this table, volumes of CO_2, H_2O, and O_2 are high, whereas volumes of N_2 and SO_2 are low. This table also reveals that combustive power, dry smoke power and wet fumigant have similar values with slight variation. The theoretical mass of chimney gas is low than theoretical oxygen index. The combustion process inputs are fuel and

TABLE IV: FLUE GASES COMPOSITION

VCO_2	VSO_2	VH_2O	VO_2	VN_2	Va	VFS	VFH	Wt	Wdfg
0.908 ± 0.004	0.0255 ± 0.001	0.639 ± 0.001	0.289 ± 0.001	0.006 ± 0.020	4.588 ± 0.021	4.564 ± 0.02	5.203 ± 0.019	593.589 ± 2.635	755.602 ± 3.216

Note: **Va**: combustive power, $\mathbf{V_{FS}}$: dry smoke power, $\mathbf{V_{FH}}$: wet fumigant power, **Wt**: theoretical oxygen index, **Wdfg**: theoretical mass of chimney gas.

TABLE V: HIGH HEATING VALUE (MJ/KG) AND ENERGY POTENTIAL (GJ) CALCULATED FROM DIFFERENT MODEL

HHV from ultimate analysis	HHV from proximate analysis	HHV from proximate and ultimate analysis	HHV from structural analysis
19.36 ± 0.12 MJ/kg	19.89 ± 0.11 MJ/kg	19.71 ± 0.08 MJ/kg	17.60 ± 0.20 MJ/kg
EP from ultimate analysis	EP from proximate analysis	EP from proximate and ultimate analysis	EP from structural analysis
1.26 ± 0.07 GJ	1.30 ± 0.06 GJ	1.29 ± 0.05 GJ	1.11 ± 0.10 GJ
Syngas production	CH_4 production	Bioethanol	Bio oil
1.58 × 10^7 Nm^3/year	1.62 × 10^4 m^3/year	15.21 × E^6 L/year	26 × E^6 L/t/year
Chemical formula		$CH_{1.394}O_{0.638}S_{0.163}N_{0.012}$	

Note: HHV: High heating value, EP: Energy potential.

air. Samomssa *et al*. [8] reviewed that carbon dioxide (CO_2) limit in the air is set at 15%. The concentration more than this value could cause humans unconsciousness. In addition, oxygen excess associated with sulfur dioxide is transformed to sulfur trioxide (SO_3). However, the formation of sulfur trioxide is favoured. at higher temperatures, approximately 800 °C. Besides, the air nitrogen, in combination with the nitrogen contained in the fuel, led to the formation of the hazardous nitrogen oxides. During combustion, the nitrogen from the fuel combined to oxygen from the air initially form nitrogen monoxide. In a further step tis nitrogen monoxide, in the presence of oxygen is oxidised to form the hazardous nitrogen dioxide (NO_2) which, in association with sunlight, leads to the formation of ozone (O_3).

According to the results of study, the value of flue gas is within the environment impact admissible limits set by Burkart [49]. However, these values are out of heath problem limit fixed, hence it is imperative to consider these flue gases during work conditions for limiting severe health problem in long term.

3.5. Analysing of Heating Value and Energy Potential

Table V shows calculated HHV from ultimate, proximate, and structural analysis. It comes from this table that HHV from proximate, ultimate, and proximate/ultimate analysis vary slightly and nearly identical as reported in the literature using calorimetric bomb. That can justify the reliability of used models. HHV from structure analysis is a bit low but not significant different from other. The highest value of higher heating value around 17 MJ/kg–19 MJ/kg of cotton shell reveals that this bioresources can be used efficiently in thermochemical and physical conversion. Energy potential follows the same behavior and can produce 1.30 GJ per year, 1.58 × 10^7 Nm^3/year, 1.62 × 10^4 m^3/year, 15.21 × E^6 L and 26 × E^6 L for annual combustion energy, syngas, methane, bioethanol and bio-oil, respectively.

3.6. Practical Applications

According to statements on compositional characteristics of cotton shell, bioethanol, bio-oil/syngas and biochar are suitable conversion technologies as well as fuel briquette. However, for less developing country such as Cameroon, densification to produce fuel briquettes is the affordable and promising because it is low cost and easy to put in place. This can be a local solution for deficit energy observed mostly in Garoua center town, which is constituted with three subdivisions namely Garoua I, Garoua II and Garoua III. The literature reveals that in Garoua center town, 0.75 kg/Person/day is used and can lead to 164,250 tons per year of wood energy consumption. Quantity of cotton shell is 64,500 tons per year thus, could replace 40% of wood energy consumption in Garoua center town.

4. CONCLUSION

At the end of this study, the energy potential from cotton shell is around 1.2 GJ/year. Cotton shell properties show that efficient thermal conversion is bioethanol, bio-oil/syngas and biochar, as well as fuel briquette. This could produce 1.30 GJ per year, 1.58 × 10^7 Nm^3/year, 1.62 × 10^4 m^3/year, 15.21 × E^6 L and 26 × E^6 L for annual combustion energy, syngas, methane, bioethanol, and bio-oil, respectively. Nevertheless, the compositional characteristics reveals that the process parameters and design plant could be taken into account to enhance product yield. Amongst these conversion processes, densification for fuel briquette seems to be suitable for less developing countries such as Cameroon and could supply 40% of cooking energy consumption in Garoua center town. In this way, environmental sustainability can be improved in the company.

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CONFLICT OF INTEREST

The authors have no relevant financial or non-financial interests to disclose.

AUTHOR CONTRIBUTION

All authors contributed to the study conception and design. Sampling, data collection, and analysis were performed by Onguene Mvogo Philippe and Samomssa Inna. Modeling was performed by Rodica Dinică Mihaela and Circiumaru Adrian. The first draft of the manuscript was written by Samomssa Inna, Domga Richard and Onguene Mvogo Philippe. Research planning, organizational designing, and framework of the manuscript were done by Samomssa Inna and Rodica Dinică Mihaela. All authors read and approved the final manuscript.

STATEMENTS AND DECLARATIONS

This article is original and contains unpublished material. The corresponding author confirms that all authors have read and approved the manuscript and no ethical issues involved. In addition, order of authors has been approved by all authors.

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