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Evaluation of Blends of Agricultural Solid Biomass Waste for Solid Fuel Production

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Abstract: In this study, the calorific values of solid fuel samples and their blends in different proportions were determined. Waste samples as sawdust, charcoal, palm kernel bagasse, palm kernel shell, corn cob, palm fronds and coconut shell were subjected to combustion in an isothermal bomb calorimeter and their heating temperature profiles and corresponding heating values were estimated. Individual materials and different blending ratios in weight by weight (1:1, 1:1:1, 3:1:1, 1:3:1, and 1:1:3) heating contents were established. Burning time test was evaluated for blended materials with highest caloric values. Charcoal had the highest calorific value amongst all individual samples with a calorific value of 17,062 kJ/kg with palm fronds having the least heating value of 12,997 kJ/kg. In the 1:1 ratio mix, charcoal:palm oil bagasse had the highest heating content of 21,907 kJ/kg. Considering the ratios of three different solid mass in varying weight proportions, the combination of charcoal:coconut shell:palm oil bagasse (1:1:1) in equal weight percent gave the highest heating content of 23,373 kJ/kg. The blend of charcoal:coconut shell:palm kernel bagasse had the highest burning time of 20 minutes and 12 seconds. From the evaluations, charcoal in mixed proportions with other solid biomass are excellent materials to be considered for solid fuels production.

Key Words: Biomass; Bomb calorimeter; Caloric value; Combustion; Pellets

1. Introduction

Energy security, global warming and proper use of locally sourced materials are the driving factors for using biomass as an alternative energy source [1]. Biomass fuel utilization provides great advantages for the environment. Biomass absorbs carbon dioxide during growth, and emits it during combustion. As a result, biomass helps the atmospheric carbon dioxide recycling, does not contribute to the greenhouse effect, and consumes some amount of CO_2 from the atmosphere during growth and releases the same during combustion [2]. Fossil fuel, a non-renewable form of energy, provides 80 percent of man's energy [3]. This conventional form of energy is being gradually depleted through the growing world industrialization. In addition, the utilization of fossil fuel for industrialization has negative effects on the world's climatic conditions such as the emission of greenhouse gases into the atmosphere leading to global warming. Increasing industrial activities and world's population are related to the general energy utilization. It is estimated that world's energy demand will be more than 50% by 2025 [4]. A good solution to reducing all these setbacks brought about by the utilization of fossil fuel for world's industrial development is to investigate and to find new alternative fuel sources. Biomass is said to be the third largest energy resource in the world after coal, gas and oil [5].

Biomass is nearly carbon neutral; hence its utilization helps mitigate greenhouse gas emissions [1]. Use of traditional biomass fuels in combustion systems, either alone or in combination with oil or coal, reduce emissions of NO_x, SO_2 and CO_2 compared to using fossil fuels alone [6], Waste materials from sawdust, papers, leaves, rice husk, coconut husks, corn cob, palm kernels, palm oil bagasse, and other agricultural wastes in many combinations and proportions can be developed into fuel briquettes or pellets [7], [8]. Many of these agricultural materials lie as waste heaps not utilized adequately. In such waste dumps, these materials get decayed ultimately releasing carbon dioxide to the atmosphere. These materials could be used to produce pellets or briquettes which are a form of fuel. Biomass pellets are usually in form of cylindrical sticks. They are utilized in home pellet stoves, central heating boiler, industrial boiler, or in power plants. Biomass briquettes can be in form of sticks or blocks with large diameter and different shapes. They are primarily for industrial use for heating. Briquette making has the potential to meet the additional energy demands of urban and industrial sectors, thereby making a significant contribution to the economic advancement of any country. Due to high moisture content, irregular shape and size, and low bulk density, biomass is very difficult to handle, transport, store, and utilize in its original form [9]. As a result of these setbacks, densification of these materials into durable compact forms (as pellets or briquettes) is effective in solving these challenges and can reduce material waste. Densification can increase the bulk density of biomass from an initial bulk density of 40-200 kg/m^3 to a final compact density of 600-1200 kg/m^3 [10], [11]. Also, densified biomass, as pellets, has drawn attention due to its superiority over raw biomass in terms of its physical and combustion characteristics [12]. The utilization of these biomass materials also depends on the following: feed constituents, energy content, volatile matter, ash content and slagging characteristics, reactivity, size and size distribution, adding binders or additives, densification equipment, bulk density, and post- production treatment conditions like heating or cooling and storage conditions [13]. These properties could be altered by subjecting raw biomass to various processing methods and forming composites [11]. If biomass or agro-waste briquettes are to be used efficiently and rationally as fuel, they must be characterized to determine parameters such as the calorific values, flame propagation rates, ignition time, burning time, burning efficiency among others. The calorific (heating) value of biomass feed-stocks are indicative of the energy they possess as potential fuels. The gross calorific value (higher heating value, HHV) and the net calorific value (lower heating value, LHV) at constant pressure measures the enthalpy change of combustion with and without water condensed, respectively [14]. Most agricultural wastes as those considered in this study can be converted from solid to either gaseous or liquid fuels by biochemical, thermal and chemical processes [15]. Adequate utilization of biomass fuels gives enormous benefits in terms of environmental concerns. During their growth, biomass absorbs carbon dioxide during growth, and emits it during combustion. In addition, biomass as fuel for power production offers the advantage of a renewable and CO2-neutral fuel [2].

In this study, the energy contents of some agricultural solid wastes and their mixed proportions were investigated amenable to further large-scale pelletising or briquetting. Variations of energy contents based on samples mixing ratios, burning time, ignition and ashing time were evaluated. Furthermore, the best combination of these variations was established.

2. Materials and Methods

2.1. Materials Sourcing and Preparation

Charcoal was collected at a local cooking store while sawdust was sourced from a wood milling factory, both at Ikorodu Town (6o37´N 3o30´E, elevation of 28 m), South West, Nigeria. Coconut shell, corn cob, palm fronds, palm oil bagasse, palm kernel shell were all sourced from a farm settlement at Iju Town (7o22´N 5o15´E, elevation of 353 m), South West, Nigeria. Samples were sun dried for approximately 48 hours to reduce their moisture contents. All samples were pulverized to accepted size fractions. Samples were made to pass through sieves of different aperture diameter ranging from 500 μm to 106 μm. The samples were further dried in a convection oven at 105 oC to completely eliminate moisture. The dried materials were stored in different rubber packs until they were ready to be used.

2.2 Determination of Heat of Combustion of Materials

The heating value measurement or the heat of combustion of the individual raw materials and their mixed proportions were determined by an isothermal oxygen bomb calorimeter (Fig. 1). The bomb calorimeter consists of metal bomb designed to withstand heat and pressure, a large flask to hold the bomb and a known volume of water, which are means of remotely igniting the sample (typically electrically, through the use of a fuse wire), and a means of accurately measuring the temperature of the water. The heating or calorific value of a fuel sample is the amount of heat liberated per unit mass of the sample. After standardization with benzoic acid (standard heating value of benzoic acid was determined and its known heat of combustion was used to determine the heat capacity of the bomb calorimeter). Once the calorimeter has been calibrated, the caloric values of raw samples were determined. 1.0 g of grounded sample (150 μm size fraction) was weighed and pelletized using the pellet press (Fig. 2(a)). The pelletized material was burnt in the bomb calorimeter for a particular duration. For each batch of experiments, 0.1 m of chromium wire was attached to the bomb electrodes. The wire was bent so that the loop bears against the top of the pellet firmly enough to keep it from sliding against the side of the capsule. The bomb was placed securely on the bomb basket after injecting oxygen at 2,020 kPa into the bomb through the knurled valve knob. 2 L of distilled water was poured into the metal bucket sufficient to submerge the nut of the bomb to a depth of 0.003 m (Fig. 2(b)). An initial 10 min was allowed before the firing temperature was noted. After the initial temperature rise and with no reasonable change in temperature, the bomb was removed from the calorimeter, and residual gas was allowed out of the bomb by opening the knurled valve knob. The remaining length of the fuse wire was recorded in order to determine the correction for firing energy. Oxygen was supplied to the bomb calorimeter before immersion into the bucket with compressed oxygen present in a gas cylinder at 20 atmospheres. Acid correction is carried out after each step to correct for any incomplete combustion in the calorimeter using 0.1 M sodium hydroxide solution. All measurements were duplicated. The schematic diagram of the isothermal bomb calorimeter is as shown in Fig. 1.

A resultant energy value for any material tested was calculated from;

$$Q_v = \frac{E\,(\Delta T - C_1 - C_2)}{M_{ST}}$$

Q_v = Caloric value of sample at the final temperature (kJ/kg)

M_{ST} = Weight of the standard sample

C_1 = Correction for firing energy (determined from the left over of the chromium wire burning equal to 2.6 x length of chromium burnt)

C_2 = Total acid correction (determined from the after-wash solution of the interior of the bomb by titrating with 0.1 M NaOH solution)

ΔT = Measured change in temperature

E = Energy equivalent of the bomb calorimeter (J/degree (^{o}C)), given as;

$$E = \frac{Q_{ST}(M_{ST} + C_1 + C_2)}{\Delta T}$$

Q_{ST} = Heat of combustion of the standard sample (benzoic acid)

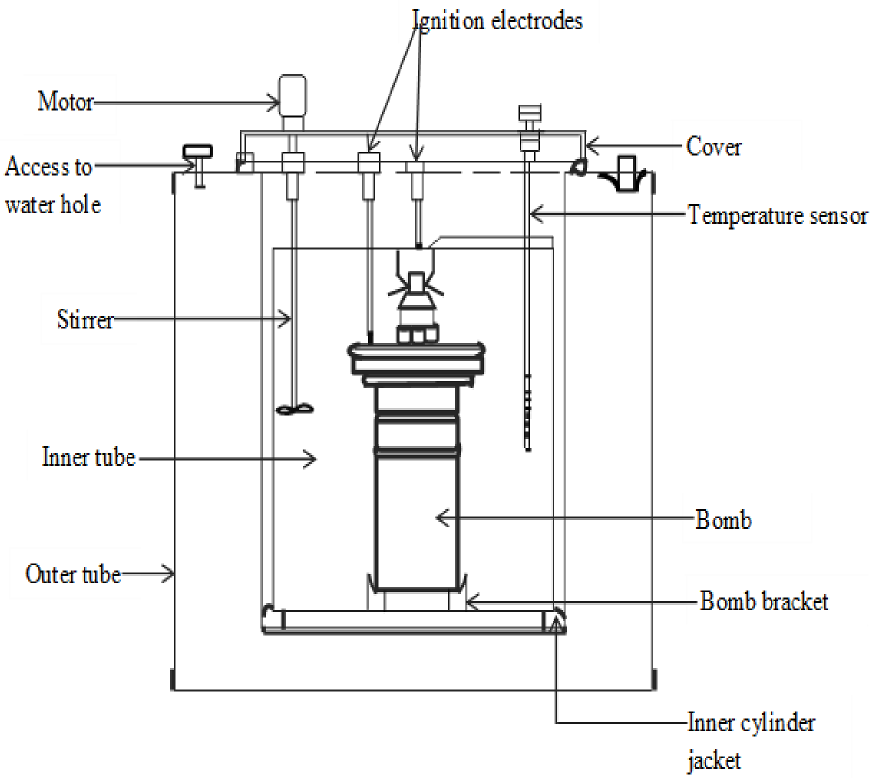

Fig. 1. Schematic representation of a simple isothermal oxygen bomb calorimeter

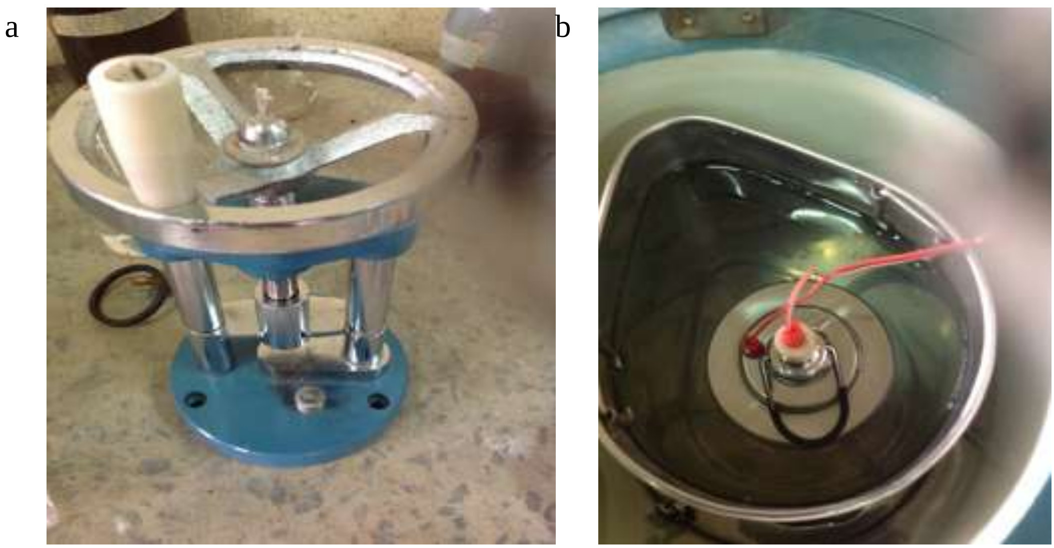

Fig. 2. (a) and (b) views of manual pelletizing set up and calorimetric bomb immersed in the metal bucket respectively.

Materials in mixed proportions were bound with starch paste, mould into small shapes and sun dried. The mixed proportions were investigated as blends of materials in 1:1 ratio (using either sawdust or charcoal in same proportions with the other materials) and combining the best three materials that gave the highest individual heating contents in four different ratios (Table 1). The burning time was

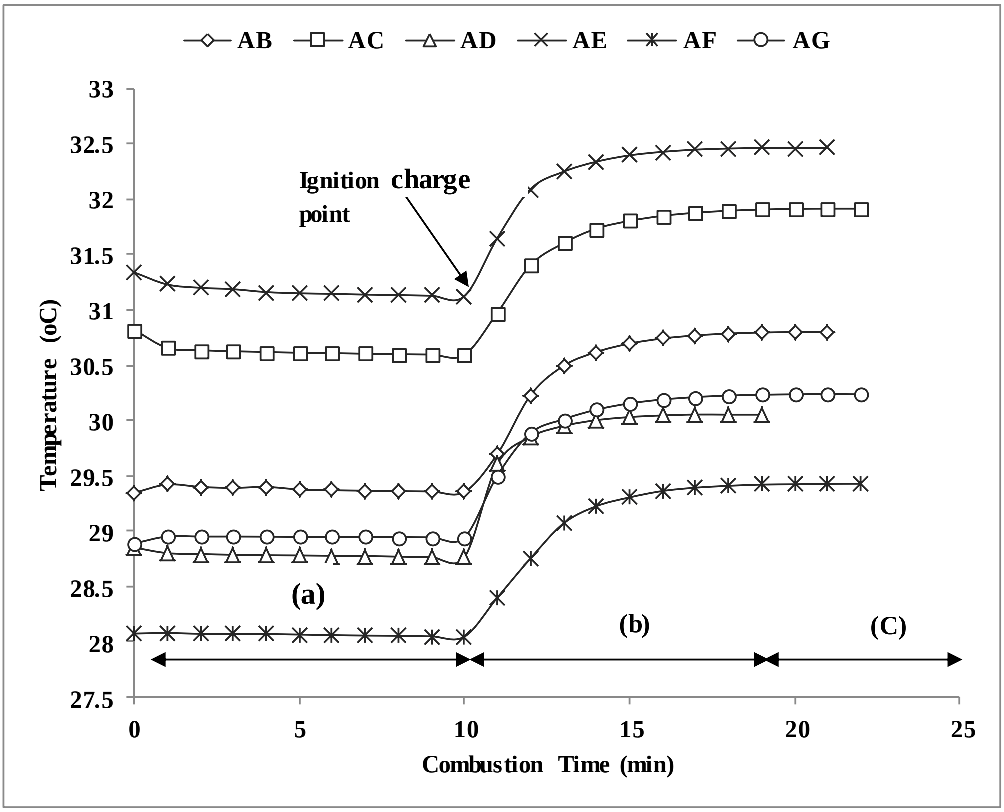

Fig. 3. Temperature profile illustration during the combustion of blends of charcoal with other materials in 1:1 mixed proportions (B = Coconut shell, C = Corn cob, D =Palm fronds, E= Palm oil bagasse, F= Palm kernel shell, G= Sawdust). Section (a) is the initial temperature test period, section (b) is the temperature rise period, and section (c) is the final temperature test period.

Table 1: Estimated Heating Values of Individual Materials and their Mixed Proportions.

		Mixed proportion (1:1)			
Sample	Heating content (kJ/kg)	Sample	Heating content (kJ/kg)	Sample	Heating content (kJ/kg)
A (Charcoal)	17,062	AB	21,299	GA	19,219
B (Coconut shell)	16,480	AC	20,337	GB	16,681
C (Corn cob)	10,798	AD	17,325	GC	15,270
D (Palm fronds)	12,997	AE	21,907	GD	14,820
E (Palm oil bagasse)	16,307	AF	19,890	GE	15,744
F (Palm kernel shell)	15,396	AG	19,219	GF	15,908
G (Sawdust)	14,941				
Mixed proportions	A:B:E	A:B:3E	3A:B:E	A:3B:E	
Heating content (kJ/kg)	23,373	18,598	21,891	18,740	

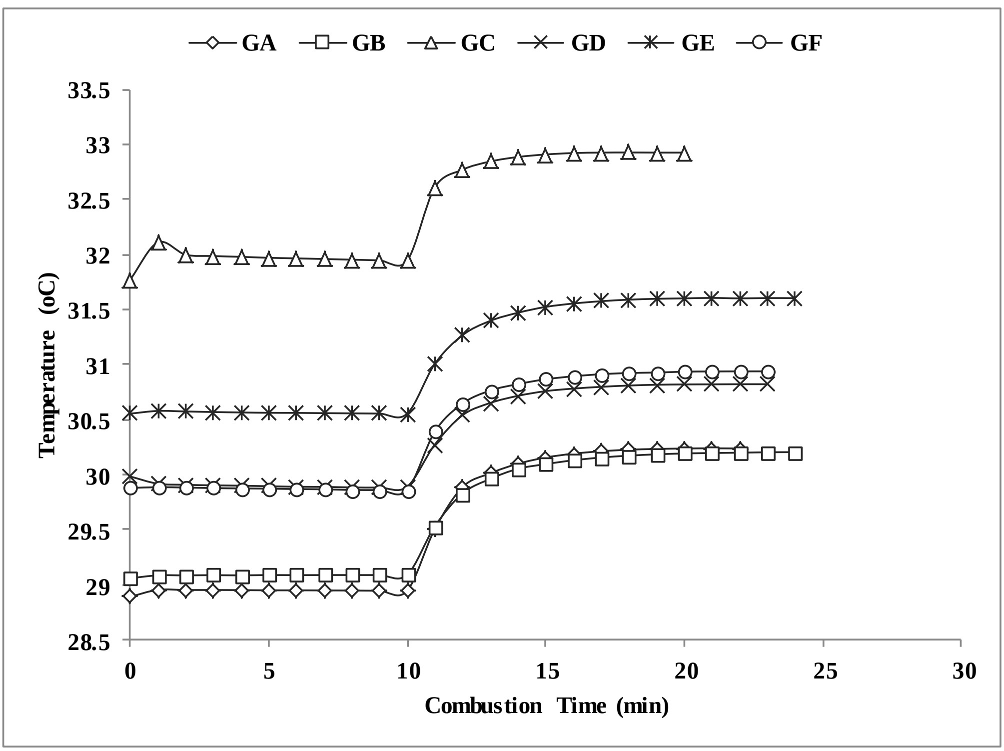

Fig. 4. Temperature profile illustration during the combustion of blends of sawdust with other materials in 1:1 mixed proportions (A = Charcoal, B = Coconut shell, C = Corn cob, D =Palm fronds, E= Palm oil bagasse, F= Palm

kernel shell). taken as the difference between ignition time and ashing time (time of samples completely turning to ash) of different mixed samples.

3. Results and Discussion

3.1 Heating Contents of Individual and Blended Materials

The measured temperatures for the different blends of materials in different mixes (using charcoal and sawdust as the materials with highest individual energy contents) are given in Fig. 3 and Fig. 4. The caloric values for individual materials were obtained in kJ/kg as (Table 1); charcoal (17,062), coconut shell (16,480), corn cob (10,798), palm fronds (12,997), palm oil bagasse (16,307), palm kernel shell (15,396), sawdust (14,941). Corn cob has the least heating content. In a previous study [6], the caloric value of plain sawdust briquette was obtained as 18.82 MJ/kg. This value is greater than the caloric content of raw sawdust in this study. This may be due to variations in the species and experimental conditions. The caloric value of charcoal is the highest among the individual heating contents. The firing temperatures of blended materials (at zero time) corresponding to a particular temperature increases with the burning strengths of the materials (Fig. 3 and Table 1). For example, AB (charcoal: coconut shell; 21,299 kJ/kg) has temperature of 29.4 oC. In addition, AE (charcoal: palm oil bagasse; 21,907 kJ/kg) has temperature of 31.4 oC. Equally, for the 1:1 mixed proportions of sawdust wth other materials, GA (sawdust: charcoal) produced the highest heating content of 19,219 kJ/kg with the highest firing temperature of 31.7 oC.

3.2 Burning and Ashing rates of Blended Materials

Generally, solid fuel samples ignite easily due to the presence of large amount of in organic salts. In this study, the blend of charcoal, palm kernel shell and coconut shell in ratio 3:1:1 respectively ignited very fast at 1 minutes and 30 seconds. This was as result of the large proportion of charcoal which is very rich in carbon. The presence of charcoal in a blend makes the blend easily fireable. The blend also had a long burning time making a good fuel source.

4. Conclusions

The choice of a biomass for energy conversion will in part be decided by its heating value. All solid mass pellets examined in this study had no problem in the combustion procedure. The heating contents of all materials tested varied from the lowest at 10,798 kJ/kg (corn cob) to the highest in a mixed proportion of 1:1:1 (charcoal, coconut shell, and palm oil bagasse) having heating value of 23,373 kJ/kg. The presence of charcoal in any form of solid fuel blend increases the calorific value of such blend. Palm kernel bagasse had a higher calorific value than palm kernel shell because of the presence of combustible fibers in palm kernel bagasse. Amongst the individual samples investigated, charcoal had the highest calorific value of 17,062 kJ/kg with palm fronds having the least heating value of 12,997 kJ/kg. Charcoal and its blends had the highest burning rates.

References

[1] A. Sultana, A. Kumar, and D. Harfield, “Development of agri-pellet production cost and optimum size,” Bioresour. Technol., vol. 101, pp. 5609-5621, 2010.

[2] A. Demirbas, Combustion characteristics of different biomass fuels, "Prog. Energy Combust. Sci.," vol. 30, pp. 219-230, 2004.
[3] R. E. H. Sims, R. N. Schock,, A. Adegbululgbe, J. Fenhann, I. Konstantinaviciute, W. Moomaw, H. B. Nimir, B. Schlamadinger, J. Torres-Martínez, C. Turner, Y. Uchiyama, S. J. V. Vuori, N. Wamukonya, and X Zhang, "Energy supply," in Climate Change: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer, Eds., Cambridge, UK: Cambridge Univer Press, 2007.
[4] A. J. Ragauskas, K. W. Charlotte, B. H. Davison, G. Britovsek, J. Cairney, C. A. Eckert, W. J. Frederick, J. P. Hallett, D. J. Leak, C. L. Liotta, J. R. Mielenz, R. Murpgy, R. Templer, and T. Tschaplinski, "The path forward for biofuels and biomaterials," Sci., vol. 311, pp. 484-489, 2006.
[5] J. S. Tumuluru, C. T. Wright, J. R. Hess, and K. L. Kenney, "Review of biomass densification systems to develop uniform feedstock commodities for bioenergy application," Biofuels Bioproc. Biorefin., vol 5, pp. 683-707, 2011.
[6] J. E. Hustad, Ø. Skreiberg, and O. K. Sønju, "Biomass combustion research and utilization in IEA countries," Biomass Bioenergy, vol., 9, pp. 235-255, 1995.
[7] T. Brleka, L. Pezo, N. Voća, T. Krička, Đ. Vukmirović, and M. Bodroža-Solarov, "Chemometric approach for assessing the quality of olive cake pellets," Fuel Process. Technol. Vol,, 116, pp. 250-256, 2013.
[8] B. Lela, M. Barišić, and S. Nižetić, "Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics," Waste Manag., vol., 47, pp. 236-245, 2016.
[9] S. Sokhansanj, S. Mani, X. Bi, P. Zaini, and L. G. Tabil, "Binderless pelletization of biomass," in ASABE Annual International Meeting, Tampa Convention Centre, Tampa, Florida, USA, 2005.
[10] P. K. Adapa, G. J. Schoenau, L. G. Tabil, E. A. Arinze, A. K. Singh, and A. K. Dalai, "Customized and value-added high-quality alfalfa products: A new concept," Agric. Eng. Internatl., The CIGR Ejournal, vol., IX, pp. 1-28, 2007.
[11] L. Tabil, P. Adapa, and M. Kashaninejad, "Biomass feedstock pre-processing – Part 2: Densification," Biofuel Engineering Processing Technology, M. A. Dos Santos Bernardes, Ed. InTech [online]. Available: http://www.intechopen.com/books/biofuel-s-engineering-processtechnology/biomass-feedstock-pre-processing-part-2-densification, (Accessed 15 July, 2016)
[12] I. Obernberger, and G. Thek, "Physical characteristic and chemical composition of densified biomass fuels with regard to their combustion behaviour," Biomass Bioenergy, vol., 27, pp. 653-669, 2004.

[13] N. Kaliyan, and R. Vance Morey, "Factors affecting strength and durability of densified biomass products," Biomass Bioenergy, vol., 33, pp. 337-359, 2009.

[14] A. Demirbaş, "Effect of moisture and hydrogen content on the heating value of fuels," Energy Sour., Part A: Recover., Utilization Environ. Eff., vol. 29, pp. 649-655, 2007. Available: http://dx.doi.org/10.1080/009083190957801 (Assessed 15 November, 2017)

[15] D. L. Klass, "Energy and synthetic fuels from biomass and wastes," Handbook of energy technology and economics, Wiley-Interscience, USA, 1983.

[16] C. O. Adegoke, "A preliminary investigation of sawdust as high grade solid fuel," Niger. J. Renew. Energy, vol., 7, pp. 102-107, 1999.