VALORIZATION OF POST-PINEAPPLE HARVESTING RESIDUES AND SAWDUST WASTE INTO FUEL BRIQUETTES

Abstract

Faced with the problem linked on the one hand to the phenomenon of climate change, which is reflected among other things in deforestation, desertification, greenhouse gas emissions and poor management of agricultural waste on the other hand, our study was part of a dynamic of recovery of agricultural waste into a product with high added value. The methodology we adopted was to determine the lignocellulosic components of pineapple leaves and sawdust waste. The results from this characterization allow us to affirm that these two biomasses contain enough lignin (about 30%) and therefore, their combinations can give combustible briquettes with a good calorific value. In order to optimize production, a mixing plan was adopted to generate the composition of the various fuel briquette tests. They consist of pineapple leaves, sawdust waste and clay as a binder. As part of our study, the waste was charred in a carbonizer designed for this purpose. After the production of the briquettes, physical parameters as well as energy performance tests were carried out to know the best quality briquettes. At the end of these different tests, the briquettes manufactured have more acceptable characteristics compared to other combustible briquettes obtained in the literature. Only the B4 briquette perfectly meets all the measured parameters and is therefore considered the best with a PCI of 21.38 MJ/K ; a value very close to that of charcoal. The polynomial model of order 2 with minitab is explicit because the theoretical and measured values are not far from each other.

Keywords : Combustible briquettes, pineapple waste, sawdust waste.

INTRODUCTION

Benin has been committed for several years to a sustainable development approach through the adoption of its framework law on the environment and the principles of sustainable development. This approach aims to create a greener economy that is more respectful of the environment. Thus, the development of renewable energies or new innovative technologies is actively sought and encouraged.

One of the sectors with a high potential for the production of renewable energy or biomaterials is the recovery of waste. Among the hundreds of tons of all types of residual materials produced each year by domestic and industrial activities, some can be used for recycling or reclamation purposes (with high economic profitability) rather than being subject to disposal that is often out of the norm (in accordance with Article 9 of Decree No. 2003-332 of 27 August 2003 on solid waste management in the Republic of Benin of the Framework Law on the Environment) (L'Environnement, 2018).

As a result, we know to this day that the management of agricultural waste from different plantations remains an unsolved problem in our country even if many companies and small businesses are looking for ways to fully overcome this obstacle. In addition, this waste causes harmful effects on the environment such as air pollution, congestion in the fields. Wood – energy (fuelwood and charcoal) is the main source of energy, heating and cooking in Africa

(FAO, 2014). African charcoal consumption accounts for more than half of global production (BAD, 2012).

This massive use of wood energy in Africa contributes to deforestation and forest degradation. Unfortunately, in both rural and urban areas, the demand for wood energy is growing putting more pressure on dwindling resources. Thus, the development of clean technologies is increasingly encouraged with a view to reducing pressure on forest resources while ensuring an efficient and sustainable source of energy for users. They also have the advantage of being both financially and technically accessible to populations, and they are also able to bring about behavioural changes in communities.

Biomass is any organic matter of plant origin that has the energy available for combustion. Benin is a party to the United Nations Framework Convention on Climate Change (UNFCCC) and has signed the Paris Agreement. Article 6 of this agreement aims to set up and frame cooperation mechanisms between the various actors of the ecological transition (Climate, Directorate General of Environment and Climate of Benin, 2021).

Benin stands out as a country with high potential for the use of biomass in the thermochemical conversion process, particularly wood, forestry and agricultural waste. Among agricultural waste, pineapple crown leaves from fields (waste) and sawmill waste that are available in quantity can be identified for carbon sequestration for energy recovery. The present study entitled: "Energy recovery of post-harvest pineapple leaves and sawdust waste into fuel briquettes" has the general objective of valuing agricultural waste into a product with high added value (fuel briquettes).

Specifically, it will be a question of :

- Characterize pineapple leaves collected from crop fields;
- Formulate fuel briquettes with pineapple leaves, sawdust waste and a binder;
- Test manufactured fuel briquettes.

This brief presents the various works we carried out during our study. Apart from the general introduction, this document contains a literature review on pineapple waste, sawdust waste and fuel briquettes ; the materials and methods used as well as the results obtained and the related discussions.

1 Materials and methods

Figure 1 shows the lignocellulosic components of pineapple leaf and sawdust waste. On the one hand, from this figure it can be seen that cellulose for sawdust waste is very high compared to that for pineapple waste. On the other hand, the proportion of lignin in sawdust waste is higher (30%) than that of pineapple leaves (26.71%). This shows the complementarity of the two types of waste.

These results confirm the values obtained by (Onjania, 2014) and (Braga et al., 2015). The work of the latter shows that lignin has a polyaromatic structure with a higher carbon content than cellulose and hemicellulose. It is the essential element sought for energy recovery.

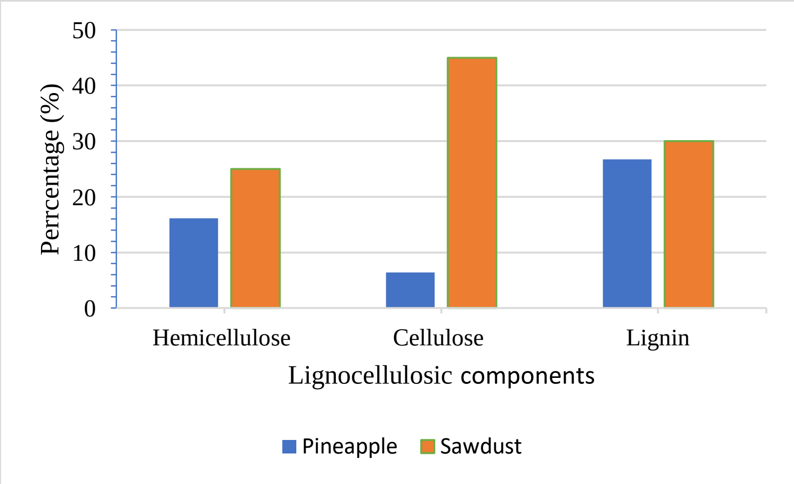


Figure 1 : Lignocellulosic components of biomass

It presents the optimized mixing ratios. The optimization methodology is the plan of centered mixtures (Simplex-centroid designs) composed of 7 tests. The study factors for mixing designs are the proportions of the constituents of the mixture (Goupy, 2000). The sum of the proportions of a mixture is always equal to 100%. This mixture obtained by mixing different biomasses in certain proportions makes it possible to estimate the effects of each variable on the final result. This plan was chosen because it makes it possible to observe the influence of the different factors on the responses studied (biochar).

Table 1 shows the proportions of the different briquettes that the mixing plan allowed us to formulate.

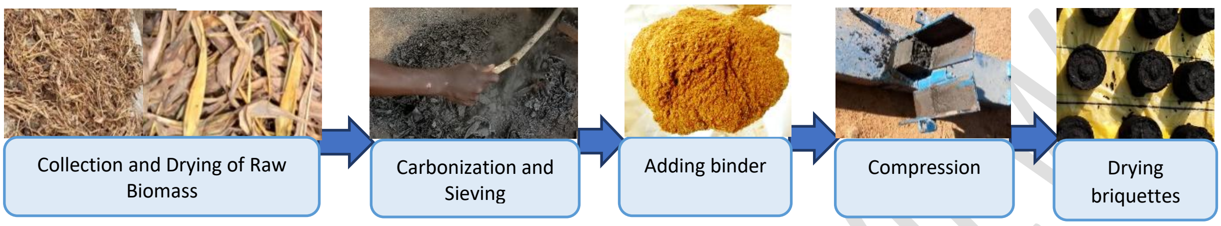
Table 1 : Composition of formulated briquettes

Formulated briquettes	Compositions
B1: BFa70 Sb10 A20	Pineapple leaves (70%) Sawdust (10%) Clay (20%)
B2: BFa50 Sb30 A20	Pineapple leaves (50%) Sawdust (30%) Clay (20%)
B3: BFa50 Sb10 A40	Pineapple leaves (50%) Sawdust (10%) Clay (40%)
B4: BFa60 Sb20 A20	Pineapple leaves (60%) Sawdust (20%) Clay (20%)
B5: BFa60 Sb10 A30	Pineapple leaves (60%) Sawdust (10%) Clay (30%)
B6: BFa50 Sb20 A30	Pineapple leaves (50%) Sawdust (20%) Clay (30%)
B7: BFa60 Sb30 A10	Pineapple leaves (60%) Sawdust (30%) Clay (10%)

The plant biomass to be valued in our study being pineapple leaves, their proportions are the majority in the mixture. The clay used as a binder varies between 10 and 40%. These percentages were given to us by the mixing plan in order to observe the influence of this binder on the briquettes and also to have the best percentage for a briquette of better quality.

Preparation of raw biomass and production of fuel briquettes

Freshwater hyacinth was collected on Lake Nokoué, near the general education college, while pineapple leaves were obtained from agricultural production fields in Zoundja, abomey-Calavi commune. Cassava starch waste is purchased at the local market. The dried biomass was separately charred and then mixed manually, into small particles. The raw materials were kept in a polyethylene bag at room temperature until it was used for the production of briquettes. This production follows the steps below :



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A 84g of clay (binding agent) was mixed 1000 ml of hot water. The binder has thus been prepared and the different constituents of the briquettes are mixed according to the proportions presented in Table 1.

Operation of the carbonization device used

The most widespread techniques in Africa are still based on the oldest model, which is characterized by the use of earth as an insulating screen. To prevent oxygen entry and excessive heat loss, 7.5 cm thick clay bricks were used (picture 3). It is a barrel consisting of a cylinder 53cm in diameter and 50 cm in height (picture 4).

A door at the bottom of the device allows easy access to the interior for unloading the tank produced. This reactor is equipped with several nosiliaries equipped with plugs to regulate the amount of air entering the reactor. A burner mounted above the pyrolysis reactor, allows the combustion of gases generated by pyrolysis and a loading hopper, easily accessible for biomass supply (picture 5). The hatches are used to tightly insulate the hopper and burner of the pyrolysis reactor. The hopper hatch allows the reactor to be easily supplied even during the process.

The start-up of the system consists of its heating, by means of an internal biomass fire, because carbonization by internal combustion is our process. This device was designed and made by the technician of the workshop of the mechanical and production engineering department of the National Higher Institute of Industrial Technology (INSTI) ex IUT of Lokossa and with clay from Sê, whose finish was left to our care.

Humidity

The moisture content of a plant material represents its water content in relation to its wet mass. It is a determining parameter for the combustion of briquettes : if it is high, combustion is almost impossible. The sample is heated in a Memmert oven 11-25 at 105 ° C and weighed after 24 hours. Its determination follows the European standard EN 14774, according to the following formula :

$$W(\%) = \frac{\text{M humid} - \text{M dry}}{\text{M humid}} \times 100$$

- *Volatile matter content*

Volatile matter is the part of the MO that escapes as gas during combustion. The MOV rate guarantees the flammability of the fuel. The same sample used to find the humidity level is heated in a Naberthern B180 muffle oven to a temperature of up to 550 °C. Its determination follows the French standard NF, 1985. The level of volatile matter is determined by the loss of mass during this heating. The following formula is used to calculate the volatile matter content :

$$\text{MOV} = \frac{\text{M } 105°\text{C} - \text{M } 550°\text{C}}{\text{M humid}} \times 100$$

- *The fixed carbon content*

Generally if the carbonization is well conducted, the tank contains mainly fixed carbon, which has a great energy potential. This is the amount of carbon remaining after removal of volatile matter, ash and moisture. Il est différent de carbone total qui est la somme du carbone fixe et le carbone contenu dans la partie volatilisée.

The fixed carbon content was determined according to the ASTM standard and is calculated with the following formula :

$$\text{Cf}(\%) = \frac{\text{M } 550°\text{C} - \text{M } 850°\text{C}}{\text{M } 550°\text{C}} \times 100$$

- *The ash rate*

The ash content represents the amount of mineral matter contained in a fuel. It is important for the assessability of the fuel because when it is very high, this ash becomes an obstacle to the progress of combustion.. The ash content is obtained by heating the sample to 850°C in a Naberthern B180 muffle oven. Its determination follows the European standard EN 14775. The ash content is determined by the mass of the residues after incineration. The result is obtained with the following formula :

$$A(\%) = \frac{\text{M } 850°\text{C}}{\text{M humid}} \times 100$$

- Calorific value

This power is relative to the energy released during combustion, it expresses the amount of energy associated with a unit of mass of a fuel (Dusabe, 2014).

It is expressed for a solid fuel in KJ/kg or Kcal/kg. The higher calorific value (SCV) corresponds to the energy released during combustion, after restoring the initial temperature of the fuel. The lower calorific value (LCV) does not take into account the energy associated with water vapour. This measurement is usually carried out by means of a calorimeter, but can be estimated from a correlation between different parameters (Leluc, n.d.). In the absence of a calorimeter, this study therefore made use of the correlation matrix.

2 Results and discussion

For these different analyses, the moisture content, the values of the three parameters (volatile matter content, ash content and fixed carbon content) that will be presented were analyzed on dry matter. These analyses were carried out in the Laboratory of Science and Technology of Water and Environment (LSTEE) and the Laboratory of Physical Chemistry (LCP) at the University of Abomey-Calavi (UAC/BENIN). Figure 2 shows the results obtained for the moisture content of manufactured briquettes and charcoal. According to (Braga et al., 2015) a value greater than 10% is not desirable because it reduces the calorific value thus making it difficult to burn. These briquettes have a moisture content of 20.77% this could be explained by the fact that these briquettes undergo a slight humidification during formulation and a short drying time. It can be seen that charcoal has a very low moisture content (6.08%) compared to briquettes. This is explained by the fact that the charcoal undergoes several days of drying before its sale, or even before its use. Despite this discrepancy between the moisture content of these briquettes and charcoal, our briquettes were able to have an acceptable ignition time compared to other fuel briquettes obtained in the literature. It will therefore take a long drying time (5 to 7 days) at least to have briquettes of good calorific value and a long burning time.

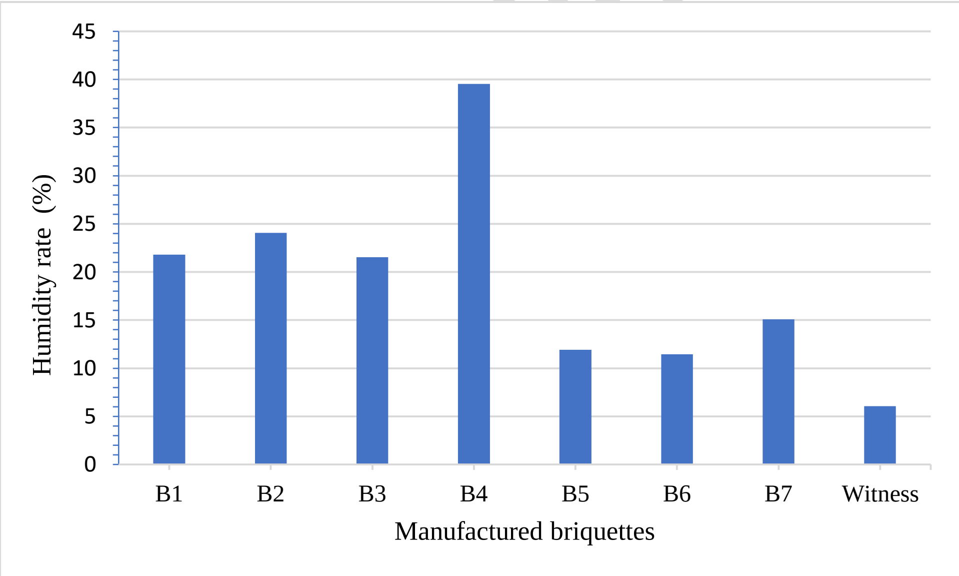

Figure 2 : Moisture content of manufactured briquettes and charcoal

Figure 3 shows the % distribution of these three parameters (volatile organic matter content, fixed carbon content, ash content) in the dry matter of the fuels under consideration and charcoal. The witness is coal, but coal is a reference of excellence (Rezania et al., 2016). A high volatile organic matter value is more favorable for combustion (more than 80%) (Rezania et al., 2016). Note that the MOV rate of briquettes is on average 60%. A value much higher than that of (Dusabe, 2014) (less than 30%) for briquettes based on household waste.

Briquettes B3, B5 and B6 exceed the volatile matter values obtained by (Dusabe, 2014), (Koala, 2012) et al, for organic waste. On the other hand, the values of briquettes B1, B2, B4 and B7 are close to those of charcoal and can be considered better for this parameter. A small percentage of ash is recommended for biomass briquettes (less than 10%) (Id et al., 2018)).

The average obtained for the ash content of the seven (07) fuel briquettes is 39%. This value is close to that obtained by (Dusabe, 2014) for paper briquettes and organic waste and much higher than that of charcoal (8%). This is explained by the presence of clay (rich in mineral matter) which is an element in the composition of our briquettes. Remember that this clay is not troublesome because it can be reused for the manufacture of other fuel briquettes and also the chemical composition of the ash can be recovered for other uses (soap making ...). The fixed carbon values of fuel briquettes produced are lower than those of charcoal. This is justified by the composition of the briquettes more precisely pineapple leaves which have a high level of volatile matter (more than 60%).

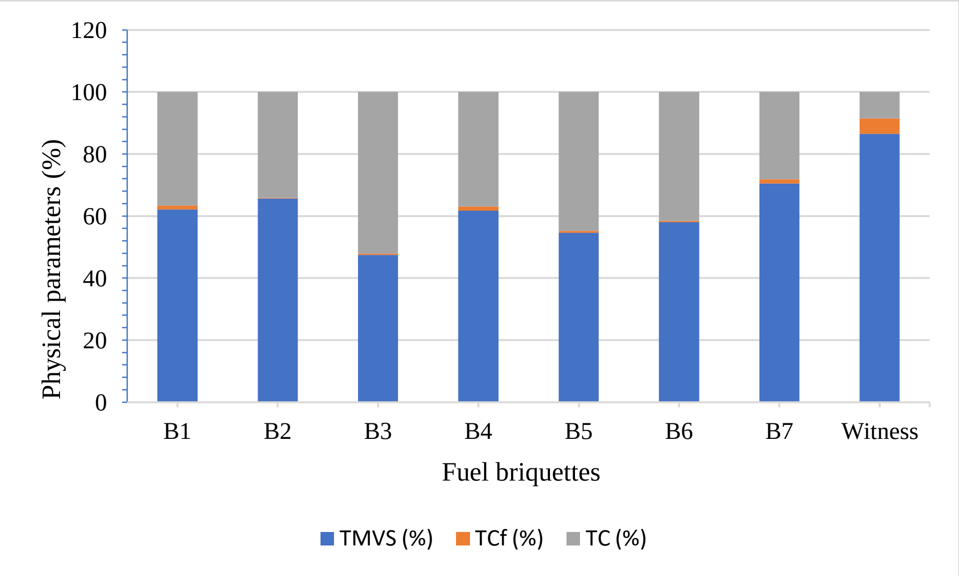

Figure 3: Physical parameters of fuel briquettes

The combustion test, which consisted of boiling a previously known quantity of water of 300 ml, by various fuels of equivalent weight (150g), made it possible to evaluate their individual performance and to make comparisons. In particular, this test made it possible to obtain the combustion time required for each fuel to bring the water to boil, thus making it possible to obtain the information necessary for calculating the calorific value. This test requires the use of a fireplace and an aluminum container of known weight. A conventional fireplace is used for briquette and charcoal testing.

The test starts at ignition by adding an oxidizer (palm kernel meal) after positioning the fuel within the fireplace : the ignition time, the time at which the water is brought to a boil (100 ° C) and the burning time are collected. The pot is then carefully placed in the fireplace, it is previously weighed and filled with 300ml of water, whose temperature is measured (29.9 ° C).

The different results are reported in Figure 4. Fuels burn in a gaseous state. The higher the level of volatile organic matter, the shorter the flammability time. It is noted that briquettes have a lower average volatile matter content than charcoal. For this reason, briquettes have a higher flammability life than charcoal. Briquettes B1 (150.5s), B4 (186.5s), B5 (172.5s) and B6 (165s) have a flammability life close to that of charcoal (135s). However, remember that the data collected on charcoal are the average of a series of 4 trials. The acceptable fuel briquette in terms of flammability time is B1 consisting of 70% pineapple leaves, 10% sawdust waste and 20% clay. The very long ignition time observed for briquettes B2, B3 can be explained by the fact that they have a very high clay composition that contains mainly mineral matter (40% clay and 60% biomass) (Akowanou, 2017) and B7 a very low composition. Since flammability is a very important factor for combustion, B2 and B3 do not meet this parameter and can therefore be excluded.

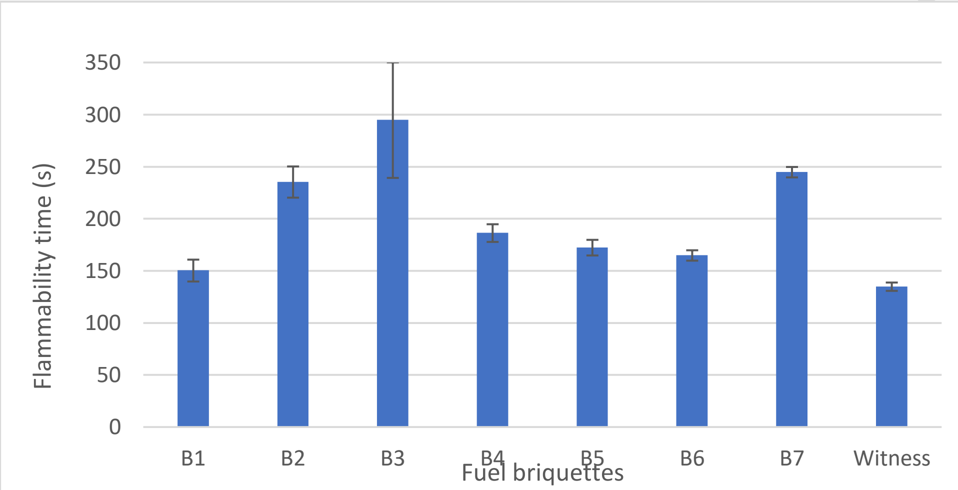

Figure 4 : Flammability time of briquettes

Figure 5 shows the burning time of fuel briquettes and charcoal. Fuel briquettes have an average burning time of 5764seconds (about 2 hours). Briquettes B3 (8400s) or about 2 hours 30 min and B4 (9600s) or about 3 hours have a burning time well above average and that of charcoal (2 hours). This is explained by the fact that these briquettes are strongly composed of clay. According to the work of (Agbo, 2014), the presence of clay as a binder and in high proportion confers a strength and long burning time to the briquette. B3 and B4 briquettes are therefore possible in terms of burning time. These results are close to those found by (Dusabe, 2014), (Agbo, 2014). The burning time of briquettes B1, B2 and B6 is close to that of charcoal while those of B5 and B7 are lower.

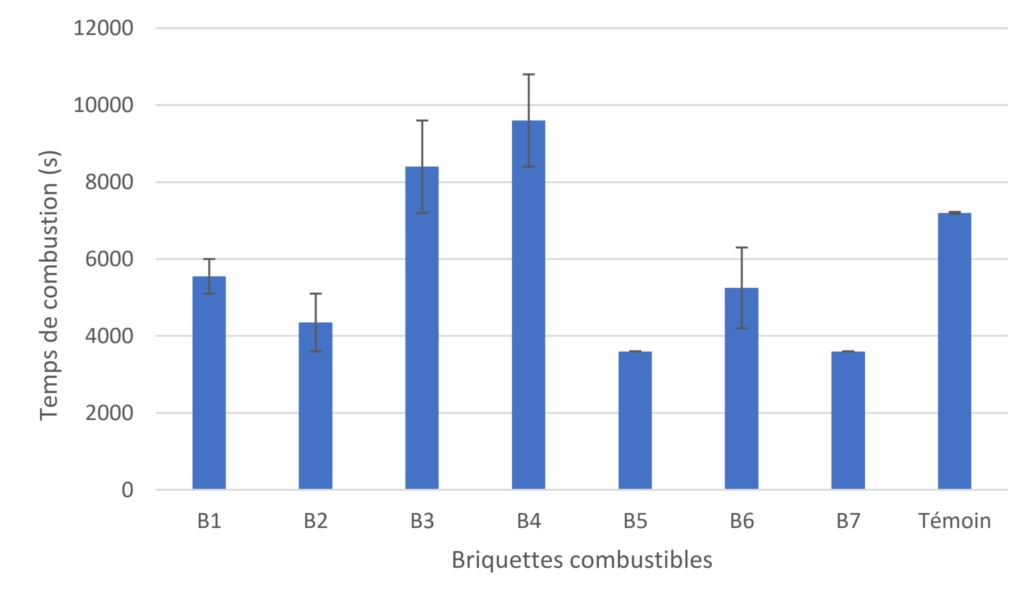

Figure 5 : Briquette burning time

Figure 6 shows the boiling test performed on fuel briquettes and charcoal. All briquettes have a slightly higher boiling time than charcoal except the B3 briquette which has a very long time. On the other hand, the boiling time of the B4 briquette is very close to that of coal. According to (Technique, 2018), the shorter the boiling time with water, the higher its lower calorific value. B4 briquette has a PCI close to that of coal and is therefore considered acceptable for this parameter.

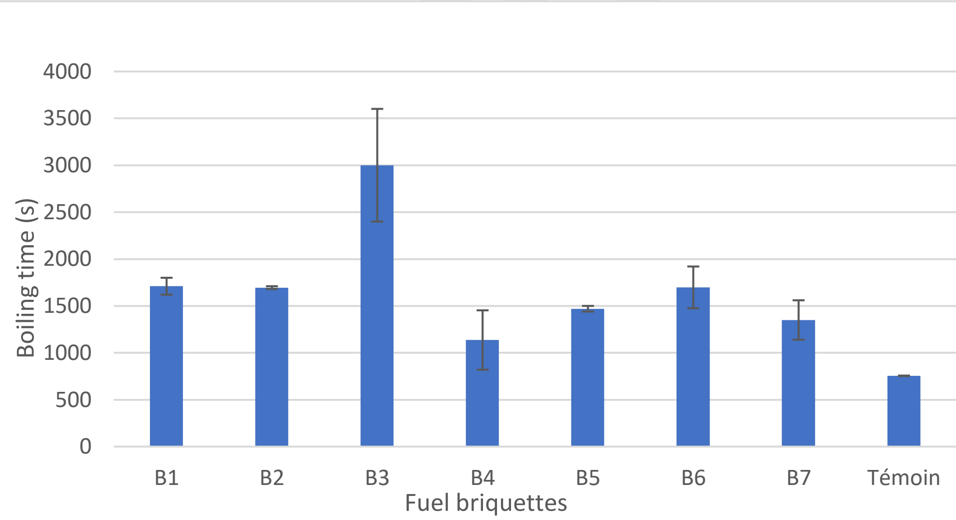

Figure 6 : Briquette Boiling Test

Not having the calorimeter to evaluate the net calorific value, we based ourselves on the work of several authors namely (Id et al., 2018) ; (Davies & Davies, 2013) ; (Kple, 2018) ; (José, 2015) to estimate this parameter. Calorific value is relative to the energy released during combustion, it expresses the amount of energy associated with a unit of mass of a fuel (Dusabe, 2014). It is expressed for a solid fuel in KJ/kg or Kcal/kg. Two calorific values are differentiated, the upper and the lower. The gross calorific value (GCV) corresponds to the energy released during combustion, after restoring the initial temperature of the fuel. It is thus taken into account all the energy expenditure associated with combustion including that of water vapor. The one measured during our study is the net calorific value (see Table 2) which does not take into account the energy associated with water vapour.

Table 2: Calculated calorific values of briquettes

N° Briquettes	PCI (MJ/KG)
B1	16,74
B2	19,47
B3	17,90
B4	21,38
B5	17,45
B6	17,21
B7	19,78
Witness	28-33 (Machefaux, 2018) 30 (Dusabe, 2014)

The calorific value at incomplete combustion (boiling stop) of the fuels could be deduced on the basis of the data obtained during the combustion test, and the correlation equation. These calculations show that fuel briquettes have a lower calorific value between 16-22 MJ/KG. The witness is coal, but coal is a reference of excellence (30.97 MJ/KG) (Dusabe, 2014).

In the literature other calorific values have been obtained for example fuel briquettes based on MSW which vary between (8-15MJ/KG) (Dusabe, 2014). Compared to these types of waste, our briquettes are valid. The work of (Bird et al., 2011); (Rezania et al., 2016); (Davies & Davies, 2013) have shown that fuel briquettes have an NCV between 13Mj/kg and 32Mj/kg.

Only briquette B4 has a high PCI value (21.38 MJ/KG), close to that of charcoal. This identified briquette consists of 60% pineapple leaf, 20% sawdust waste, 20% clay. Briquettes B1, B2, B3, B5, B6, B7 have an acceptable PCI vis-à-vis other briquettes obtained in the literature. Nevertheless, a well-justified choice would be much more oriented towards the B4 briquette because it presents acceptable results from the general point of view. All the data collected on the different fuels and qualitative variables is analysed together in relation to the different graphs. The witness (charcoal) represents a theoretical data, an ideal of energy performance. It is identified as flammable and of good capacity for heat transmission to water and aluminum and therefore a sharp increase in temperature during short-term combustion (Marignol, 2021). Fuel briquettes are flammable and have a high heat transmission capacity, which is responsible for the rapid consumption of fuel. On the other hand, these briquettes require a short time for ignition and boiling of water. Charcoal, which is also flammable, is however in opposition to fuel briquettes. This fuel has characteristics of higher heat transmission capacity and lower ignition and boiling times.

Conclusion

This work that we have carried out at the Laboratory of Science and Technology of Water and Environment (LSTEE) aims to develop fuel briquettes with agricultural waste and to show that residues from fields can be recovered into biofuels that respect the environment. The characterization of plant biomass (pineapple leaves and sawdust waste) has shown that they have a high content of lignin and carbon, which designates them as a biomass with high energy potential. In the experimental phase, residue yields are large quantities that make it possible to set up biofuel production units.

The work carried out allows us to say that the briquettes produced show competitive performance compared to charcoal and also to choose the B4 briquette as the best in terms of evaluated parameters, namely physico-chemical and energy performance. The production of fuel briquettes based on agricultural residues allows a new resource that is very necessary on several levels. In terms of new energy, it will complete the biomass ranges with its calorific capacities, in environmental terms, the reduction of deforestation for the direct practice of charcoal and firewood and economically a new source of income for direct operators.

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