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Valorization of Pineapple Post-Harvest Residues and Sawdust Waste into Fuel Briquettes

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Faced with the problem of climate change, which is reflected in deforestation, desertification, greenhouse gas emissions and the poor management of agricultural waste, this study was part of a process to convert agricultural waste into a high value-added product. We therefore produced fuel briquettes from pineapple post-harvest residues and sawdust waste in order to reduce the enormous pressure on the forests and to find another use for this poorly managed waste. The

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methodology we adopted was to determine the lignocellulosic components of pineapple leaves and sawdust waste. The results of this characterisation allow us to affirm that these two biomasses contain enough lignin (about 30%) and consequently, their association can give combustible briquettes with a good calorific value. In order to optimise production, a mixing plan was adopted to generate the composition of the different fuel briquette trials. They are made of pineapple leaves, sawdust waste and clay as binding agent. In this study, the waste was carbonised in a carboniser designed for this purpose. After the production of the briquettes, physical parameters and energy performance tests were carried out to determine the best quality briquettes. After these tests, the fuel briquettes have more acceptable characteristics compared to other fuel briquettes obtained in the literature. Only briquette B4 meets all the measured parameters perfectly and is therefore considered the best with a calorific value of 21.38 MJ/kg ; a value very close to that of charcoal. The second order polynomial model with minitab is explicit as the theoretical and measured values are not far from each other.

Keywords: Fuel briquettes; pineapple waste; sawdust waste.

1. 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 green 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 strong 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 revalorization (with high economic profitability) rather than being subjected to an often out-of-standard disposal (in accordance with Decree No. 2003-332 of 27 August 2003 on solid waste management in the Republic of Benin in its Article 9, of the framework law on the Environment) [1].

As a result, we know to this day that the management of agricultural waste from different plantations remains an unsolved problem in Benin country even if several companies and small businesses are looking for ways to fully address this obstacle. In addition, these wastes have negative effects on the environment such as air pollution, clutter in the fields.

Wood energy (fuelwood and charcoal) is the main source of energy, heating and cooking in Africa [2]. African charcoal consumption accounts for more than half of global production [3]. This massive use of wood fuel in Africa contributes to deforestation and forest degradation. Unfortunately, in both rural and urban areas, the demand for wood energy is growing, putting further pressure on dwindling resources. Thus, the development of clean technologies is increasingly being promoted as a way to reduce pressure on forest resources while providing users with an efficient and sustainable energy source. They also have the advantage of being both financially and technically accessible to people, and they are also able to bring about behavioural changes in communities.

Biomass is any organic material of plant origin that has 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 put in place and frame cooperation mechanisms between the different actors of the ecological transition [3]. Benin stands out as a country with a high potential for the use of biomass in the thermochemical conversion process, in particular wood, forestry and agricultural waste. Among the agricultural wastes, pineapple crown leaves from the fields (rejects) and sawmill wastes which are available in quantity can be highlighted for carbon sequestration for energy recovery.

The present study entitled: "Energy recovery from post-harvest pineapple leaves and sawdust waste into fuel briquettes" has the general objective of recovering agricultural rejects into a high value added product (fuel briquettes).

Specifically, the project will focus on :

- Characterise pineapple leaves collected from fields
- Formulate fuel briquettes with pineapple leaves, sawdust waste and a binding agent
- Testing the fuel briquettes.

This thesis presents the different works that we carried out during this 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 related discussions.

A briquette is a form of solid fuel produced from plant material. It can be used as a substitute for coal, firewood, for domestic cooking and even for heat production in industry (Hamish, 2012) and even heat production in industries (Hamish, 2012). The main components that biomass in general, and plant biomass in particular, the raw material for briquettes, are carbon briquettes, are carbon, hydrogen, oxygen, nitrogen and sulphur. Carbon is the most important element important for the energy recovery of biomass due to its energy potential.

According to [5], two types of briquettes can be distinguished: carbonised and non-carbonised briquettes. Charcoal has been used by man for many years. This is obtained by the same same process as carbonised briquettes. The aim was to have products that were easily transportable, clean when burnt (little smoke, little ash), better for simmering, etc. for simmered dishes, etc. Later, the technique of carbonising other types of biomass was born: agricultural residues for the production of briquettes. This biomass is not very dense and is often thrown away with other final waste, so its recovery is to be encouraged. Biomass is currently used in the production of green energy [6]. In some countries in Europe and America, the densification of agricultural residues into fuel briquettes has become one of the sources of energy. Briquettes has become one of the energy sources. However, in Asia and However, in Asia and Africa, there have been failures in this sector due to poor planning but also to marketing problems [7]. Several countries such as : Uganda, Kenya, Malawi, Rwanda, Ethiopia, Haiti, Tanzania, Mali, Senegal and the United States have Tanzania, Mali, Senegal, Burkina Faso etc [5] have already conducted studies on fuel briquettes from solid waste. The majority of briquette production units in these countries most of the briquette production units in these countries complain about major sales problems or high costs of maintenance costs of the presses (especially for the densification of non-carbonised briquettes); this is due to the fact that, generally high pressure presses are generally made to densify specific residues. The raw materials and production methods used in the briquetting process differ from country to country depending on the availability of biomass and the means used. All organic waste does not have the same energy potential, hence the need to optimise the quality of the residues and the techniques used to obtain the maximum possible energy produced. Sawdust, rice husks, coffee parchment, maize cobs, charcoal dust, banana leaves, paper and banana leaves, paper and cardboard [5] are the most commonly used residues in briquette production. At least 5% of fuelwood consumption and 50% of charcoal can be substituted for fuel briquettes. waste-based fuel briquettes (solid waste and agricultural residues) in Uganda (Hamish, 2012). In Senegal, several technologies for using agricultural and agro-industrial residues for household energy are being for domestic energy purposes are being experimented with. These include:

- The production of biochar from groundnut shells by the Carbosen company in Kaolack with a production capacity of Kaolack with a production capacity of 1800t/year ;
- The production of Typha charcoal, which will certainly be a start to the struggle that the production of Typha charcoal, which will certainly be a start to the fight that the people living along the Senegal River are waging against this invasive plant ;
- The production of 500t/year of charcoal balls from rice husks in Ross Béthio with Bioterre SA ;
- The production of biochar from coal dust with the company BRADES.

In Benin, studies have been carried out and continue to be carried out at both institutional and research levels. At the institutional level, the General Directorate of Forests and Natural Resources within the framework of phase 2 of the "Bois de Feu Project" has initiated a study on the feasibility of biofuels and substitution for charcoal and firewood in Benin. In this study, the potential for agricultural or industrial residues in a number of localities was determined and the possibility of implementing biofuel projects was assessed. Biofuel substitution projects in Benin. For this purpose, four projects were selected in of the country, namely Zou, Collines, Atlantique, Littoral and Ouémé because of their proximity to the Cotonou market. In terms of research, the issue of waste recovery was addressed by

Daniel MEDEDJI and Joël GNACADJA. The first developed a press to densify the surplus. The first developed a press to densify the surplus fibre and shell dust mixture to produce marketable briquettes, part of which is already used in a boiler. The second has carried out a study on the recovery of palm kernel stalks from the SONICOG. At the end of this study, it was concluded that dried stalks are more suitable for carbonization, the only recovery process that can be carried out with low investment costs and guarantee the recovery of the ash used for soap making. In addition, when crushed, the stalks are suitable for when crushed, the stalks are suitable for agglomeration and the agglomerates can be used in used in households. In addition, as part of the fight against deforestation and the clutter of residues on fields, several associations have conducted research into the use of agricultural and agri-food energy recovery from agricultural and agri-food residues. Some companies and associations use household waste, agricultural and food residues in the manufacture of their green charcoal briquettes. The two main types of briquettes are : non-carbonised briquettes and carbonised briquettes. The production process is almost the same with the only difference is that non-carbonised briquettes do not go through the carbonisation. This study will be limited to the description of the production of carbonised briquettes. This process is mainly carried out in five main stages, namely : collection and drying, carbonisation, preparation of the binding agent, compacting and drying of the briquettes.

2. MATERIALS AND METHODS

2.1 Materials

Fig. 1 shows the lignocellulosic components of pineapple leaf and sawdust waste. On the one hand, it can be seen from this figure that the cellulose content of sawdust waste is very high compared to that of pineapple waste. On the other hand, the proportion of lignin in sawdust waste is higher (30%) than that in pineapple leaves (26.71%). This shows the complementarity of the two types of waste. These results confirm the values obtained by [8] and [9].

2.1.1 Preparation of raw biomass and production of fuel briquettes

The pineapple leaves were obtained from the agricultural production fields in Zoundja, in the commune of Abomey-Calavi. The dried biomass was separately carbonised and then mixed manually into small particles. The raw materials were kept in a polyethylene bag at room temperature until used for briquette production. This production process follows the following steps:

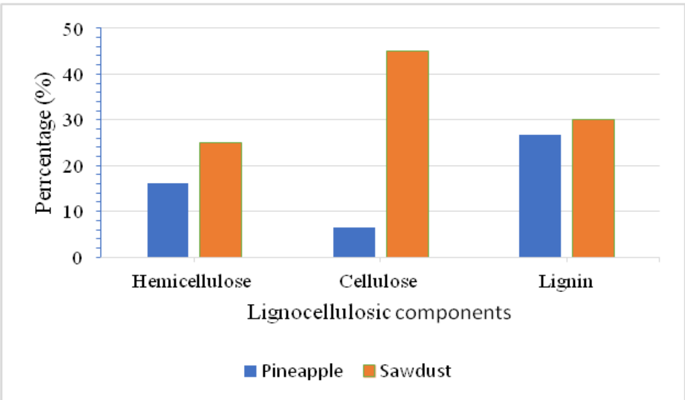

Fig. 1. Lignocellulosic components of biomass

The binding agent was thus prepared and the different components of the briquettes were mixed in the proportions shown in Table 1.

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%)

It presents the optimised mixing ratios. The optimisation methodology is the simplex-centroid designs consisting of 7 trials. The study factors of the mixture designs are the proportions of the mixture constituents [10]. 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 design was chosen because it allows to observe the influence of the different factors on the studied responses (biochar).

2.1.2 Functioning of the carbonisation device used

The most widespread techniques in Africa are still based on the oldest model, which is characterised by the use of earth as an insulating screen. To avoid oxygen ingress and excessive heat loss, 7.5 cm thick clay bricks were used. The carboniser is a metal drum consisting of a cylinder 53cm in diameter and 50cm high.

A door at the bottom of the device allows easy access to the interior for unloading the char produced. This reactor is equipped with several nozzles with plugs to regulate the amount of air entering the reactor. A burner mounted above the pyrolysis reactor allows the combustion of the gases generated by the pyrolysis and a loading hopper, easily accessible for the biomass supply. Hatches are used to seal the hopper and burner from the pyrolysis reactor. The hopper door allows easy feeding of the reactor even during the process.

The start-up of the system consists of its heating, by means of an internal biomass fire, as carbonisation by internal combustion is this process. This device was designed and built by the technician of the workshop of the mechanical engineering and production department of the Institut National Supérieure de Technologie Industrielle (INSTI) ex IUT of Lokossa and with clay coming from Sê, the finishing of which was left to us.

2.2 Methods

2.2.1 Moisture

To obtain the moisture content, the sample is heated in a Memmert 11-25 oven at 105°C and weighed after 24 hours. Its determination follows the European standard EN 14774, according to the following formula:
M=Mass

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

2.2.2 Volatile mater content

To obtain the volatile matter content, the same sample used to find the moisture content is heated in a Naberthern B180 muffle furnace to a temperature of up to 550 °C. Its determination follows the French standard NF, 1985. The volatile matter content is determined by the loss of mass during heating. The following formula is used to calculate the volatile matter content :

$$\mathrm{VOM} = \frac{\mathrm{M\ 105°C} - \mathrm{M\ 550°C}}{\mathrm{M\ humid}} \times 100$$

2.2.3 Fixed carbon

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

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

2.2.4 Ash content

The ash content is obtained by heating the sample to 850°C in a Naberthern B180 muffle furnace. Its determination follows the European standard EN 14775. The ash content is determined by the mass of the residue after incineration. The result is obtained with the following formula:

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

2.2.5 Calorific value

Calorific value is measured with a calorimeter, but can be estimated from a correlation between different parameters. In the absence of a calorimeter, this study therefore made use of the correlation matrix. 500°C was the average mesure of the carboniser temperature.

3. RESULTS AND DISCUSSION

For these different analyses, the moisture content and the values of the three parameters (volatile matter content, ash content and fixed carbon content) were analysed on the dry matter. These analyses were carried out in the Water and Environment Science Laboratory and Chemical and Physical Laboratory at the University of Abomey-Calavi in Bénin. Fig. 2 presents the results obtained for the moisture content of the fuel briquettes and charcoal. According to [9] a value higher than 10% is not desirable as it reduces the calorific value making it difficult to burn. These briquettes have a moisture content averaging 20.77% which 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 the charcoal has a very low moisture content (6.08%) compared to the briquettes. This is due to the fact that the charcoal undergoes several days of drying before it is sold or even used. Despite this difference in moisture content between these briquettes and charcoal, these briquettes were able to have an acceptable ignition time compared to other fuel briquettes obtained from the literature. Therefore, a long drying time (5-7 days) is required to obtain briquettes with a good calorific value and a long burning time.

Fig. 3 shows the % distribution of these three parameters (volatile organic matter content, fixed carbon content, ash content) in the dry matter of the considered fuels and charcoal. The control is charcoal, and charcoal is a reference of excellence [11]. A high VOM value is more favourable to combustion (more than 80%) [11]. It can be seen that the VOM content of briquettes is on average 60%. A value largely higher than that of [5] (less than 30%) for briquettes based on household waste. The B3, B5 and B6 briquettes exceed the values of volatile matter content obtained by [5], [12], for organic waste. On the other hand, the values of B1, B2, B4 and B7 briquettes are close to that of charcoal and can be considered as better for this parameter. A low percentage of ash content is recommended for biomass briquettes (less than 10%). The average obtained for the ash content of the seven (07) fuel briquettes is 39%. This value is close to that obtained by [5] for paper and organic waste briquettes and much higher than that of charcoal (8%). This is due to the presence of clay (rich in mineral matter) which is an element in the composition of these briquettes. It should be remembered that this clay is not a problem because it can be reused for the manufacture of other fuel briquettes and also the chemical composition of the ash can be used for other purposes (soap making, etc.). The fixed carbon values of the fuel briquettes produced are lower than those of charcoal. This is justified by the composition of the briquettes, more precisely the pineapple leaves which have a high volatile matter content (more than 60%).

The combustion test, which consisted of boiling a previously known quantity of water (300 ml) with 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 the boil, thus providing the information needed to calculate the calorific value. This test requires the use of a firebox and an aluminium container of known weight. A conventional firebox is used for the briquette and charcoal tests. The test is started at ignition by adding an oxidant (palm kernel cake) after the fuel has been placed in the firebox: 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 firebox, weighed and filled with 300ml of water, whose temperature is measured (29.9°C). The different results are shown in Fig. 4. The fuels burn in a gaseous state. The higher the volatile organic matter content, the shorter the flammability time. It can be seen that briquettes have a lower average volatile matter content than charcoal. Therefore, briquettes have a higher flammability time than charcoal. Briquettes B1 (150.5s), B4 (186.5s), B5 (172.5s) and B6 (165s) have an ignition time close to that of charcoal (135s). However, it should be remembered that the data collected on charcoal is the average of a series of 4 tests. The acceptable fuel briquette in terms of flammability time is 70% pineapple leaves, 10% sawdust waste and 20% clay. The very long ignition time observed for B2, B3 briquettes can be explained by the fact that the latter have a very high clay composition which contains mainly mineral matter (40% clay and 60% biomass) [13] and B7 a very low composition. As flammability is a very important factor for combustion, B2 and B3 do not meet this parameter and can therefore be excluded.

Fig. 5 shows the burning time of fuel briquettes and charcoal. The combustible 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 much longer burning time than the average and charcoal (2 hours). This is due to the fact that these briquettes are strongly composed of clay. According to the work of [14], the presence of clay as a binding agent and in high proportion confers a solidity and a rather long burning time to the briquette. B3 and B4 briquettes are therefore feasible in terms of burning time. These results are close to those found by [5], [14]. The burning time of B1, B2 and B6 briquettes is close to that of charcoal, but B5 and B7 are shorter.

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

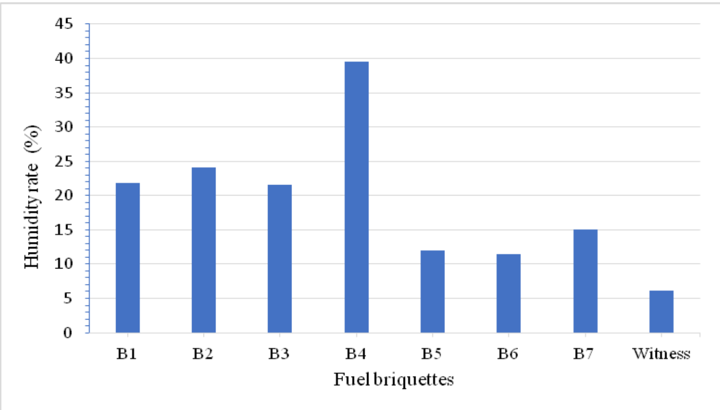

Fig. 2. Humidity content of fuel briquettes and charcoal

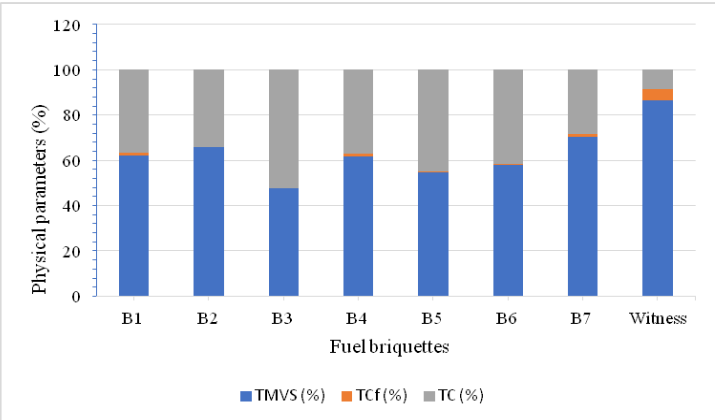

Fig. 3. Physical parameters of fuel briquettes

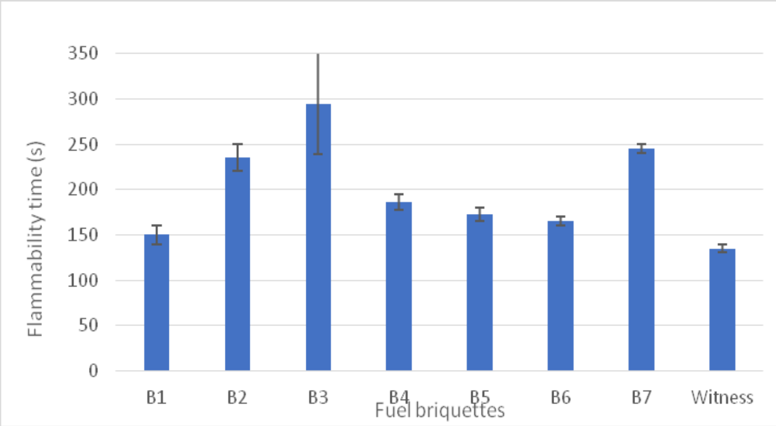

Fig. 4. Burning time of briquettes

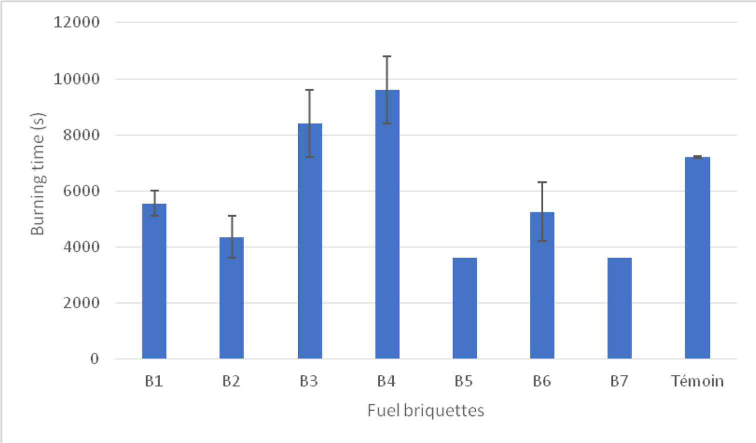

Fig. 5. Burning time of briquettes

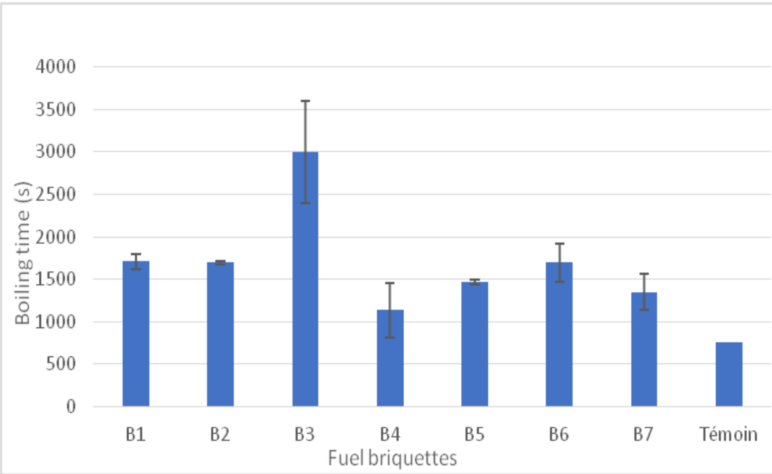

Fig. 6. Briquette boiling test

Not having the calorimeter to measure the net calorific value, we relied on the work of several authors namely [15,16,17] to estimate this parameter. The net calorific value relates to the energy released during combustion, it expresses the amount of energy associated with a unit mass of a fuel [4]. It is expressed for a sol fuel in KJ/kg or Kcal/kg. Two calorific values are differentiated, the higher and the lower. The gross calorific value (GCV) corresponds to the energy released during combustion after the initial temperature of the fuel has been restored. It thus takes into account all the energy expenditure associated with combustion, including that of water vapour. The one measured in this 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	Calorific value (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 [18]
	30 [4]

The calorific value at incomplete combustion (stop boiling water) of the fuels could be deduced from the data obtained in the combustion test and from the correlation equation. These calculations show that the fuel briquettes have a lower calorific value between 16-22 MJ/kg. The control is coal, and coal is a reference of excellence (30.97 MJ/kg) [4]. In the literature other calorific values have been obtained for e.g. MSW-based fuel briquettes which vary between (8-15MJ/kg) [4]. In relation to these types of waste, these briquettes are valid. The work of (Bird et al., 2011) [11,15] showed that fuel briquettes have an ICP between 13MJ/kg and 32Mj/kg. Only briquette B4 has a high calorific value (21.38 MJ/kg), close to that of charcoal. This identified briquette is made of 60% pineapple leaf, 20% sawdust waste, 20% clay. Briquettes B1, B2, B3, B5, B6, B7 have an acceptable calorific value compared to other briquettes obtained in the literature. However, a well justified choice would be more towards the B4 briquette as it presents acceptable results from a general point of view. All data collected on the different fuels and categorical variables are analysed together in relation to the different graphs. The control (charcoal) represents a theoretical data of an ideal energy performance. It is identified as being flammable and having a good capacity to transfer heat to water and aluminium and therefore a high temperature increase during short combustion [19]. Fuel briquettes are flammable and have a high heat transfer capacity, which is responsible for the rapid consumption of the fuel. On the other hand, these briquettes require a short time for ignition and boiling water. Charcoal, which is also flammable, is however in opposition to combustible briquettes. This fuel has the characteristics of higher heat transfer capacity and shorter ignition and boiling time.

4. CONCLUSION

This work, which we carried out at the Laboratoire des Sciences et Techniques de l'Eau et de l'Environnement (LSTEE) (LSTEE) aims to develop fuel briquettes with agricultural waste and to show that agricultural waste and thus show that residues from the fields can be used to produce environmentally friendly into environmentally friendly biofuels. The characterisation of the plant biomass (pineapple leaves and sawdust waste) has shown that it has a high lignin and carbon content, which makes it a biomass with a high energy potential. In the experimental phase, the yields of residues are high enough to allow the setting up of biofuel production units. The work carried out allows us to say that the briquettes produced show competitive performances compared to charcoal and also to choose the B4 briquette as being the best in terms of the parameters evaluated, i.e. physicochemical and energy performances. The production of fuel briquettes from agricultural residues provides a much needed new resource on several levels. In terms of new energy, it will complement 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 the direct operators. In the future, it would be interesting to study the following points:

- A study focused on the carbonisation process in order to control all the parameters that influence this process and to optimise it ;
- A study on the char resulting from the carbonisation of pineapple residues is possible because it is made up of carbon and mineral elements that are still unknown ;
- The binding agent used in this study is clay, after the biofuels are burnt, the ash from them can be used for other purposes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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