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PRODUCTION OF FUEL BRIQUETTES FROM POST-HARVEST RESIDUES OF PINEAPPLES AND WATER HYACINTH

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ABSTRACT

On the one hand, the proliferation of water hyacinth on rivers in Benin causes several nuisances including navigation difficulties. On the other hand, the management of post-harvest pineapple residues is painful for producers. This study proposes to recover these two wastes as raw materials for the production of combustible briquettes. According to the quadratic method, the amount of post-harvest residues of pineapple, of the sugar loaf variety studied; is estimated at 106t/ha each year. A mixing plan was adopted to generate the composition of the various fuel briquette tests. They consist of water hyacinth, pineapple leaves and starch as a binder. In addition, as part of this work, the carbonizer was specially designed at the INSTI ex IUT of Lokossa. After the production of the briquettes, physical parameters as well as comparative combustion tests were carried out to know the best quality briquettes. These analyses and tests allowed us to highlight two types of briquettes of better quality (2 and 4). The fuel briquette n°2 is composed of 20% water hyacinth, 60% post-harvest pineapple residues and 20% starch. And the fuel briquette n°4 consists of 45% water hyacinth, 35% post-harvest pineapple residues and 20% starch. Compared to charcoal, the briquettes selected as better have a lower calorific value than charcoal (22.29Mj/kg and 22.36Mj/kg). Combustible briquettes 2 and 4 also have better flammability and better burning time compared to charcoal. The results of this study prove that combustible briquettes obtained from water hyacinth and post-harvest pineapple residues have a high energy potential and can be used as an alternative source to conventional charcoal.

Keywords: combustible briquettes, water hyacinth, pineapple residues, high energy potential, alternative source.

1. INTRODUCTION

Water hyacinth is an invasive aquatic plant that poses a permanent threat to waterways (Adjahatode et al., 2016). Its presence in infested areas of tropical and subtropical countries has caused serious economic and environmental damage (Ghabour et al., 2004 ; Center et al., 2005). Most of the time, local populations use fish products and water for their current needs. With the presence of floating water hyacinths, we are witnessing an alteration in the organoleptic and physico-chemical quality of the water, then a reduction in fishing stocks. The plant, due to the height and density it can reach, reduces the supply of light and oxygen to the water. This asphyxiation of aquatic life affects the balance of its ecosystem (Fragoso, 2011). It also hinders transport on the water, fishing activities and clogs irrigation networks. Water hyacinth covers more than three quarters of the Porto-Novo lagoon during periods of flooding ; this leads to a decrease in fish yields, from 25% to 55% as in 2004 (GOLD, 2017). Dembélé et al (1994), reported that given the reproductive capacity of water hyacinth, its adaptability, nutrient requirements and resistance to adverse conditions, it is so far impossible to eradicate this plant, once it is introduced into an environment. Valorization initiatives have emerged to mitigate its invasiveness. It emerges the multiple uses such as the production of artisanal decorative placemats, industrial absorbents and others ... It is also very effective for wastewater treatment (Aïna et al., 2012).

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But, faced with the climate challenges of today's world, this study proposes to make use of it, for the production of coal briquettes in addition to another agricultural biomass. The coal produced will make it possible to sequester carbon for different uses, and thus participate in the renewal of terrestrial carbon sources, while mitigating CO2 emissions.

The agricultural biomass highlighted is a representative mass of waste from agricultural production in Benin : pineapple leaves. Indeed, pineapple cultivation accounts for 0.42% of national GDP and 1.95% of agricultural GDP. It is the third most exported crop, after cotton and cashew nuts (Desclee et al., 2019). Its production therefore provides sufficient post-harvest waste (nearly 111.4t/ha) that can be used for this purpose given its energy potential (Marignol, 2021). The lignocellulosic composition of post-harvest pineapple residues gives them an inherent capacity for renewal and carbon sequestration. However, these biomasses are mostly piled up around the fields and the surpluses burned; causing serious environmental damage. On the other hand, we are witnessing a high consumption of wood for energy, with a low rate of access of populations to modern cooking energies and electricity (DGEA/MEFPD, 2015). This high consumption of woodfuels has serious repercussions on the environment that result in the depletion of forest resources (Marignol, 2021). The objective of this work is to transform water hyacinth and post-harvest pineapple waste into combustible briquettes. Specifically, it will be :

- Characterize the different raw biomass collected
- Determine the optimal proportions of mixtures for the production of combustible briquettes
- Carry out a comparative study by combustion tests

This document is structured in three main chapters. The first serves as a reference point for bibliographic knowledge on the production of combustible briquettes from post-harvest residues of pineapple and water hyacinth. The second chapter presents the methodological approach and analytical techniques used to achieve the previously defined objectives. The third chapter was devoted to the presentation of the results and discussions resulting from the various works carried out.

2. MATERIALS ET METHODS

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 :

A 84g of cassava starch (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 presentedin Table 1.

Tests	Type	Coordinates in the plan		
		X1 : Hyacinth	X2 : Pineapple	X3 : Starch
B1	1	0,7	0,1	0,2

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B2	1	0,2	0,6	0,2
B3	1	0,2	0,1	0,7
B4	2	0,45	0,35	0,2
B5	2	0,45	0,10	0,45
B6	2	0,20	0,35	0,45
B7	0	0,36	0,27	0,37

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).

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.

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

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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 :

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 :

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

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.

3. RESULTS AND DISCUSSIONS

These humidity tests allow us to justify the weight variations observed during drying. Indeed, water hyacinth has a moisture content ranging from 93.51% to 94.41%, while the leaves of thepineapple crown have a humidity of 80.87% to 81.37%. This moisture content obtained for water hyacinth corresponds to that of Djihouessi, observed in 2018. For carbonization, we needed dry matter, which therefore does not exceed 7% and 21% respectively. This humidity provides some information on the volatile matter that would probably be low.

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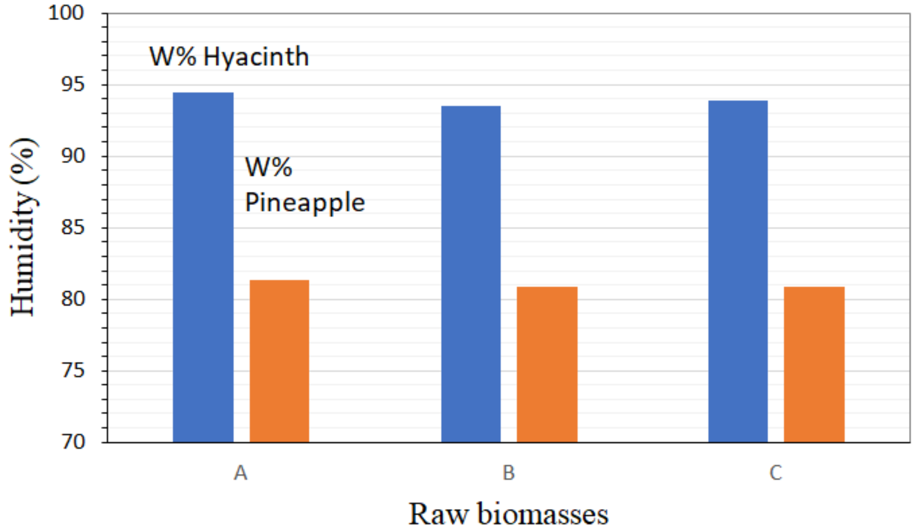

Figure 1 : Moisture content of hyacinth and post-harvest pineapple residues

Binder preparation

The binder used in this study is starch with a density of 84g/l. In order not to create a conflict of interest through the use of food products, it would be wiser to use a non-food binder considered as waste. Not having quickly had a starch-like binder, so we obtained starch waste for other lucrative activities.

Characterization of combustible briquettes Humidity

The final stage of production was to pass the different mixtures in the press for compression,
depending on the capacity. It was then the turn to dry the oven of the latter. Drying makes it possible to measure the humidity level of the briquettes, before moving on to physical analyses. From these analyses, the moisture content that will be represented (Figure 1) is the percentage of the water content of the fuel in the wet state. On the other hand, the values of the three parameters (volatile matter content, ash rate and fixed carbon content) that will be presented have been analyzed on dry matter. These analyses were carried out in the IRHOB laboratory and at the LSTEE in Benin

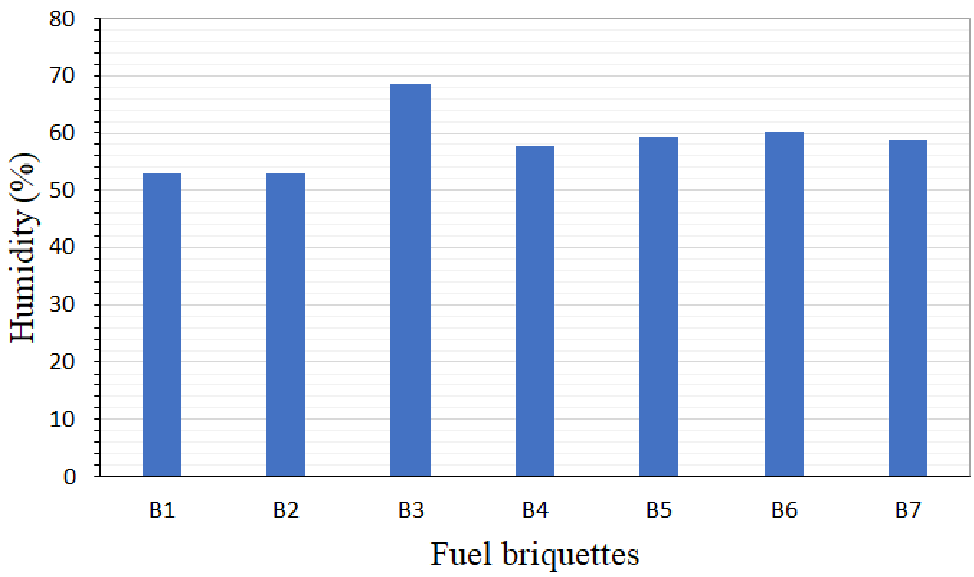

Figure 2 : Measurement of the moisture content of briquettes produced

Figure 15 shows the results obtained after the analysis of the moisture content of the 7 combustible briquettes. These briquettes have a humidity content of 59%. This could be explained by the fact that the biochar undergoes a slight humidification, after carbonization. This moisture could lead to several days of drying before its sale or even its use. Test B3 has the highest humidity level of 68.5%. This is explained by the fact that this mixture received a very high proportion of binder (wet starch) of 70%. This could induce a relatively long drying time, since climatic conditions can change from one day to the next on the one hand and on theother hand the mode of production of briquettes. It is therefore an essay not to be considered. Fuel briquettes B1 and B2 have the lowest humidity levels (53.1%), while other combustible briquettes have a humidity close to average.

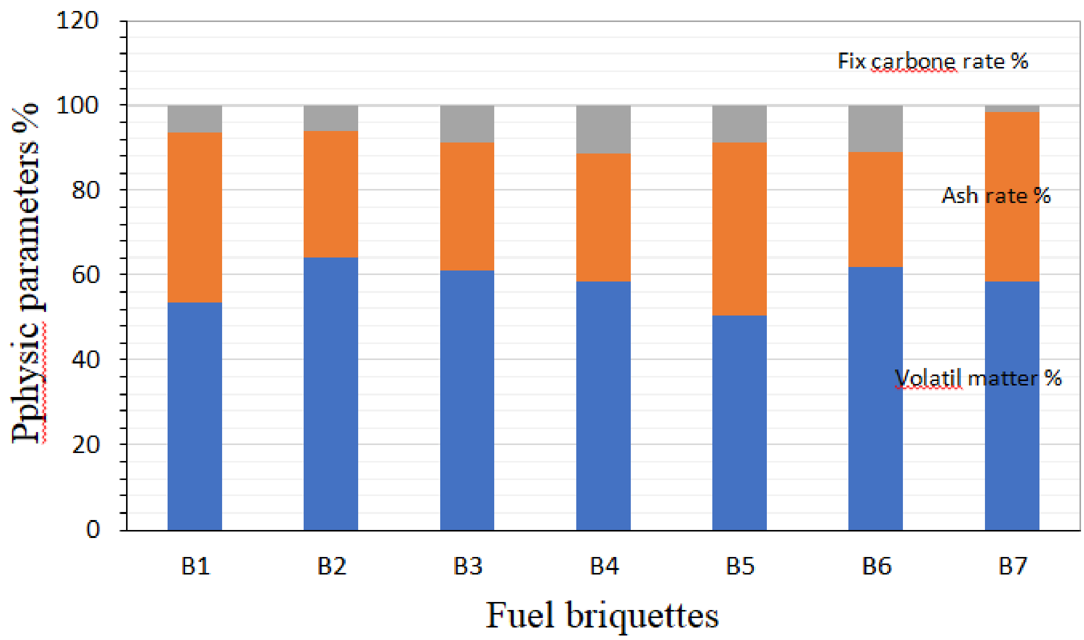

Figure 3 : Physical parameters of fuel briquettes

The histogram of the physical parameters presents the values of volatile matter, ash rate and fixed carbon observed on the different briquettes made.

According to Rezania et al. (2016), high volatile matter is more favorable to combustion. Let us first note that the values of volatile matter obtained vary between 50.36 and 63.91% ; which is a bit below the literature. The maximum value obtained for the B2 briquette could make this briquette a better fuel. Moreover, the average of these values is 58.12% ; which is a significant value. Briquettes B3 and B6 have a high volatile matter content of 60.93% and 61.73% respectively. These capacity values make them possible choices.

Unlike volatile matter, a low percentage of ash for agricultural residues is most preferable for biomass briquettes (Supatata et al. 2013), and thus leads to an increase in particulate emissions during the combustion process. Based on Figure 3, the lowest ash content was obtained with B6 (27.27%) and the highest with the fuel briquette obtained with B5. Briquettes B2, B4 and B3 follow with 30.12%, 30.22% and 30.32% ash respectively. The lower ash content is more favorable, as it also has a detrimental effect on the environment due to dust generation (Rezania et al, 2016). In addition, in terms of combustion efficiency, the lowest ash content is the most preferable, which provides good heating performance at a low cost (Akowuah et al., 2012). Briquettes B2 and B6 are therefore the best indicated.

In addition, the results showed that there is an increment in the fixed carbon content, from the lowest proportion of hyacinth to the largest, as shown in Figure 16. Akowuah et al. (2012), demonstrated that the high fixed carbon content of biomass makes it a better and highly reactive fuel. For this, the B4 and B6 briquettes remain

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the best. In general, the combustible briquettes that catch our attention in terms of physical parameters are B2, B3, B4 and B6.

Test de combustion

The combustion test makes it possible to obtain the energy performance of briquettes based on post-harvest residues of pineapple and hyacinth. This test consists of boiling a predetermined volume of water (401ml), using each fuel. The fuels used for this test correspond to the different briquettes produced during the production process, but also to charcoal.

All these fuels are used at an equivalent weight of 103g. This test requires the use of a fireplace and an aluminum container of known weight. A conventional fireplace is used for tests on briquettes and charcoal.
The test starts at the ignition by adding an oxidizer (palm kernel cake and / or oil) after the positioning of the fuel within the fireplace: the duration of ignition, the time to bring the water to a boil (100 ° C) and the duration of combustion are collected. The pot is then carefully placed in the fireplace, it is previously weighed and filled with 400ml of water, whose temperature is measured (29.9 ° C). The different results are reported through the following graphs :

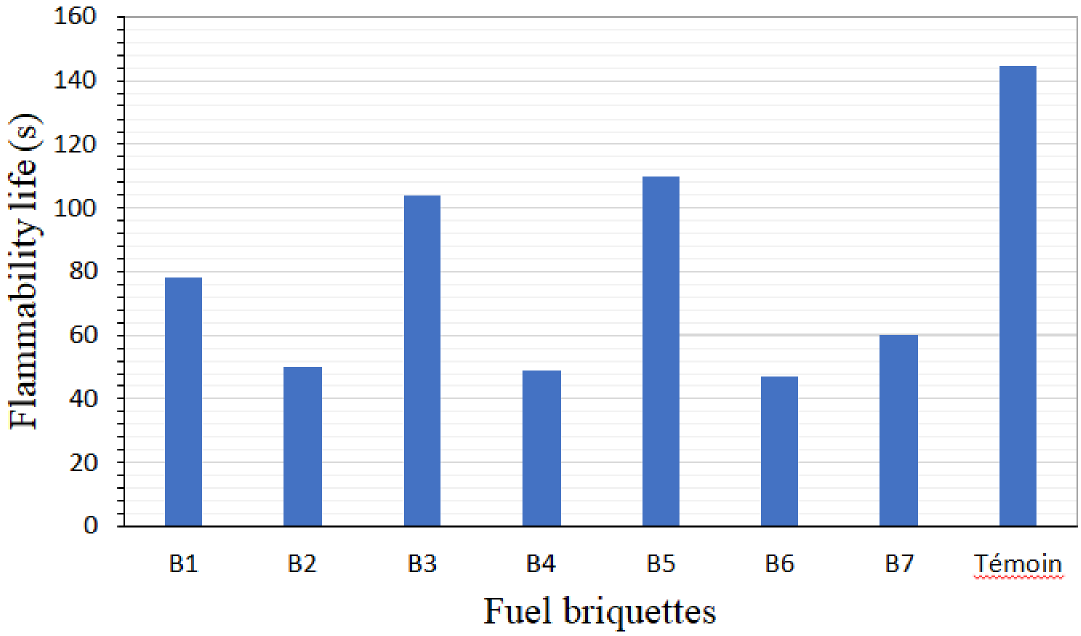

Figure 1: Flammability life of the fuel briquettes

According to this graph it took an average of 71 seconds (1min11s) for the combustible briquettes to start a combustion, with a fast time of 47 seconds and the slowest of 110 seconds (or 1min50s). On the other hand, charcoal (Witness) took an average of 144.6 seconds to ignite; or 2min25s, with a shorter time of 1min55seconds (above the longest time of the briquettes). However, it should be remembered that the data collected on charcoal are the average of a series of 4 tests. The fastest ecological briquette of ignition is B6 ; consists of 20% hyacinth 35% pineapple leaves and 45% starch. These results reveal that ecological briquettes are highly flammable compared to charcoal, because the time taken by the slowest briquette to ignite far exceeds that of the fastest charcoal to ignite. In addition, the rate of binder used for the B6 briquette (45%), makes it a questionable choice. However, briquettes B2 and B4 also have a relatively short flammability time that is below average. So we could call them better by taking into account the other parameters. The relatively long flammability time of the B3 briquette may be due to its high starch content (70%). Indeed, starch is not flammable below 410°C (WHO, 2018). Flammability being a very important factor for combustion, B3, could therefore be excluded, briquettes with high potential.

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The following graph reveals combustion information about eco-friendly briquettes and charcoal. It presents the increment of temperature as a function of time.

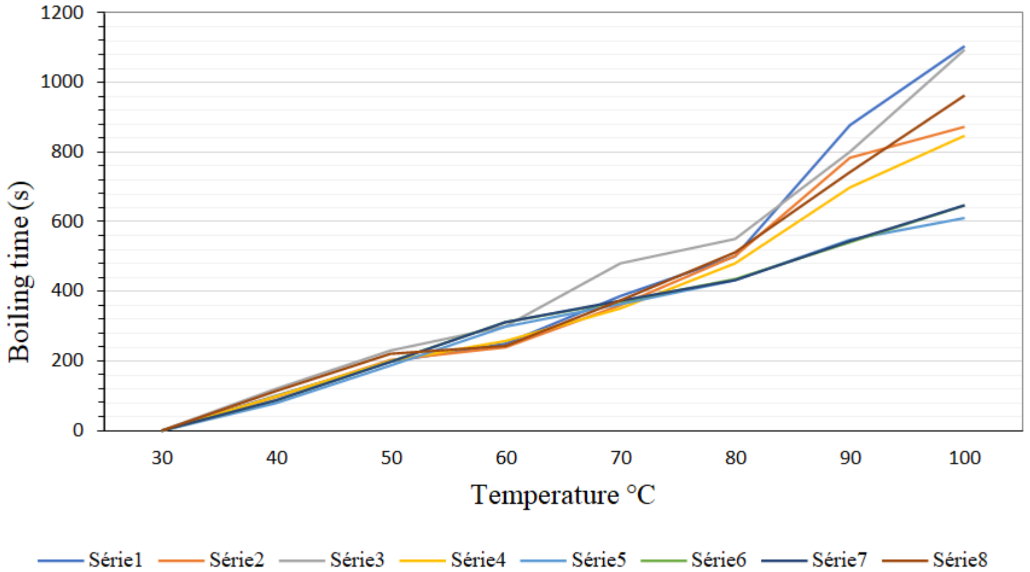

Figure 4 : Temperature incrementation curves as a function of time

In particular, it made it possible to obtain the combustion time necessary for each fuel to bring the water to a boil (100 ° C) thus making it possible to obtain the information necessary for the calculation of the lower calorific value. The minimum burning time required for ecological briquettes to reach the boiling of water was noted at 10 minutes 11 seconds. And the maximum one noted at 18 min 14s. These durations are obtained with briquettes B5 and B3 respectively. The time taken by the B3 briquette to bring the water to a boil, do not make it a better choice. Charcoals had a slightly longer time with an average of 16min3s which is above the average of ecological briquettes (13min 52s), for a fuel consumption equivalent to 103g and an amount of water equal to 401ml. The observation is therefore that ecological briquettes, when well optimized, can release more heat during combustion than traditional charcoal.

As for our ecological briquettes identified above (B2, B4 and B6), they bring the water to a boil in a time close to average and lower than that of charcoal. In short, the best flammability times are obtained with briquettes with a capacity of 35-60% pineapple leaves and 20-45% water hyacinth. The objective of this research work being to valorize the biomasses, the briquette B6 may not suit us, because it has a proportion of starch close to half of the mixture (45%).

In addition, in order to better appreciate these briquettes additional parameters were evaluated. They complement the first given the sociodynamic aspect of our living environments. The briquettes were tested for their equal mass burning times and other physical aspects. The findings made are notified in the following table :

Tableau 2 : Combustion test results

N° Briquette	Burning time (s)		Smoke	Smell	Apparent resistance	Observation
B1	30min10s	1810	No	No	Resistant	Not very salismessy
B2	35min11s	2111	No	No	Not very resistant	Salismessy

B3	36min45s	2205	No	No	Very resistant	Not very Salismessy
B4	30min57s	1857	No	No	Crumbly	Not very salismessy
B5	31min28s	1888	No	No	Not very crumbly	Not very salismessy
B6	32min14s	1934	No	No	Not very résistant	Salismessy
B7	32min47s	1967	No	No	Resistant	Not very salismessy
Witness test	44min	2638	No	No	Resistant	Blackening

In view of the various aspects noted, briquettes produced from post-harvest residues of pineapple and water hyacinth and charcoal do not have the same burning times. At the same mass, charcoal lasts longer in the fireplace making an average of 43 minutes 58 seconds, compared to 32min47s for ecological briquettes. This may be due to the stronger and more durable nature of the wood. In addition, observations during combustion have shown that charcoal has blackened the aluminum pan while some ecological briquettes dirty it with an oil. In addition, all coals and briquettes did not emit any smell or smoke during combustion. As for strength, charcoal has a hard appearance. We could thus conclude that ecological briquettes therefore remain technically competitive and can overcome the energy problem while protecting our environment from deforestation.

Calorific value

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 higher calorific value 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 in our study is the lower calorific value (see Table 3) which does not take into account the energy associated with water vapour.

Table 3 : Calorific values calculated of fuel briquettes

N° Briquette	Calorific values (Mj/kg)
B1	20,49±3,44
B2	22,29±3,23
B3	18,82±3,21
B4	22,36±3,18
B5	18,43±3,54
B6	22,48±3,12
B7	21,65±3,52
Witness test	28-33 (Machefaux, 2018) 29-31 (Louppe, 2014)

The incomplete combustion calorific value (boiling cessation) of the fuels could be deduced on the basis of the data obtained during the combustion test and the correlation equation. These calculations show us that ecological briquettes B2, B4 and B6 have a high calorific value, but lower than that of charcoal, which varies between 28-33Mj/kg (Machefaux, 2018). These identified briquettes have a capacity of 35-60% pineapple leaves and 20-45% water hyacinth. As for the B7 and B1 briquettes, they display values close to the average (20.91Mj/kg). In general, combustible briquettes have an IDP between 13Mj/kg and 32Mj/kg (Sotannde, et al.

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2010; Gao, et al. 2013; Rezania, et al. 2017). The B2, B4, and B6 briquettes identified above average all have above-average values (20.93Mj/kg). Nevertheless, a justified choice would be much more oriented towards briquettes B2 and B4, because they present acceptable results from a general point of view. But given the friable character of the B4 briquette, the B2 remains the best. The B6 briquette has, unlike the others, a high starch composition. The importance must therefore be put on the raw materials and not the binder.

All the data collected on the different fuels and qualitative variables is analyzed together in relation to the different graphs. The witness (charcoal) represents a theoretical data, an ideal of energy performance. This is identified as being flammable and of good capacity for heat transmission to water and aluminum and consequently a sharp increase in temperature during short-term combustion (Marignol, 2021). Carbonaceous briquettes are flammable and have a high heat transmission capacity, which is responsible for the rapid consumption of fuel. In return, these briquettes require a short time for ignition and boiling of water. Charcoal, which is also flammable, is in opposition to carbonaceous briquettes. This fuel has higher heat transmission capacity and lower ignition and boiling time characteristics.

4. CONCLUSION

The efficient management of water hyacinth is a challenge that is topical. With the climatic consequences of the use of fossil fuels, it is urgent to explore other alternative energy sources, in this case renewable ones. However, lignocellulosic biomass is the most abundant source of renewable carbon on our planet. They are essentially made up of macromolecules, which, forming a complex and highly resistant three-dimensional structure, give rigidity to plants. The objective of this study is to valorize the water hyacinth as an alternative energy source that constitutes combustible briquettes, in addition to another biomass (pineapple leaves). This study uses pineapple pot-harvest residues as part of the agro-industrial waste recovery program. In addition, the recommended energy alternative makes it possible to increase green investments in line with the Paris Agreement. Indeed, the transformation of water hyacinth and pineapple leaves into combustible briquettes mitigates deforestation and plays an important role in increasing forest carbon stocks. To do this, the production of combustible briquettes began with the collection and drying of raw biomass. They then underwent the carbonization step and mixed it with starch, then were compacted and dried. The optimization method used is the centered mixing plan of degree 2, which made it possible to obtain a total of 7 tests. Each test follows the different proportions of mixture obtained and consists of pineapple leaves, water hyacinth, and starch. However, briquette B2 is worth 20% water hyacinth, 60% pineapple leaves and 20% starch and B4 ; 45% water hyacinth, 35% pineapple leaves and 20% starch. The results revealed that these B2 (50s) and B4 (49s) combustible briquettes are more flammable than charcoal (144.6s). The same applies to the rate of volatile matter, ash and fixed carbon. On the other hand, the complete combustion of 103g of coal, revealed that the briquettes of coal B2 (35min11s), B4 (30min57s) quickly consumed than the charcoal (44min). Its combustion is therefore slow. The calculation of the calorific value of the different combustible briquettes shows that briquettes B2 (22.29 MJ/kg±3.23) and B4 (22.36 MJ/kg±3.18), are effective. At the end of this process, the optimal proportions are therefore 35-60% for pineapple leaves and 20-45% for dried water hyacinth. Given the efficiency of the process, it would be possible to popularize it within households, in this case those of farmers.

5. ACKNOWLEDGE

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