**Sustainable energy recovery from water hyacinth (Eichhornia crassipes) through briquetting as an eco-friendly alternative to wood fuel in Burkina Faso**

**Abstract**

This study focused on the energy recovery of water hyacinth as an alternative source of wood energy in Burkina Faso. It involved measuring the physical and chemical characteristics of ground water hyacinth. The study also involved manufacturing agglomerates of ground, non-carbonized water hyacinth and determining their physico-chemical characteristics.

The results of the analysis reveal that ground hyacinth has a promising Net calorific value (15.54 MJ/kg) with a high ash content (18.78%).

The study shows that the 5% starch formulation meets biofuel criteria with satisfactory impact resistance, a maximum moisture content of 2.76%, an ash content of 15.26%, a volatile matter content of 67.32%, a fixed carbon content of 17.42% and an Net calorific value of 15.24 MJ/kg. The study highlights the dual environmental advantage of mitigating water hyacinth proliferation while reducing reliance on forest resources, though challenges such as compressive strength require further optimization

**Keywords:** Biofuel, Water hyacinth, Energy recovery, deforestation

**Introduction**

The major challenge facing humanity today is the fight against climate change. This disruption is due to a number of factors, including overpopulation, the use of fossil fuels that produce greenhouse gases, and deforestation [1]. The latter is caused by the lack of financial means, the scarcity of fertile land, the need to cultivate new fields, the high consumption of wood and charcoal by households, which leads people in rural areas to cut wood abusively in order to meet their needs [2].

However, given the demographic growth we are currently observing, the demand for wood is experiencing exponential growth, for which sustainable renewal will eventually present a significant challenge [3].

This intensive use of woody fuel for cooking and heating leads to excessive harvesting of forest resources, thereby worsening deforestation and compromising the natural regeneration of forests [4]. With the exponential demographic growth recorded in many regions of the world, particularly in sub-Saharan Africa, the demand for firewood continues to increase steadily, making the sustainable renewal of forest resources increasingly difficult to ensure in the long term [5].

In Burkina Faso, more than 65.6% of households used firewood for cooking in 2019 [6]. This situation leads to excessive wood consumption. It becomes imperative, in order to achieve a reasonable and sustainable energy solution, to explore all existing and available energy sources and to diversify energy production methods.

Among the various renewable sources, biomass is often one of the underutilized resources. Water hyacinth (Eichhornia crassipes), an invasive aquatic plant widely present in the country’s water bodies, represents an interesting opportunity. Indeed, this biomass is considered a promising renewable energy source in many regions of the world [7], notably for the production of solid fuels such as briquettes, thus contributing to the reduction of wood consumption.

It is regularly observed during the rainy season that water hyacinth proliferates in various water reservoirs in Ouagadougou. An assessment of this biomass indicates an average density of 168 water hyacinth plants per square meter, with an average weight of 0.34 kg of fresh biomass per unit [8]. This biomass, which is a harmful species threatening the survival of aquatic animal species, can be valorized for energy purposes. This study aims at the energy valorization of water hyacinth through briquetting. The present study contributes to combating climate change, but its primary objective is the elimination of water hyacinth.

# Materials and methods

##  Selection of the Raw Material

Water hyacinth is a harmful and invasive plant that proliferates rapidly in aquatic environments in general and specifically in the reservoirs of the city of Ouagadougou, thus offering a potentially abundant source of biomass for energy production. It is a plant that naturally regenerates, making it a long-term energy source.

The municipality has made it its mission to clean up the reservoir by removing this plant, which turns out to be exploitable biomass for energy purposes. Hence, the choice of this biomass for energy valorization, which will contribute to resource diversification and environmental protection.

##  Study area

The harvesting of the raw material for our study, as well as the production of water hyacinth briquettes, were carried out in the city of Ouagadougou, located at 12°21'56'' north and 1°32'01'' west. Reservoir No. 2, located in Ouagadougou within the Nongr-Maasom district, flows from west to east, joining the Massili River. It was constructed in the 1950s with the purpose of meeting the potable water demand of the city of Ouagadougou. The reservoir covers an area of approximately 226 hectares and has a volume of 2,333,334 cubic meters. The upstream protection is made of masonry stone, and the downstream protection consists of hand-arranged stones. The spillway has an elevation of 285.28 m, a discharge capacity of 180 m³/s, and 60 rectangular orifices through which water flows in case of floods [9]. The reservoir receives water from Reservoir No. 1 and the Némnin canal. It is used for fishing, livestock watering, irrigation, fish farming, washing of equipment, and supplying potable water to the population [10].

##  Choice of binder

Given its excellent natural adhesive properties, its ability to improve particle cohesion, and its clean combustion without a significant increase in ash content, the binder used in this water hyacinth briquetting study is cassava starch [11]. Moreover, it is a renewable, non-toxic, and economically accessible material, making it a sustainable starch suitable for biomass briquette production [12].

##  Experimental setup

This experimental study required the use of a number of items of equipment, including :

* A Heraeus drying oven, model Type UT 6060, which was used to dry the raw material and measure the moisture content;
* A Precisa precision balance, model XT 220A;
* A Retsch SM 100 knife mill;
* A muffle furnace for the carbonization of water hyacinth...

##  Experimental method

## Biomass Grinding

Water hyacinth, being a rather bulky plant even after drying, must be ground before use. Indeed, this plant has a low density, which complicates its handling and therefore does not allow for its carbonization in large quantities in the muffle furnace when it is not ground.

It was therefore ground using a Retsch knife mill and then passed through a sieve with a diameter of 1 mm. The obtained dry biomass powder has a particle size smaller than 1 mm. This particle size was chosen based on studies indicating an optimal particle size between 0.5 mm and 1 mm, favorable for briquetting [13]. After grinding, a sample is taken to be dried in the oven before the analysis of physicochemical parameters.

## Thermophysical characterization

The Thermo-physical properties that were determined are: the calorific value, moisture content, volatile matter content, ash content, and fixed carbon content.

* **Moisture content**

The moisture content of a biomass represents its water content. The determination of moisture content on a dry basis was carried out following a method developed based on the French standard NF V 03-921. The result is expressed by the equation 1.

$\%W= \frac{(m\_{12}-m\_{13})}{(m\_{12}-m\_{11})}×100$ (1)

m11: mass of the empty container;

m12: mass of the container with the sample before drying;

m13: mass of the sample after drying at 105 ℃ ± 2 ℃

The determination of moisture content was carried out following a method developed based on the French standard NF MO3-005, the European standard EN 14918, and the international standard ISO 1928.

* **Calorific value**

The calorific value of a fuel represents the amount of energy contained in one unit of mass of that fuel. It thus indicates the quantity of heat released during complete combustion, with water being expelled in the form of vapor. It is expressed in terms of energy per unit of mass (for solids: MJ/kg) and per unit of volume (for gases: MJ/m³).

The lower heating value (LHV given by equation 2) is derived by a simple calculation from the higher heating value (HHV given by equation 3), the elemental composition, and the moisture content of the fuel.

$HHV= \frac{K\_{1}\*E\_{cal}\*\left(T\_{m}-T\_{i}\right)- K\_{1}\*E\_{pt}\*\left(L\_{i}-L\_{f}\right) }{m\_{echantillon}}$ (2)

$LHV= HHV-(\frac{K\_{2}\*E\_{cond}\* H\_{ech} }{100}+\frac{E\_{cond}\* W }{100})$ (3)

Where *K*1 = conversion factor from calories to joules = 4.1855 J/Cal,

*Ecal* = calorimetric equivalent of the calorimeter, the bomb, its accessories, and the water

introduced in the bomb, *Ecal*=2476 Cal/°C,

*Tm* = maximum temperature, in °C,

Ti = initial temperature, in °C.

Ept = Calorific value of platinum: 2.3 cal/cm.

Li = Initial length of the platinum wire, in cm.

Lf = Remaining length of the platinum wire, in cm.

mechantillon = Mass of the test sample to be analyzed, in grams.

K2 = Proportionality factor: mass of water formed / mass of hydrogen present = 8.937.

Econd = Heat of condensation of water = 2511 J/kg.

Hech = Hydrogen content of the sample, in %.

W = Moisture content of the sample, in %.

* **Volatile matter content (MV)**

Volatile matter of a biomass is the portion of organic material that escapes as gas during its combustion. The determination of the volatile matter content was carried out following a method developed based on the French standard NF MO3-004 and the international standard ISO 562. The method consists of heating, in the absence of air, a previously ground and sieved solid fuel sample to 900°C and maintaining it at this temperature for exactly 7 minutes. It is obtained using equation (4):

$\%MV=\frac{(m\_{22}-m\_{23})}{(m\_{22}-m\_{21})} ×100$ (4)

m21: Mass of the empty crucible with its lid,

m22: Mass of the crucible, the anhydrous sample, and the lid,

m23: Mass of the crucible, residue, and lid after heating at 900 ℃ for 7 minutes

* **Ash content (MM)**

The ash content represents the amount of mineral matter contained in a fuel; it is the mass percentage of the ashes obtained. Ashes are grayish, whitish, or sometimes brown residues resulting from the complete incineration (complete combustion in the presence of air) of solid

biofuels until constant mass is reached. The determination of the volatile matter content follows a method developed according to the French standard NF VO3-922 given by the equation 5.

$\%MM = \frac{(m\_{33}-m\_{31})}{(m\_{32}-m\_{31})} ×100$ (5)

m31: Mass of the empty container

m32: Mass of the container with the dry sample before incineration
m33: Mass of the sample after incineration at 815℃

* **Fixed carbon rate**

It is the amount of carbon remaining after the removal of volatile matter, ash, and moisture. It is different from total carbon, which is the sum of fixed carbon and the carbon contained in the volatilized fraction.

%CF= 100 – (%MV+ %MM) (6)

## Manufacturing Process of Non-Carbonized Biomass Briquettes

The briquettes obtained by compacting the non-carbonized biomass are not produced using a press, but rather in a manual, artisanal manner, applying a certain amount of pressure by hand. Indeed, when using a press for compaction, cracks are observed on the resulting briquettes regardless of the applied pressure, the amount of water, or the binder content. This shows us that the available press is not suitable for compacting our non-carbonized biomass briquettes. Therefore, manual pressing was performed to obtain more resistant agglomerates. For this purpose, the amount of water was varied until an adequate level of 70% was reached. Starting from this favorable amount for manual compression, the starch content was also varied (5%, 8%, 11%, 14%) to produce agglomerates.

## Mechanical Characterization of Briquettes

The mechanical characterization tests performed on the briquettes are: impact resistance tests, compression tests, and density measurements. The mechanical tests were conducted using a compression machine from LEMC (Laboratory of Eco-Construction Materials at 2iE) for the briquette compression tests, a caliper, a clamp, and an electronic balance. To determine the compressive strength, a mechanical or hydraulic testing machine operating in compression mode is used. The briquette is placed between two horizontal metal plates. A constant load is applied on its flat surface at a constant speed until the briquette cracks. The compressive strength is calculated by taking the ratio of the applied force to the cross-sectional area at the point of cracking. To determine the impact resistance of a briquette, a device positioned at a height of 2 meters above the ground is used to hang the briquette. The briquette, once hung, is dropped from this height. This process is repeated until the briquette breaks. This experiment is performed with briquettes of the same type. The bulk density is the mass per unit volume. The dimensions of the briquette are measured using a caliper. The bulk density is calculated using equation (7) [14] :

$ρ = \frac{m}{V} $ (7)

$with V=\frac{πD^{2}H}{4}$ (8)

Where D is the diameter, H is the height, V is the volume, and m is the mass of the briquette.

# Results and discussion

##  Characteristics of ground biomass

Table 1. The results of the analysis of ground water hyacinth after drying.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Humidity (%) | Volatile matter content (%) | Ash rates (%) | Fixed carbon rate (%) | LHV(MJ/kg) |
| Ground water hyacinth | 7,28 | 65,54 | 18,78 | 15,67 | 15,54 |

These results show that the characteristics of ground water hyacinth are less favorable than those of certain biofuels.

The moisture content of the ground water hyacinth (7.28%) is relatively low, making it suitable for use as a biofuel. Generally, ideal biomass for combustion has a moisture content below 10% to maximize the calorific value [15].

##  Characteristics of Briquettes Obtained by Compacting Non-Carbonized Biomass

The following figures (1 and 2) present briquettes obtained by compacting non-carbonized biomass.

|  |  |
| --- | --- |
| C:\Users\HP\Desktop\Redaction mémoire M2\PHOTO\IMG_20180109_103429.jpg **Figure 1: Hand-made briquette** | C:\Users\HP\Desktop\Redaction mémoire M2\PHOTO\Briquette NC 2.PNG **Figure 2: Briquette made with the press** |

The presence of cracks and breakage observed on the briquette in Figure 2 illustrates that compaction using a press does not yield good results. In contrast, the 5 cm diameter agglomerates obtained after manual compaction do not exhibit cracks, as shown in Figure 1.

## Thermo-physical characteristics of agglomerates

* **Humidity level**

The moisture content on a dry basis of the briquettes after drying is shown in Figure 3. It indicates that the moisture content depends on the amount of starch used during the briquette manufacturing. Indeed, briquettes with the same water content but different binder proportions during fabrication do not exhibit the same moisture content after the same drying time. The higher the starch content, the higher the moisture content, and consequently, the drying time should be longer, which was not the case.

The obtained briquettes comply with the ISO 18134-1 standard, which recommends a moisture content below 15% for good-quality briquettes [15].

**Figure 3: Moisture content of non-carbonized biomass briquettes**

**- Ash content and volatile matter content**

Figure 4 presents the ash content and volatile matter content as a function of the starch percentage in briquettes made from non-carbonized water hyacinth.

|  |  |
| --- | --- |
|  |  |

**Figure 4: Ash and volatile matter content of non-carbonized biomass briquettes**

It appears that the ash content decreases as the starch amount increases, going from 15.26% to 10.99%. Conversely, the volatile matter content increases with the starch amount, rising from 67.32% to 73.41%.

This variation is due to the fact that starch is essentially composed of volatile matter, which explains the decrease in ash content and the increase in volatile matter content as the starch amount increases. However, the ash contents of our briquettes are below the values reported by Mwampamba *et al.* (2013) [16] which evaluates the ash content of charcoal briquettes between 10% and 30%. This difference can be explained by the fact that the binder (starch) contains little ash (0.54%) and that the briquettes of Mwampamba et al. (2013) [16] use mineral-based binders such as clay.

A study on non-carbonized water hyacinth briquettes reports values of 13.25% and 74.5% for ash content and volatile matter content, respectively [17]. These values do not deviate from those obtained in this study.

**- Fixed carbon rate**

Figure 5 presents the fixed carbon content of the briquettes as a function of the starch amount.

 **Figure 5: Fixed carbon content of non-carbonized biomass briquettes**

The fixed carbon content decreases as the starch amount increases. This can be explained by the fact that fixed carbon is what remains after subtracting the volatile matter and ash from the initial material. Therefore, if the increase in volatile matter content is greater than the decrease in ash content, the fixed carbon content will only decrease. The values obtained in this study are significantly better compared to those reported in the literature, which indicate a fixed carbon content of 8.6% for non-carbonized water hyacinth briquettes [17].

**- Lower heat value**

The evolution of the lower heating value of briquettes obtained directly by compressing non-carbonized biomass as a function of the starch content is shown in Figure 6.

**Figure 6: Lower heat value of non-carbonized biomass briquettes**

The lower heating value (LHV) decreases as the starch content increases. This is due to the fact that starch has a very low LHV (16.22 MJ/kg).

The briquette containing 5% starch has the best LHV and meets the recommendation for a good briquette, for which the LHV should be higher than 14.9 MJ/kg [15].

## Mechanical Characteristics

**- Density**

Figure 7 presents the bulk density of the briquettes.

**Figure 7: Density of non-carbonized biomass briquettes**

The bulk density of the briquettes varies, and this variation is not linear considering that these briquettes were made using a traditional method. However, an overall decreasing trend is observed as the starch content increases.

* **Impact Resistance**

The briquettes obtained by compacting ground non-carbonized water hyacinth have high impact resistance. Tests conducted on these briquettes confirm this resistance. Indeed, during these tests, no cracks are observed, regardless of the starch content. Consequently, the resistance index of these briquettes is greater than 50, according to the work of Richards (1989) [18], These briquettes exhibit a satisfactory IRI (Impact Resistance Index).

* **Compressive Strength**

Figure 8 presents the compression rates of the different briquettes made from non-carbonized water hyacinth.

# Figure 8: Compression ratio of non-carbonized biomass briquettes

These briquettes do not exhibit an acceptable compression rate, as a briquette is considered acceptable if its compressive strength exceeds 350 kPa. This is due to the fact that these briquettes were obtained by manually compressing the non-carbonized water hyacinth powder. Therefore, the pressure applied was not sufficient for these briquettes to achieve adequate strength.

# Conclusion

This study had as its main objective the diversification of energy resources through the valorization of a biomass, namely water hyacinth. Agglomerates were produced from ground and dried water hyacinth. This was made possible by the use of starch as a binder. To achieve the study objectives, the work primarily focused on the physico-chemical characteristics of the raw material as well as those of the ground water hyacinth briquettes. The briquettes made from ground water hyacinth exhibit a satisfactory lower heating value (LHV) for use as a biofuel but do not have sufficient resistance to the recommended pressure.

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