Briquettes From Solid Waste: A substitute For Charcoal in Burundi

M. Mizero, Th. Ndikumana and C.G. Jung

In Burundi, the problem of solid waste management is acute as dependence on wood and charcoal as solid fuel is creating a major problem of deforestation [1].

The purpose of this work is to promote material and energy valorization of solid waste in Bujumbura where a preliminary study has been realized showing the inventory with the composition and the quantification of MSW (0.6 kg/day.capita). The present work is especially devoted the characterization of the briquettes made by using specific solid waste in a process developed by Bioenergy Burundi enterprise [2]. A random sampling of 3 briquettes from a 5kg package is used for the determination of their characteristics to meet the criteria to be used as solid fuel substitute.

Materials to be characterized in this work are briquettes manufactured by Bionergy Burundi Enterprise [2] and their ashes. The process is using a specific solid waste mixture. The mixture consists of residues of charcoal, dry Eragrostis grass, sawdust and wood shavings from the furniture manufacturing workshops, rice hulls from the husking units and MSW (partially sorted). The mixture, in well-known proportions of the listed waste, is then heated (mainly dried), milled and introduced into a mould to produce the briquettes (L~20 cm and Φ~ 7cm).

Results on proximate analysis of the briquettes are detailed in this work. The mean humidity content is in the order of 20%. Results on dry matter show an ash content of 44%, a high volatile matter of 42%. The value of the fixed carbon content is presented and is very depended on the sampling method. Fixed carbon content lies between 13% and 26%. The calorimetric bomb method (ISO 1928) has been used to evaluate the gross calorific value. The lower calorific value is then calculated (LCV~11 MJ/kg). On the other hand, to be able to use safely the briquettes as substituted solid fuel, further investigation was made to evaluate the presence of pollutants. XRF and XRD measurements were performed on the briquettes and their ashes respectively. Elemental analysis and detection of crystallized compounds are presented showing only traces of pollutants.

The main conclusion of this work is that preliminary results on Bioenergy Burundi briquettes are encouraging and would incited to consider this path for the valorization of some solid waste as substitution solid fuel for charcoal. Currently, in the city of Bujumbura, energy needs for a growing population are real and the use of these briquettes as a substitution solid fuel could be one of the alternate routes.

Références:

Keywords: waste, substitution fuel, briquettes, energy valorisation

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BRIQUETTES FROM SOLID WASTE: A SUBSTITUTE FOR CHARCOAL IN BURUNDI

M. MIZERO\textsuperscript{1}, Th. NDIKUMANA\textsuperscript{1} and C.G. JUNG\textsuperscript{2,*}

\textsuperscript{1} Université du Burundi, Faculté d’Agronomie et de Bioingénierie, Département de Socioéconomie rurale, Faculté des Sciences, Département Chimie, Bujumbura, BURUNDI.

\textsuperscript{2} Université Libre de Bruxelles, Faculty of Applied Science, 4MAT, Bruxelles, BELGIQUE.

*Corresponding author: cgjung@ulb.ac.be, +3226503051, +3226504873

\textbf{Keywords:} waste, substitution, fuel, briquettes, energy valorisation

\textbf{Abstract}

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Références:


1. INTRODUCTION
In Burundi, the wood is the main source of energy for cooking, making bricks and tiles for the construction of houses and many other uses. Deforestation is intense due to uncontrolled cuts and the consequences have arisen already environmentally. More than 99% of the population use wood to meet the energy needs of households. Every year, 404 ha and 16 ha of trees, 10 years old, are cut to power the city of Bujumbura respectively in cubic meters for charcoal [1]. An alternative for the use of municipal waste to override the wood is a real option to be developed.
This study is to evaluate the physico-chemical properties of briquettes made from household waste. For the moment, the main objective is to inform users of the real value of the product in terms of heating value and chemical composition. This could be a tool of decision-making for users and suppliers. They may know the properties of the product delivered and improve if necessary.

Description of the manufacturing process of the briquettes
The process is presently purely artisanal as seen in Figure 1 [2]. Collected waste is essentially unsorted household waste, chips and wood sawdust, rice balls and unsold of charcoal recovered from the points of sale. Household waste is then sorted to remove plastic, metal, glass, paper, cardboard and textiles. Sorted waste is first spread on the ground to dry and is then crushed. The importance of sorting municipal waste for valorisation of the sorted fraction has been studied in Africa [4] and especially in Bujumbura [3].
The dried and crushed waste is then introduced into a mold to come out as a solid in the form of compacted cylindrical briquettes of blackish colour (on the right side of Figure 1). Sometimes, the mixture is made of additional carbonaceous materials such as waste oils in order to increase the heating value of the briquettes. Drying the briquettes is done in the sun, on the ground. So, it is likely that these briquettes are not homogeneous neither form their shape/size nor in their composition.

Figure 1: Process for the preparation of briquettes: input material and artisanal mold.
2. MATERIALS AND METHODS

2.1 Proximate analysis of the briquettes

Three briquettes were chosen at random from a lot of briquettes ready to be sold. Each briquette was broken into two pieces with a knife. Samples are collected from the internal and external faces of the briquette. Briquettes have the form of a cylinder about 10 cm in diameter and 25 cm long.

Proximate analysis was realized for moisture and ash content. Volatile organic matter and fixed carbon were determined. Fixed carbon has been evaluated using two different methods. Results were then compared. The first method is realized on samples taken on internal and external faces of the briquette dried in an oven at 105 °C and then carbonized in an oven at 850 °C. The results are expressed as a percentage of dry matter.

The second method was realized on homogenized pieces of briquettes by the Analyser TRUMAC CN from LECO Corporation (France)

- **Search element**: carbon and nitrogen
- **Desired levels**: ~ 20-40% for briquettes prior to combustion
- **Chemical nature**: Powders on basis of vegetal material, quartz, muscovite, halloysite and hematite for briquettes.
- **Type**: 7 solid from powder of crushed briquettes

**Analytical conditions:**
- **Instrument used** for samples of briquettes: TRUMAC CN analyser
- **Analysis time**: approximately 5 min for briquettes
- **Test sample**: ~ 150 mg
- **Flux used**: 1 g com CAT 502-321: powder of briquette
- **Method used and note:**
  1) Calcination of the crucible was performed to eliminate all traces of carbon.
  2) Due to its vegetal origin, resistance furnace was used.
  3) Repeatability of the measures was possible for the briquette samples.

Finally, the calorific heating value of the briquettes was evaluated by combustion in a calorimetric bomb in the presence of oxygen.

The formulas (1) to (5), hereunder, were used for the evaluation of the various parameters.

**Humidity content:**

\[ TH = \frac{(M_1 - M_2)}{M_1} \]  \hspace{1cm} (1)

Where:
- M1: mass of fresh sample without the mass of the crucible
- M2: mass of sample at 105 °C without the mass of the crucible

**Volatile Organic Matter:**

\[ VOM = \frac{(M_2 - M_3)}{M_2} \]  \hspace{1cm} (2)

Where
- M2: Mass of the sample at 105 °C without the mass of the crucible
- M3: Mass of the sample at 550 °C without the mass of the crucible
Fixed Carbon: \[ FC = \frac{(M4 - M3)}{M2} \] (3)

Where:
M3: Mass of the sample to 550 °C without the mass of the crucible
M4: Mass of the sample at 850 °C without the mass of the crucible
M2: Mass of the sample at 105 °C without the mass of the crucible.

Ash content: \[ A = \frac{M4}{M2} \] (4)

Where:
M4: Mass of the sample at 850 °C without the mass of the crucible
M2: Mass of the sample at 105 °C without the mass of the crucible

High Calorific Value \( P_y \) (with \( y = \) briquette): \[ P_y = \frac{(4.1868 \times E) \times ((t_m - t_i) + C) - (a + b)}{M} \] (5)

E = water equivalent of the calorimeter (calorimeter bomb, its fittings and water introduced into the bomb)
ti = initial Temperature of the water in degrees Celsius,
tm = maximum Temperature of the water in degrees Celsius,
a = correction necessitated by the formation of acids (it is zero)
b = correction required by the heat of combustion of the ignition wire,
C = correction in temperature required by the heat exchange with the outside: void because used calorimeter is adiabatic.
M = mass of the sample (g)
4,1868: conversion factor (cal to J).

2.2 Elemental analysis

Preparation of the samples was made at the Université Libre de Bruxelles, 4MAT department. Briquettes have been disaggregated by an hammer to reduce their size. Coarsely crushed powder was dried in an oven at 105 °C until constant weight. Then, it was crushed with a concentric Disc Grinder into a fine powder. The samples analysed were collected as a powder and then compacted into a tablet.

The first elemental analysis was made by X-ray fluorescence. Results were obtained by using the non-standard high-resolution method under vacuum. The device used is the BRUKER 3000 SRS with an Rh anode.

X-ray diffraction was made for detecting crystallized compounds that would be present in the briquettes or in the ashes. The device used is Mark D500 Brucker to anode of Cu.

3. RESULTS AND DISCUSSION

The measurements on the briquettes are presented and discussed in this chapter. The purpose of this work is to characterise the briquettes, as received from the manufacturer, using an artisanal process and available rural and urban domestic waste, in order to evaluate their potential as substitution solid fuel. Therefore, results on the carbon content, the possible pollutants and the calorific value were selected.
3.1 Proximate analysis results

The results of proximate analysis of the briquettes are presented in table 1.

Humidity is consistently higher in the heart of the briquette compared to the outer. This is explained by the failure of drying of the entire briquette due to its large size. On the other hand, as the process is artisanal, manufacturing conditions are not standardized. Results of humidity content show that the poor drying conditions of the briquettes, not exposed uniformly to the sun, a gradient increasing moisture from the internal part to the external part.

<table>
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<tr>
<th>N° of briquette</th>
<th>Sample codes</th>
<th>Sample portion</th>
<th>DM (%)</th>
<th>TH (%)</th>
<th>VOM (% of DM*)</th>
<th>A (% of DM*)</th>
<th>FC (% of DM*)</th>
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<td>1</td>
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<td>43%</td>
<td>51%</td>
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<td>12%</td>
<td>41%</td>
<td>49%</td>
<td>10%</td>
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<td>3</td>
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<td>72%</td>
<td>28%</td>
<td>46%</td>
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<td>4</td>
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<td>27%</td>
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<td>44%</td>
<td>11%</td>
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<td>2</td>
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<td>48%</td>
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<td>7</td>
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<td>77±6%</td>
<td>23±7%</td>
<td>42±5%</td>
<td>44±3%</td>
<td>13±6%</td>
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</table>

Table1: Proximate analysis of briquettes

*: Dry Matter

The results in Table 1 show a relatively high content in volatile matter. This is due to the fact that the manufacturing process does not include a carbonizing step for the preparation of the briquettes.

We notice that the results for the fixed carbon vary from 6 to 24% from one briquette to another with a mean of 13% ± 6%. This result was realized by the technique using formula (3) and non-homogenized samples of briquettes.

For this reason, to control these results, another technique needed to be performed on homogenized crushed samples of briquettes.

Experiments were realized using a TRUMAC CN analyzer from LECO. Crushed and homogenized samples of briquettes were sent at LECO Corporation in France to be analyzed. Results of these analyses issued from LECO are reported in Table 2.
<table>
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<th>Name</th>
<th>Mass</th>
<th>Carbon %</th>
<th>Nitrogen %</th>
<th>Method</th>
<th>Analysis Time</th>
<th>Analysis Date</th>
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</table>

Table 2: Values and mean of carbon content issued from homogenized samples of briquettes
This result shows a value of carbon content of 27% ± 3% in fixed carbon and 0.79 ± 0.8% in nitrogen. These results differ from those presented in Table 1, mainly for the samples 1 and 2 of the briquettes but correspond to the content obtained for the sample 3 of the briquette for the internal as well as for the external part of the briquette. Indeed, sampling and analytical methods are different and the later, the TRUMAC method, is certainly more reliable as it used homogenized samples. It is to be noted that the difference in the results is especially large for the two first samples of briquettes (Nos 1 and 2) with much lower carbon content (5 to 11%). It is important to note that the material and the amount of waste used in the manufacture of these briquettes are variable and therefore could explain this variation. For this reason, sampling of the briquettes to be test influences mostly the results regardless of the method of analysis used. Indeed, if the briquettes are used as solid substitution fuel, it is evident that they would be of lower carbon content then other solid fuels.

On the other hand, due to the input material, the mean ash content for the briquettes is very high, 43 ± 3% for all samples (see Table 1). The next step is then to evaluate the calorific heating value of the briquettes.

### 3.2 Calorific heating value results of the briquettes

The results obtained for the LCV were calculated by deducting from the HCV the value of the heat of vaporization of the water present in the fresh sample of each briquette and are presented in the Table 3.

<table>
<thead>
<tr>
<th>Briquette number</th>
<th>HCV (MJ/kg)</th>
<th>LCV (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.2</td>
<td>8.6</td>
</tr>
<tr>
<td>2</td>
<td>15.5</td>
<td>12.7</td>
</tr>
<tr>
<td>3</td>
<td>14.4</td>
<td>10.9</td>
</tr>
<tr>
<td>Average</td>
<td>13.7±1.7</td>
<td>10.7±1.4</td>
</tr>
</tbody>
</table>

Table 3: High and low Calorific value of the briquettes manufactured by Bioenergy Burundi

Compared with the LCV of some fuels, such as wood and charcoal, respectively 15 and 27 MJ/kg, briquettes have a lower average LCV ~ 11 MJ/kg.

As shown in Table 1, the high moisture content in the briquettes influences the low value of the calorific values. Moreover, the presence of mineral matter into the briquettes can be the origin of the high ash content. This content could be explained by the biomass as intrant and especially silica in rice balls. Subsequently, further analyses to highlight other chemical elements contained in the ashes and fresh samples of these briquettes were performed. Fluorescence and X-Ray diffraction were realized on the briquettes and their ashes.

### 3.3 X Ray Fluorescence (XRF) of the briquettes and their ashes

By this semi-quantitative method, analyses were realized to evaluate the different elements present in the briquettes and find out if elements such as heavy metals are present. It is an important issue especially if the population would be using the briquettes as solid fuel in replacement of charcoal for cooking.

The XRF analyses showed that fuel briquettes contain mainly and in varying proportions of oxides of Si (30 to 35%), Al (15-18%) and Fe (5-6%). They also contain oxides of S (2-3%),
oxides of K, Ti and Ca (< 2%) and oxides of P, Mg, Zr, of Ba, Mn and Cl (<1%). Traces of Ni, Rb, Sr, Cr, Pb, Nb, Zn, Cu, Br and Ga were also found.

The sum of the components found in briquettes do not sum to a total of 100%. This is due to the content in carbon of about 27% that is not detected by X-ray fluorescence. In the ashes, the same elements were found in higher level ac concentrated in the solid after burning the carbon.

Silica can have two possible sources into the briquettes as in the ashes. Material used for the preparation of briquettes are stocked on the ground (see Figure 1) so sand contamination is very likely. The rice balls are also rich in silicates.

The presence of sulphur in quantities greater than 0.2% is an indicator of the corrosion of the aluminium pans that users of briquettes have been reporting. Chlorine presence, even in small quantities, is undesirable in fuels as precursor of dioxins formation. Heavy metals (Pb, Cr) are in the form of traces and are supposed under the nuisance threshold. The presence of macronutrients such as P, Ca and K as well as trace elements such as Zn, Cu, Mn and Mg are useful for plant growth and it is then an advantage to enhance the use of briquette’s ashes in agriculture.

3.4 X-Ray Diffraction (XRD) results of the briquettes and their ashes

These measures were realized to find the structure of the briquettes and their ashes.

Figure 2 represents the results of the analyses by the XRD method and shows the crystallographic characteristics of the briquette (crystallized or amorphous).

![Graph showing XRD results of briquettes and ashes]

Figure 2: Crystallographic characteristics of the briquettes

A detachment of the curve from the axis is observed. This shift represents a background noise that would be due to the non-crystalline organic fraction. All samples showed the same trends for elements crystallized in briquettes. The mineral form corresponding to the highest peak is quartz. This confirms the XRF results that showed the presence of silica in large quantities.
Other crystallized forms correspond to illite and halloysite, a hydroxyl aluminum silicate. However, it was not easy to distinguish if there were illite or muscovite who are all alumino-silicates. Next to these clay forms, there is also a titanium oxide in crystalline form.

Figure 3 shows the results of the XRD on the ashes. The background noise is less intense than in briquettes. This is due to the fact that amorphous organic matter was not present to amplify background noise and influence the results of RX diffraction.

Three crystallized elements have been found in the ashes as well in the briquettes. These are quartz, muscovite and anatase. Halloysite becomes amorphous above 600 °C. The iron that was not crystallized into briquettes, becomes crystallized after cooking in the oven at 850°C. It changes from goethite into hematite (Fe₂O₃).

**4. CONCLUSIONS**

The use of briquette is to be encouraged to reduce deforestation for the purpose of charcoal production. However, this preliminary study shows that to improve the quality of the briquettes, sorting of the input material (waste) should be recommended to minimize the presence of toxic substances such as chlorine (PVC) and its derivatives, sulfur compounds and lead. On the other hand, the calorific heating value of the briquettes (LCV ~ 10MJ/kg) could be improved by reducing its size to increase the humidity content (H~ 23%). On the environmental front, the briquettes could be used to reduce the quantities of wood and charcoal consumed by ordinary households, military camps and police camps.

This work is aimed to help in the management of solid waste and could be used as a tool for taking a decision towards waste produced daily in various sectors of activities in Burundi.
It is an important implement in the field of waste treatments and point out that the valorization of waste contributes to the socio-economic development and the protection of the environment.

Currently, in the city of Bujumbura, energy sources are needed for a growing population. Rate of urbanization is growing in an environment where hygiene is deficient and unemployment and poverty are growing. All these challenges encourage researchers, policy makers and civil society to join together to search for durable solutions.

The area of material and energy recovery from solid waste is a promising niche of hope for sustainable development in Burundi.

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