VALORISATION OF SUGAR CANE PROCESSING RESIDUES INTO SOLID FUEL ADDITIVES IN PELLETS FORM

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ABSTRACT

In the Urban Commune of Antananarivo, Saccharum officinarum bagasse, commonly known as sugar cane, is thrown into rubbish bins by small juice sellers, even though it is a resource that can be used for various purposes. This study aims to promote the use of this biomass, which is considered a waste, as an additive to solid fuel in the form of pellets. The methodology adopted includes, first, the research/collection of bibliographic and webography data on solid fuels and additives ; then, the estimation of sugarcane waste after the juice extraction process at the Analakely market, a source of potential raw material that can be transformed into solid fuel additives. And finally, the transformation of the residues into fuel additive pellets. As a result, the quantity of bagasse from these sugar cane juice sellers is estimated at 82 tons/year, which represents a significant potential of raw material that can be transformed into fuel additives. In terms of effectiveness and efficiency, T.E.E. water boiling tests on fuel pellets made from residues combined with charcoal have shown that the amount of charcoal can be reduced by 33,95%. The recovery of agricultural products in a traditional environment requires taking into account the life cycle of the plant for sustainable agriculture.

Keyword : *Saccharum officinarum bagasse, mapping, solid fuel addition*

INTRODUCTION

Madagascar is one of Africa's major sugar cane producers, with a production of 1 980 000 tons in 1993 [1]. However, a large part of the bagasse, a residue from the extraction of cane juice, is usually neglected and considered waste, particularly in the Urban Commune of Antananarivo. This raises questions about resource management and the need for an integrated approach to valorize this biomass. Bagasse can be transformed into solid fuel additives, offering a sustainable alternative by reducing waste and lowering wood energy consumption. This article is part of an action research project evaluating the potential for bagasse recovery using a multi-stage methodology. By combining bibliographic analyses, field surveys in Analakely, and solid fuel additive manufacturing techniques, its aim to demonstrate the feasibility of this approach and its potential impact on the local economy and the environment. The energy recovery of bagasse residues from sugar cane juice extraction requires exploration of recent advances in the field of solid fuels. It is a substance in a solid state that can ignite in the presence of an oxidizer and at an appropriate ignition temperature. When burned, it can be used as a source of thermal energy. This designation covers all natural carbon resources. The common characteristic of solid fuels defined in this way is that they contain a high proportion of carbon [2].

Solid fuels are among the oldest used by humankind. Coal, formed millions of years ago from plant matter, remains a major source of energy in many countries. Wood, with or without prior processing, is considered a renewable energy source when managed sustainably. Biomass, which includes agricultural and forestry waste, is gaining popularity as a more environmentally friendly alternative. Among solid fuels, charcoal is produced by carbonizing natural wood, while bagasse fuel is derived from the residues of sugarcane juice production, thus reducing the amount of waste sent to landfills [3]. Cooking meals in households is one example of the use of solid fuels. It requires users to first define the accessories and type of cooking energy to be used, taking into account various financial and technological constraints and availability. Households, therefore, find themselves choosing, based on their preferences, between different fuels that enable them to produce cooking fires and meet their nutritional needs. In some cases, one fuel may be wholly or partially substituted for another. Solid fuel addition refers to the introduction of combustible materials in solid form into a combustion system. Solid fuels can include materials such as coal, wood, agricultural residues, or other biomass in different forms [4].

1. MATERIALS AND METHODS

Artisanal sugar cane juice vendors in Analakely generate bagasse as a byproduct of juice extraction. Before collecting samples for conversion into fuel additive pellets, we estimated the total quantity of this bagasse available from these vendors.

1.1 Materials and methods for assessing the quantity of bagasse in the study area

Each artisan sugar cane juice seller in Analakely is identified by their location, which is marked on a map. This map was created using base maps based on administrative data from the BNGRC and Google Maps, as well as ArcGIS, ArcMap, and SASPlanet data processing software, to delineate the boundaries of Fokontany Analakely and locate the artisanal sugar cane juice vendors. The shapefiles in ArcMap are superimposed with those from the aforementioned databases on the administrative divisions of the Fokontany of Analakely. Surveys of these artisanal sugar cane juice vendors are then carried out to obtain information on the quantity of raw materials they use and the destination of the bagasse resulting from extraction.

1.2 Materials and methods for transforming bagasse into solid fuel additives in pellets form

- The pellets are made from two main components : biomass and binder.
  - The combustible biomass is bagasse, the fibrous residue obtained after crushing sugar cane to extract the juice in the traditional mills used by juice sellers.
  - The binder is used to agglomerate the raw materials to facilitate the compaction of solid fuel. It is composed of three components : flour glue, laterite and water. These are respectively of mineral and organic origins.
- The conversion of bagasse into additive of fuel pellets takes place in three stages.

Preparation of the binders :

  - Cook a mixture of 30g of flour with 100g of water over a low heat until a paste-like consistency is obtained.
  - Add water to the laterite in a container. Mix until a soft paste is obtained.
  - Shaping the pellets :

The bagasse and binders are mixed by hand in a container. The proportions are adjusted to obtain a homogeneous paste consisting of approximately 70% biomass, 20% binder, and 10% water. A portion of the paste is pressed and rolled by hand to form round pellets of 40 to 50 mm in diameter [4][5].

- Drying :
  - Allow pellet fuels to dry in the open air to reduce moisture content to an optimal level of approximately 10-15%.

1.3 Materials and methods for analyzing the energy efficiency and effectiveness of fuel additive pellets

The method used is based on that recommended for assessing the energy efficiency and effectiveness of fuel briquettes : the TEE water boiling test. The principle is based on heating a pot containing a fixed initial quantity of water using the fuel to be tested. Two phases will be studied : a temperature rise phase, where the time required to reach the boiling point will be measured, and a boiling maintenance phase, known as 'simmering', where the focus will be on the mass of fuel consumed over a given period of time. The mass of water evaporated during the water boiling test will also be measured to determine the energy efficiency of the system.

Materials

Equipment

- Measuring equipment
  - A stopwatch
  - A scale with a capacity of 10 kg and an accuracy of ± 1 gram
  - A thermometer suitable for immersion in boiling water. It is equipped with a device to keep the probe submerged at a height of 5 cm from the bottom of the pot.

- Utensils and fuels
  - Stove or 'fatapera' and pot of the same type as those used locally for cooking.
  - Pine wood pieces are used as fire starters to ensure reproducible results. These pieces are naturally impregnated with resin.
  - Water to be boiled, representing two-thirds of the pot's capacity.
  - Charcoal.
  - Pellets made from sugar cane bagasse residues, the subject of our study.

Method

To assess the performance and energy efficiency of fuel additive pellet, they are mixed with charcoal, one of the fuels commonly used by households in cities in Madagascar. The proportion of the two components is varied during the TEE water boiling tests. Three tests are carried out for each proportion. The TEE tests performed on charcoal without pellets were used as a reference. Conducted under realistic household conditions of fuel and stove use, at both high and low power settings, performance was assessed based on the following indicators : water boiling time, unburned fuel residue, energy efficiency, and useful energy released during the boiling and evaporation of water. During the test, it is necessary to ensure that all the water boils and to measure the boiling temperature of the water using a thermocouple. Temperatures are measured over a period of more than 5 minutes. In order to obtain reliable data on the efficiency of the pellets, various variables such as the quantities of coal and pellets consumed, the amount of water vaporized, the amount of water remaining, and the duration of the test are parameters to be measured during the tests. The useful energy, i.e., the energy transferred from the stove to the pot, depends on the amount of heat accumulated by the water between its initial temperature and its boiling point, and on the latent heat of the evaporated water [6]. It is given by Equation 1 :

Equation 1 : Formula for calculating useful energy

$$Q = \text{Cwater x (T boiling} - \text{T initial)} + \text{Lwater x (M initial water} - \text{Mremaining)}$$

Q : represents useful energy, i.e. the energy transferred from the stove to the pot,
Lwater : latent heat of vaporization of water (J/kg)
Cwater initial : specific heat of water (J/kg °C)
M initial water : initial mass of water
T boiling : boiling point (°C)
T initial : initial temperature (°C)
M initial water : initial mass of water (kg)
M remaining : remaining mass of water (kg)

The values of the thermodynamic parameters used for this formula are given in Table 1.

Table -1 : Values of thermodynamic parameters and reference coal mass

Symbole	Paramètre	Valeur
L_{water}	Specific heat capacity of water (J/Kg°C)	4 180
C_{water}	Latent heat of vaporization of water (J/Kg)	2 260 000
M_{water}	Initial mass of water (Kg)	2,4
$T_{boiling}$	Boiling point (°C)	96
C_1	Reference amount of charcoal consumed (Kg)	0,59

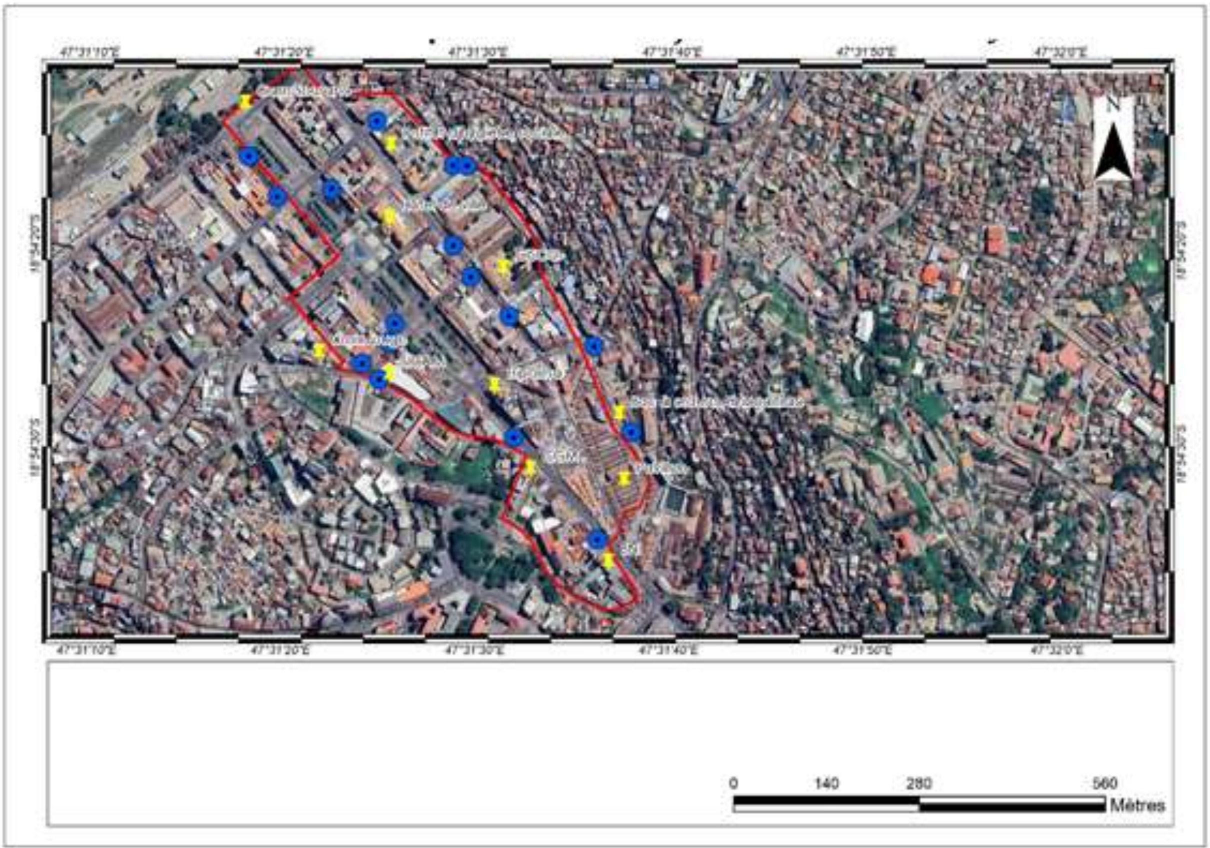
Source : Authors

2. RESULTS

The results presented are those of the estimation of the quantity of bagasse generated during the extraction of artisanal juice from *Saccharum officinarum*, by vendors in Analakely and their transformation into pellets for fuel addition.

2.1 Assessment of the quantity of bagasse from sugar cane juice sellers in Analakely

The spatial distribution of cane juice vendors in Analakely is shown on the map in Figure-1.



Légend

Sugar cane juice sales point

Analakely fokontany boundary

Source : Google Maps background image WGS 84 projection system, Authors

Figure-1 : Map showing the location of sugar cane juice sellers in Analakely

2.2 Estimation of bagasse quantity and quality

During the on-site survey, the quantity of sugar cane used by sellers varied depending on the season and location. It ranged from 30 kg in winter or the cyclone season to 80 kg in summer. The estimated annual quantity is 83.7 tons, corresponding to 558,447 m3 of waste to be collected.

The physical and chemical characteristics of bagasse are presented in Table 2.

Table-2 : Physical and chemical characteristics of bagasse

Physicochemical parameters	Quantity [%]
Moisture content	59
Dry matter content	41
Cellulose content in dry matter	44,7
Ash content in dry matter	1,11
Carbon content	38,7

Organic matter content	67

Source : Authors

2.3 Transforming bagasse into fuel additive pellets

The fuel pellets obtained are compact blocks composed of mineral and organic raw materials. They are round in shape, 40 mm to 50 mm in diameter, weigh between 12 g and 17 g, and have a moisture content not exceeding 10%. [5]

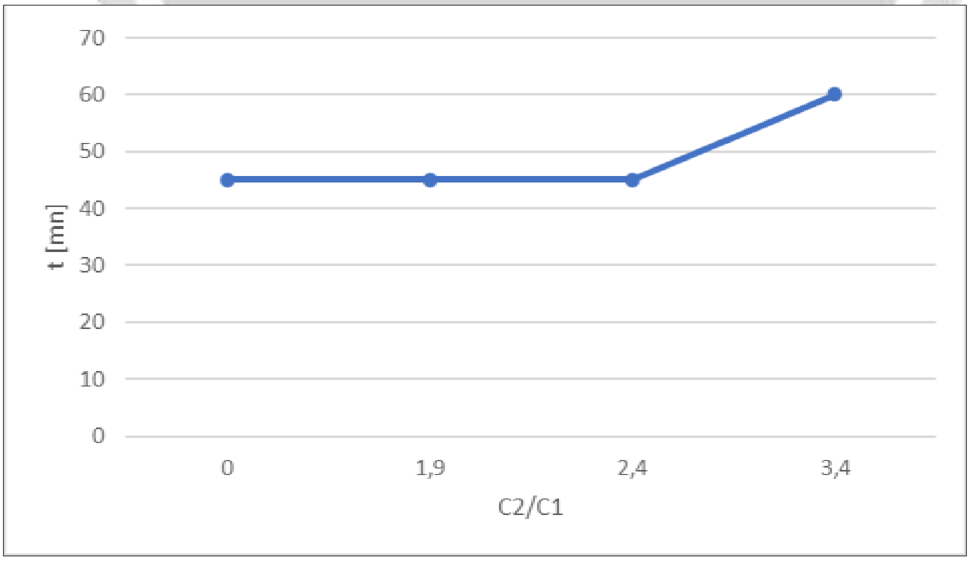
Figure-2: Photos of fuel additive pellets

Source : Authors

2.4 Energy efficiency and effectiveness of fuel additive pellets

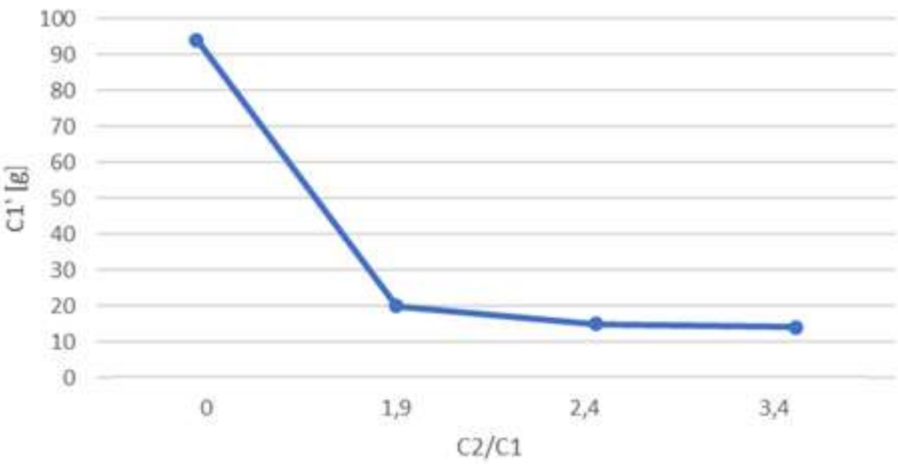
The energy efficiency and effectiveness of fuel additive pellets produced from bagasse distillation are assessed by measuring three parameters : the time it takes for water to boil, the amount of unburned fuel during TEE, and the useful energy during TEE.

The ratios of bagasse pellet fuel and charcoal quantities are shown on the x-axis.



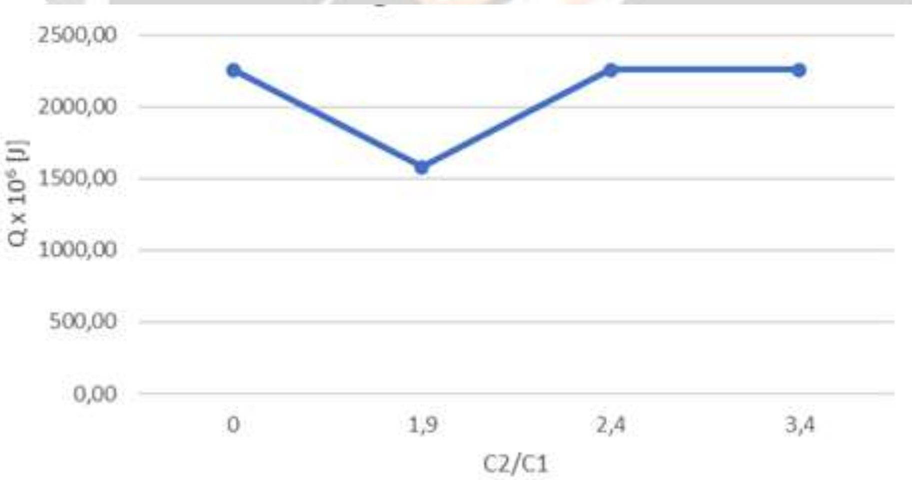
Legend:
C1 : weight of charcoal
C2 : weight of fuel pellets additive added
t: time taken for water to boil

Figure-3 : Change in the time required to bring water to a boil



Legend :
C1: Mass of charcoal
C2: Mass of fuel pellets additive
C1': Mass of unburned charcoal

Figure-4 : Variation in the quantity of unburned charcoal in relation to the mass proportion of fuel pellets additive and charcoal



Legend:
C1 : weight of charcoal
C2 : weight of fuel pellets added
Q : amount of useful energy

Figure-5 : Variation in useful energy as a function of the C2/C1 ratio

3. DISCUSSION

The estimated annual bagasse volume from artisanal sugar cane juice extraction, the subject of this study, is 558,447m^3, a significant amount in terms of recoverable waste. Artisanal cane juice sellers are not limited to Analakely but are also found in other localities of the Urban Commune, hence the interest in recovering these residues. From the study of the manufacture of bagasse pellets as fuel additives, it appears that the use of two mineral and organic binders promotes the optimization of the mixture. In addition to their adhesive properties, mineral binders also act as fillers. According to TEE water boiling tests, the use of pellets as an additive to charcoal can increase the time required to boil water. The maximum ratio of pellets to charcoal is 2,4 ; above this value, the boiling of water is delayed. Similarly, the use fuels pellet additive improves the combustion of charcoal by reducing the amount of unburned fuel by more than half. In the case of C2/C1 equal to 2,4 in Figure-4, the amount of charcoal consumed is 390 g, which corresponds to a 33.90% reduction in the amount of fuel for the same amount of useful energy transferred to the pot. The curve showing the variation in useful energy as an efficiency index indicates that there is a proportionality limit beyond which adding more pellets no longer increases the energy transferred to the pot and water. This limit is 1,9, and beyond this proportion, the pellets are no longer effective. One possible explanation is that the ignition temperature of the mixture is no longer reached.

CONCLUSION

The conversion of sugarcane processing residues into pellets to supplement solid fuels illustrates the importance of sustainable management of agricultural resources in Madagascar. The results of TEE water boiling tests reveal a significant reduction in the demand for charcoal, a solid fuel commonly used by households for cooking, thanks to the incorporation of these fuel-supplement pellets. The integration of these practices into the life-cycle assessment of agricultural product utilization paves the way for more sustainable and resilient agriculture, which is essential for the future of Madagascar. Indeed, this innovative approach, which links agricultural productivity and environmental sustainability, addresses the pressing challenges facing the island, such as deforestation and rural poverty.

5. REFERENCES

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