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Energy Efficiency Of Fuel Briquettes Based On Fine Charcoal. Case Of The Region Atsimo Andrefana (Urban Area)

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***Abstract*— The Atsimo-Andrefana region, one of the most energy-consuming in Madagascar, because of the local energy-intensive dishes causing heavy deforestation in this area, is the subject of a study on its energy potential. In view of this and the degradation of local forest resources, the recovery of waste remaining charcoal already used for domestic energy purposes is a local priority. The present research work aims to provide the local population with an ecological and hygienic source of energy from local waste, coal fines. The methodology adopted for the concretization of the present work consists in passing through the various stages of the following activities: bibliographical research and webography, the descent on the ground to see visually the local reality on the availability of the resource to be exploited, the investigations on the local culinary habits as well as the treatment and the analysis of the collected data. The result of this work showed that the population in rural areas has a waste resource of 10%. The average monthly consumption of charcoal per capita is 12.6 kg, or 63 kg/month/household of five people. Their cooking habits are very energy intensive (150 kg/year/capita of charcoal) compared to the national average (100 kg/year/capita of charcoal). The calorific value of fine charcoal briquettes varies according to two important parameters: the binder content and the fine matter content. For a binder content varying from 5% to 10%, the calorific value increases from 4284.77 kcal/kg to 6893.72 kcal/kg. With a binder content of 5%, the calorific value is maximum. The use of these briquettes for a household of 5 persons will allow to reduce the purchase of charcoal by 75.6kg/year and to preserve every year: 0.15ha/household or 5000ha for the Region of eucalyptus forest.**

Keywords*— *fine charcoal, fuel briquette, calorific value, energy efficiency.

I. Introduction

Wood is the main source of energy used by Malagasy households. It represents 92% of the energy supply in Madagascar [4]. Wood energy, particularly firewood and charcoal, has the advantage of being available, easy to store and use, and low cost compared to other cooking energy sources, such as gas or electricity.

Madagascar's forests are under great pressure, with less than 10% of the natural forests preserved. The massive use of charcoal and wood fuels is the main cause. Indeed, 98% of Malagasy households in urban area use, exclusively or partially, charcoal for domestic needs. Moreover, the distribution of available of available forest resources is not balanced. Forest areas near large cities are under heavy pressure to meet urban pressure to meet urban charcoal needs. However, the imbalance between charcoal consumption and the renewal of wood resources through reforestation is constantly increasing. This phenomenon is particularly observed in the Boeny and Atsimo-Andrefana regions, where charcoal consumption exceeds the national average by 50%: 150 kg per year per person in Atsimo-Andrefana, compared to 100 kg per year per person at the national level, while reforestation activities are extremely rare. Eventually, wood resources will disappear by 2030, Atsimo-Andrefana will have exhausted its own.

The development of resources used for energy production contributes to the achievement of several key objectives of this study. These include security of supply, with the primary goal of reducing dependence on imported hydrocarbons (oil and gas), as well as exposure to economic risks; and environmental protection by limiting deforestation, as the development of renewable energy is expected to propel Madagascar's industry into the rapidly expanding low-carbon technology sector.

The scientific and technical objectives of this study are to determine: first, the energy and ecological efficiency of briquettes compared to wood energy; second, to characterize the factors that influence the Calorific value of briquettes; and third, to evaluate the forest area saved in the Atsimo Andrefana region by using briquettes as a domestic energy source instead of wood energy.

II. Methods

1.1 Study area: Atsimo-Andrefana Region

1. Localization [3]:

Located in the southwest of Madagascar, the Atsimo Andrefana Region is in the Province of Toliara. Stretching over a coastline of 800 km, it is composed of 9 districts and 105 communes. The capital of the region is Toliara I, which is about 945 km from the capital of Madagascar. The other districts that make it up are the following: Toliara II, Ampanihy Ouest, Ankazoambo, Benenitra, Beroroha, Betioky Sud, Morombe and Sakaraha. It is limited by the following geographical coordinates:

- latitude: between 21°66' and 24°72' South.

- longitude: between 43°47' and 45°47' East.

It covers an area of 66,502 km^2 (Table I), which represents 11.4% of the total area of Madagascar.

Table I: Area Of Morombe District

District	km^2
Ampanihy (Ouest)	13 253
Ankazoabo	8 834
Benenitra	4 741
Beroroha	6 723
Betioky (Sud)	10 079
Morombe	7 109
Sakaraha	8 160
Toliara I	282
Toliara II	7 321
Total région	66 502

Source : CREAM, Monographie 2013

2. Urban population and urbanization rate [4]:

The population is the main actor of a sustainable development. They will also be the primary beneficiaries. Knowledge of the state of the population, in terms of its size, structure and living conditions, helps to measure the efforts to be undertaken to reduce poverty and support development. In addition, the state of the population describes its capacity in terms of human resources and the potential for local and regional economic activities.

As regards the weight of the urban population in the total population of each of each region (Table II), the logic that emerges follows from the observation.

Table II: Number And Share Of The Population Of Urban Municipalities In The Total Population And In The Urban Population

Region	Municipality	Number of population of the municipality	Share (%) of the population of the municipality of the urban population	Share (%) of the population of the municipality in the total population of Madagascar	Share (%) of the population of the municipality in the total population of the region
Atsimo Andrefana	Toliara I	168 756	3,4	0,7	9,4
	Morombe	22 625	0,5	0,1	1,3
	Betioky Atsimo	25 612	0,5	0,1	1,4
	Ampanihy Ouest	38 000	0,8	0,1	2,1

Source: MDG - INSTAT - RGPH2018

According to the results of the 2010 Periodic Household Survey (EPM 2010), the average number of people in a household in the Atsimo Andrefana Region of 4.8 equals that at the national level. Like the national situation, rural households are composed of more individuals (4.8) than urban households (4.6) [6]. This difference of 0.2 is less than the 0.4 observed at the national level.

1.2 Methodological Approach

The methodology adopted in this research work is both qualitative and quantitative. Its concretization in the long term requires a priori to pass through the chronological order of the following various activities: capitalization of the data relating to the topic of research, descent in the zone of studies to see visually the local reality on the availability of the resource to be exploited, the investigations on the local culinary habits, the collection of resource (sample) for the laboratory work allowing to manufacture briquettes containing rice husk and to determine the physicochemical characters. The analysis and processing of the related data completes this research work.

1. *Data capitalization*

To carry out this research work in good condition, the capitalization of various data corresponding to the research theme is a priority. Several documents were consulted, including the Regional Development Plan (PRD) of the Atsimo Andrefana Region, the Communal Development Plan (PCD) of Toliara I and the city of Morombe, and studies and research on regional and district energy, food, and forestry resources. Contacts were made to learn about the different culinary activities and local lifestyles.

2. *Laboratory work to determine the calorific value*

a. Manufacture of briquette

The manufactured briquettes were based on two main factors:

- Variation of binder content ranging from 5%, 8% and 10%;

- Variation in fine matter content of 25%, 50% and 75%. It should be remembered that rice husk has a high mineral content and a low dry matter content.

b. The binder and the choice of binders

Binders are used to agglomerate the raw materials to facilitate the compaction of the solid fuel. Binders play an important role in the quality of the fuel. They can make it brittle, slow down combustion, increase smoke...

Generally, the binders come from organic waste such as :

o Paper and cardboard waste,

o Flour waste,

o Cassava starch,

o Corn starch.

We can also use clay, and synthetic binders such as kerosene, heavy oil, waste oil (by-product of the oil industry). But we choose the cheaper binders to avoid the increase of the blow of our finished product.

Binders are used only to produce large solid fuels such as logs or chips, briquettes.

- Clay:

The clay is constituted by minerals and trace elements as: silica, aluminum silicate, magnesium, calcium, iron, phosphorus, sodium, potassium, copper, zinc, selenium, cobalt, manganese..., that it contains in variable proportions according to the place of origin.

It comes in different colors: green, red, blue, yellow, gray, white, pink ... its color varies depending on the iron oxides it contains. Some are used as natural medicines for example the green clays. And it can be found in the rice fields, in the riverbank....

The removal of clay in the rice field does not pose a problem for the fertility of soil because the proportion of its mass compared to the mass of beetle is very small. The value of the clay binder is about 10% in a briquette. In addition, the briquette ash will be used as a fertilizer supplement for a sandy soil.

The chemical characteristic of clay: it is a coagulant agent, and obviously allowing to play the role of binder.

- Paper and cardboard:

Concerning paper and cardboard, it is also constituted of celluloses and lignins a natural binder of wood. Then they behave as a binder when water is added to them to form a paste. The cardboards are everywhere in the household and industrial waste, waste of commune. In Madagascar, there are SMEs that process paper and cardboard wastes, but it is still unexpected because the population continues to reject them in the surroundings.

The use of this binder increases the calorific power, but it makes also the presence of smoke in a carbonized fuel. Indeed they contain volatile matters.

- Heavy oil, waste oil, other petroleum refining by-products:

Oils, such as heavy oil, waste oil and other by-products of petroleum refining, can be used as binders or additives to enhance the calorific value of the briquette. But when used, they can cause disadvantages. Like all petroleum products, during the combustion reaction, they release gases that can pollute the environment other than CO_2.

- Wheat flour, corn flour, cassava starch:

It is a powder made up of starch from 68 to 72%, water, then gluten, sugar, and fat, and a trace of cellulose. Thanks to the starches, this mixture has the capacity to act as a binder when water is added. Wheat flour is sold at 2400Ariary per kilo. Cassava starch is sold at 2300Ariary per kilo and corn flour at 2600Ariary per kilo. As this type of binder is not free, it is used only as an additive to optimize the quality of the fuel.

According to our experience, the presence of this product makes the briquette more and more unbreakable, even if it is used in small proportion.

In our case, we have chosen cassava starch as a binder for our fuel briquette because of its availability and affordability.

c. Determination of the physicochemical characteristics of manufactured briquettes

To determine the physicochemical characteristics of a sample of briquettes, our approach consists in calculating respectively:

- the Humidity (H);

- the ash content (Ce);

- the content of volatile matter (MV);

- and by deduction the content of fixed Carbon (C.F)

- the determination of the lower heating value (LHV) and the HCV

Our objective is to know the physicochemical characteristics of these briquettes based on rice husk allowing to dictate on the quality of the briquettes: a good fuel or not.

- Humidity (H):

Dry the container in an oven at 105°C and cool in the desiccator, then weigh.

20g (weighed to the nearest 0.1 mg) of charcoal are put into a tare box previously dried at 105°C, cooled and weighed. Spread the charcoal evenly in the container and place it in the oven heated at 105°C for 1 to 1.5 hours. Remove and place in the desiccator for 30 min then weigh to the nearest 0.1 mg

Calculation of the humidity from the loss of mass compared to the initial mass.

- Volatile matter (MV):

Determine the volatile matter index or VMI which is the mass loss expressed as a percentage, obtained under standard conditions, after pyrolysis heated in the absence of air, disregarding the mass loss due to evaporation at 550°C.

- Ash content (Ce):

Combustion of a test sample in a muffle furnace at 850°C. The ash content is the amount of residue, related to the mass of the test sample.

- Fixed carbon rate (TCF):

This is the percentage of the remainder between ash content, moisture and volatile matter index

$$TCF= 100-(H+Ce+IMV) \qquad (1)$$

- Lower calorific value (LCV):

Adoption of the formula of CASSAN:

$$LCP= (100-Ce) * 80 \text{ in kcal/kg} \qquad (2)$$

- Higher calorific Value (HCV)

Dulong and Vandralek's approach [1]

$$HCV = 3,6 \times (108 \times C) \text{ in kJ.kg-1} \ (3)$$

C: Carbon content

- Processing of the result:

The use of software Surfer 10 to have a graph representing the calorific value with the composition of the briquettes.

3. *Energy efficiency of 5%, 8% and 10% briquettes in binder compared to wood energy (Charcoal, wood)*

To determine the effectiveness and energy efficiency of the briquette bales, the following tests must be passed:

- Drop test: This test is a simulation of the stresses experienced by the fuel during transport and handling. It is a universally recognized test for assessing the friability of fuels. This test shows a clear correlation between the binder content and the ability of the fuel to resist crumbling. The test consists of dropping from several heights all the fuels to be tested and determining the behavior of each fuel from each drop height.

- Rotating Drum Test: This test is a simulation of the shocks that can occur to the fuel regardless of the rotational motion experienced by the fuel and the conditioning mode adopted before the fuel flows from production to consumers. This test consists of introducing the fuel into a rotating drum apparatus by varying the number of revolutions of the apparatus while fixing the duration of the test at 1 minute.

- Splitability test: The splitability test is the ability of the briquettes to be split. It is a convenience of use and an important parameter not negligible for the consumers. This test consists in splitting the fuel whatever the desired size.

- Flammability test: The flammability test consists in assessing the flammability of the briquettes compared to other usual fuels. The flammability test is a technical parameter that allows to judge the fuel in advance on its calorific value. The better the fuel burns, the bluer the flame, showing that the fuel is well burned and the unburned and losses are very low. On the other hand, if the flame is yellowish and with a low proportion of blue color, which shows that the unburned is important and other factors must be considered to avoid such a situation. The boil water test can be used to assess the above situation.

- Boil Water Test (BWT): To evaluate the performance and energy efficiency of briquettes alone or in comparison with other commonly used fuels such as charcoal and firewood, it is necessary to carry out water boiling tests at high and low power (real condition of use of fuels and fireplaces by households) and to assess from these tests the flammability time (ignition time) of each fuel, their behavior with respect to the fire and the fireplace used (improved fireplace) as well as the possibility of using the unburned fuel (fuel remaining after a BWT) for a new cooking

The fuels (wood waste briquettes, charcoal, and firewood) were tested with the most used stove in Madagascar: improved stove (fatana mitsitsy medium model). The performance of the briquettes will be deduced from the result of the tests by considering the various appreciations brought relative to the time of flammability, to their behavior in front of the fire and the hearth as well as to their aptitude to be able to reuse the unburned resulting from each test of boiling water.

- Test of Controlled Cooking (TCC): It is a test universally used to determine the capacity of the briquettes to cook the different culinary dishes most consumed in the country.

III. Results And Discussion

1.3 Lower heating value and higher heating value

The result of survey and data capitalization provided a waste 10% of consumption. The average monthly consumption of charcoal per capita is 12.6 kg, or 63 kg/month/household of 5 people. Their cooking habits are very energy intensive compared to the national average (100 kg/year/capita in charcoal). The lower calorific value of briquettes varies from from 4284.77 kcal/kg to 6893.72 kcal/kg for a binder content (cassava starch) ranging from 5% to 10%.

According to the different binder contents (6%, 8%, 10%) of briquettes, the calorific value is summarized in the following figure (Fig.1.).

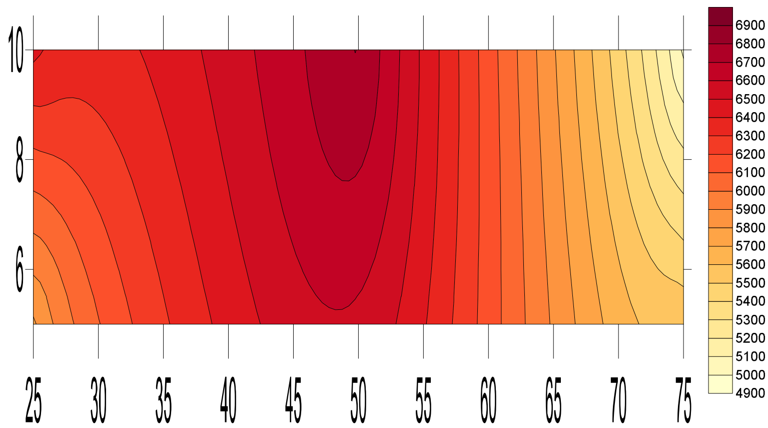

Fig. 1. Calorific value of different compositions of briquettes (With Surfer 10)

This figure 1 informs the calorific value of fine charcoal briquettes according to the content of fine matter and binder of each briquette. It should be noted here that fine charcoal briquettes have a calorific value close to that of charcoal. According to the content of fine and bulk material, when both are balanced at 50%, the calorific value is maximum.

1.4 Comparative study of calorific value and fuel consumption (charcoal, fine coal briquettes)

According to the household survey, 10% of the charcoal bags purchased are unused waste. The following Table III shows a comparison of the charcoal savings of each household if they reuse their waste.

Table III: Comparison Of Heating Value Of Charcoal And Fine Charcoal Briquette Fuel

Combustible	Charcoal (moyen)	Blinder 5%
Lower Calorifique value (kcal/kg)	6700	6400
Annual consumption for a household (kg/an)	750	800

If the household choose to use their waste, they can save 10% of their usual consumption.

1.5 Environmental impact of using briquettes instead of charcoal for a household of 5 people living in the study area

The substitution of charcoal at the household level has several advantages in several areas:

- At the household level, the budget allocated to domestic fuel will be reduced and this will allow them to improve their source of income and their living conditions by eliminating the fumes emitted using wood energy.

- At the level of the study area, the forest resources still available in the study area will be preserved.

- At the national level, the environment in general is healthy and ecological.

The following Table IV attempts to provide information on the conservation of forest resources due to the replacement of wood energy by rice husk briquettes for a household of five people for a period of one year, taking into account the carbonization yield (10%) and the productivity of eucalyptus wood (7000 kg/ha).

Table IV: Annual Savings In Charcoal And Preserved Forest For A Household Of 5 People Using Fuel Briquettes Instead Of Charcoal

Heading	Charcoal (kg)	Briquette with 10% waste (kg)
annual availability for a household of 5 people (kg/year)	750	75
Volume of wood preserved per year at the substitution of coal by briquette (ha) for a household/year	0,15ha/an	

This table 4 shows that if the 5-person household uses only charcoal, it destroys 1.071 ha of eucalyptus forest each year. However, if they reuse charcoal fines and charcoal briquettes, they will preserve 0.15 ha of eucalyptus forest each year.

Considering the number of the total population in urban areas of the Atsimo Andrefana region in RGPH3 of 2018 [4]., the area preserved goes up to 5 000 ha/year. The Table V below shows the forest in relation to the total population in urban areas of the briquettes.

Table V: Annual Savings By Substitution Of Charcoal With Briquettes As A Percentage Of The Total Population In Urban Areas

Percentage of the population	20%	50%	75%
Number of populations	50998	127496	191244
Number of households	10199	25499	38248
Preserved forest in a year (ha)	1020	2550	3825

1.6 Energy efficiency of briquettes compared to charcoal and firewood

This part tries to show the efficiency of briquettes at different concentrations compared to charcoal and firewood. To do this, we must go through the following activities:

- Conduct a fuel consumption test
- Calculate the power of each fireplace using the briquettes.
- Evaluate the efficiency of each fireplace using briquettes.
- Make a comparative study of the results obtained to classify each with wood energy.

The Table VI attempts to summarize the results of the fuel consumption test (briquette, charcoal, firewood), the power of the household using each type of fuel, and the energy transmitted to the household by the fuel, as well as the respective efficiency.

Tableau VI: Summary Of The Results Of The Different Tests: Consumption, Power, Efficiency And Transmitted Energy

Fuel	Average consumption (kg/h)	Boiling time (h)	Power (W)	Energy transmitted by the furnace (j)	Efficiency (%)
Briquette 5%	0,37	0,69	700,99	1883835	25,07
Briquette 8%	0,42	0,71	728,76	1883835	27,27
Briquette 10%	0,40	0,75	697,72	1883835	29,53
Charcoal	0,34	0,70	636,23	1943824	23,74
Wood	0,54	0,84	574,73	1744196	21,04

Obtained efficiency varies from 21 to 30 %.

IV. Conclusion And Perspectives

Considering the results of this research work, the substitution of wood energy, particularly charcoal, at the household level is beneficial in several areas, not only for the households themselves but also for the study area and the country. According to the comparison between charcoal and fine charcoal briquettes, we obtained an energy efficiency between 21 and 30%.

For households affected using briquettes, the substitution of charcoal by this fuel is interesting because it will allow respectively to preserve every year and per household of 5 persons, 0.15 ha of eucalyptus forest.

This is a significant benefit for them because it is a forced saving influencing their living condition. For the study area, the valorization of waste which has no previous use presents a particular advantage because not only an alternative fuel to wood energy but also a contribution to the reduction of greenhouse gases emitted by cooking with wood energy in households.

It is therefore a contribution of the population residing in the study area to the reduction of the global warming potential (GWP) on the one hand and on the other hand to the preservation of forest resources that can initiate the abundance of rainfall in the study area.

Finally, for the country, this preservation of forest resources ranging from 0.15ha reduction per household per year depending on the composition of the binder, is of particular interest because the environment and energy go hand in hand and in synergy. The fact of preserving the environment is one of the priorities for the country to give back to Madagascar its former image: "green island, island with perfume".

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