FACTORS INFLUENCING ICP, SCP AND ENERGY EFFICIENCY OF FUEL BRIQUETTES FROM WOOD PROCESSING WASTE FROM MORAMANGA DISTRICT, ALAOTRA MANGORO REGION.

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ABSTRACT

The Moramanga district has long been known for its wealth of forest resources on the one hand and the existence of the state-owned company FANALAMANGA and several free zone enterprises working in the field of forest exploitation and export on the other. These companies generate a lot of wood processing waste every day: planing shavings, sawdust ... etc. which are left in the open air through the open spaces in the district's chief town. The purpose of this work is on the one hand to valorise these forest wastes for energy purposes by producing combustible briquettes based on planing shavings and sawdust and on the other hand to determine the Lower Calorific Value (LCV) and the Higher Calorific Value (HCV) of these combustible briquettes. The aim of this work is therefore to have an alternative fuel capable of substituting wood energy. Two important parameters were studied: the binder and the fine materials, varying their respective contents. The result of this research work showed that there is a correlation between the binder content and that of the fine materials used. The briquette based on planing chips with 5% binder is the most efficient as it has a high Lower Calorific Value (LCV: 6897.66 kcal/kg, a power of 745.7 W, an efficiency of 39.5% compared to wood energy and other fuel briquettes produced and studied.

Keyword: *wood processing waste, Moramanga district, energy recovery, fuel briquette, energy efficiency, wood energy.*

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1. INTRODUCTION

Industrial activities generate significant amounts of waste that are both a nuisance to the environment and a loss of recyclable materials, yet they are resources that can still be recovered for various purposes. Their recovery by various biotechnological or technological processes is a solution of choice insofar as it not only contributes to the elimination of environmental pollution, but also makes it possible to produce substances with high added value and bioenergy.

The Moramanga district has long been known for its wealth of forest resources and for the existence of the state-owned company FANALAMANGA, which works in the field of forestry, as well as several free zone enterprises working in the field of forest product exports. These companies generate a lot of wood processing waste every day: planing shavings, sawdust, etc. which are left in the open almost everywhere and litter several places in the district's chief town. It is within this framework that the idea of this research work on the theme: "Optimisation of a mixture of organic matter and other mineral matter to make coal briquettes" was born.

Several questions arise, among others:

- Is it possible to produce environmentally friendly domestic fuel from these planing chips and sawdust in an appropriate mixture?
- What is the ideal proportion of fuel briquette produced from these forest wastes?
- Are these fuel briquettes based on planing chips and sawdust suitable as a substitute for wood energy?
- What type of fuel briquette is most suitable as a substitute for charcoal or firewood?

The aim of this research work is to make fuel briquettes based on planing chips and sawdust from a suitable mixture of organic and mineral material.

2. METHODOLOGIES

2.1. Study areas: District of Moramanga

The Moramanga district was chosen as the study area because of the importance of forest resources in the area on the one hand and the existence of the state company FANALAMANGA and several free zone companies working in the timber and timber products sector on the other.

This section provides information on the geographical characteristics, climate, demographic situation and forestry in the Alaotra Mangoro region.

2.1.1. Geographical location

The town of Moramanga is an unavoidable stop on the National Road N°2. It is located in the Middle East region of Madagascar, in the south central part of the Alaotra Mangoro region.

The Alaotra Mangoro Region is limited:

- In the North-East by the districts of Mandritsara, Port Berge and Befandriana- North: Sofia Region
- In the North-West by the District of Tsaratanana : Betsiboka Region
- To the West by the Districts of Anjozorobe and Manjakandriana: Analamanga Region
- In the South-West by the Districts of Andramasina and Ambatolampy: Analamanga and Vakinankaratra Regions
- To the South by the District of Marolambo: Antsinanana Region
- To the South-East by the Districts of Tanambao Manampotsy and Vatomandry: Antsinanana Region
- To the East by the Districts of Brickaville and Toamasina II: Antsinanana Region
- In the North by the Districts of Fenerive EST and Soanierana Ivongo: Analanjirofo Region.

The region as a whole represents 41% of the area of the Autonomous Province of Toamasina of which it is part and the 5.21% of the whole island. It is subdivided into two :

- the Alaotra including Ambatondrazaka, Amparafaravola and Andilamena.
- the Mangoro including Moramanga and Anosibe An'Ala

Table 1: geographical location of the town of Moramanga

Country	Madagascar
Region	Alaotra Mangoro
Province	Toamasina
District	Moramanga
Contact details	18°57' sud, 48°14' Est
Altitude	980 m

This table informs the geographical parameters allowing to locate geographically the district of Moramanga

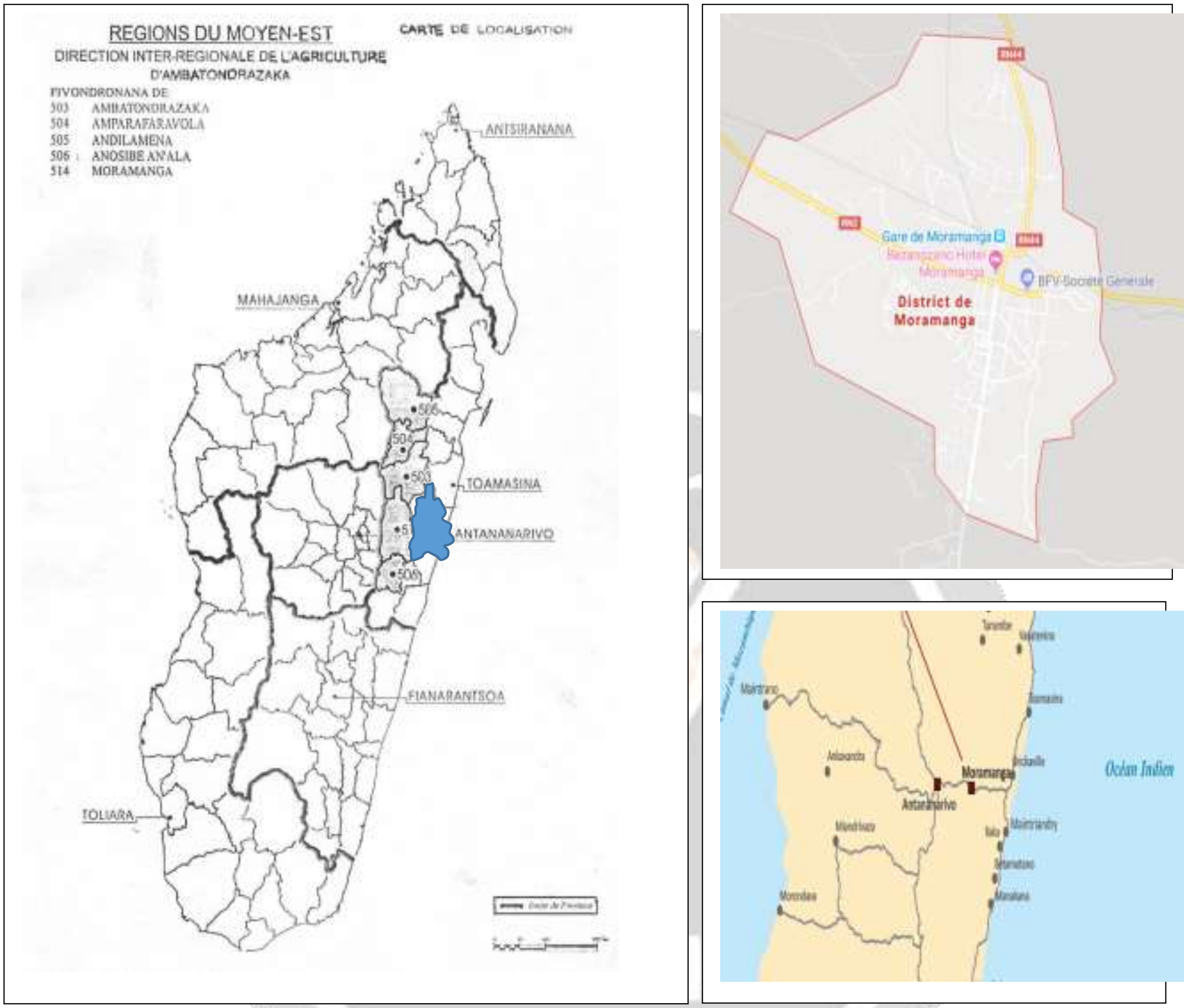

Figure 1: Location map of the town of Moramanga

2.1.2. State of forest cover in Madagascar and in the Alaotra Mangoro région : :

2.1.2.1. State of forest cover in Madagascar

In reality, it is difficult to evaluate the forest cover according to the results of the National Forest Ecological Inventory (IEFN), based on satellite data in the national forest map on a scale of 1/100,000, Malagasy natural forests cover about 22% of the territory's surface area, i.e. 260,000 ha, of which 265,000 ha are reserved for plantations. The Malagasy forests are characterized by the presence of very varied fauna and flora and their densification estimated at 80% of the total forest which, in fact, is a unique ecological heritage in the world. This heritage is seriously threatened by the accelerated ecological degradation caused by deforestation and subsequent erosion.

2.2. Laboratory work to determine Calorific Value (ICP/SCP):

2.2.1. Determination of the physico-chemical properties of briquettes of sawdust and planing shavings with different binder contents (4%, 5%, 10%) and different fine material compositions

Experimental work consists respectively of experimenting with sawdust briquettes and then with planing shavings briquettes. These tests include respectively:

- The determination of the physical and chemical characteristics of sawdust and shavings briquettes with different binder and fine material compositions;
- The determination of PCI (min, max) and PCS (min, max) of each composition in binder or fine material;

- Carrying out the various efficiency tests and the energy efficiency of each composition (binder, fine material) of sawdust and planing chips briquettes;
- the evaluation of the efficiency and energy efficiency of sawdust and shavings briquettes of different composition (binder, fine) in relation to an improved furnace with a well-defined yield;

2.2.1.1. Determination of the physicochemical characteristics of sawdust and planning chip briquettes

In order to determine the physico-chemical characteristics of sawdust briquettes and planning chips, our approach consists in calculating for each wood briquette and planning chip respectively:
- the moisture content (H);
- the ash content (Ce);
- the volatile matter (Vm) content;
- and by deduction the fixed carbon content (F.C).
- the calculation of the Lower Calorific Value (LCV) and the PCS

Our objective is to know the physicochemical characteristics of these briquettes in order to be able to dictate on the quality of the briquettes: a good fuel or not.

a) 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 briquettes (sawdust, shavings) are placed in a tare box previously dried at 105°C, cooled and weighed. Spread the briquette (sawdust, shavings) evenly in the container, and place it in the oven heated to 105°C for 1 h to 1.5 h. Remove and place in the desiccator for 30 min and weigh to the nearest 0.1 mg.

Calculation of the humidity from the loss of mass in relation to the initial mass.

b) Volatile matter (VMI):

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

c) Ash content (C):

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

d) Fixed carbon rate (FCR):

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

TCF= 100-(H+C+IMV)

2.2.1.2. Determination of PCI (min, max) and PCS (min, max) of each composition in binder or fine material

The ICP (min, max) and the PCS (min, max) will be deduced from the following CASSAN empirical formula:

ICP= (100-C)* 80 in kcal/kg.

For the calculation of PCS, the following formula is used:

PCS=3.6* (108xC) in kj/kg, where: "c": total carbon

2.2.1.3. Carrying out various performance tests on briquettes (sawdust, shavings) with a different binder and fine material content compared to wood energy (coal, wood).

In order to determine the effectiveness and energy efficiency of briquettes (sawdust, shavings), the following different tests must be carried out:
- Drop test
- Rotating Drum Test
- Cutting test:
- Flammability test:
- Water Boiling Test (WBT)
- Controlled Cooking Test (CCT):

2.2.1.4. Approach adopted for evaluating the effectiveness and energy efficiency of briquettes (sawdust, shavings) in relation to a well-defined improved efficiency furnace.

The effectiveness and energy efficiency of briquettes (sawdust, shavings) in relation to other fuels depends on the result of Water Boiling Tests (WBT), which determine the consumption of briquettes (sawdust, shavings) and other common fuels (charcoal and firewood) by the use of the most commonly used fireplace : the Fatana Mitsitsy (Improved Fireplace) by using the same kettle under the same operating conditions (same quantity of briquettes and the same kettle for each test).

Moreover, it is from this Water Boiling Test (WBT) that the parameters for each fuel can be evaluated:

- Flammability test or ignition time ;
- Fire behaviour;
- The duration of water boiling ;

- The possibility of using the unburnt fuel (fuel remaining during a TEE) for a new firing.

The methodology adopted for carrying out Water Boiling Tests (WBT) using the most commonly used furnace (Fatana Mitsitsy) consists of carrying out Water Boiling Tests (WBT). These WBTs allow to evaluate the consumption of briquettes (sawdust, shavings) compared to other commonly used fuels (charcoal, firewood).

The realization of these water boiling tests consists in grouping the activities to be undertaken in the form of Test Groups [GT(x)i,j] with respectively briquettes of planning chips with binder content (5%, 7%, 8%, 10%), then briquettes of sawdust with binder content (5%, 10%).

a) Briquettes of planning chips of : 5%, 7%,8%,10%

The following figure summarizes the test group for planing chips

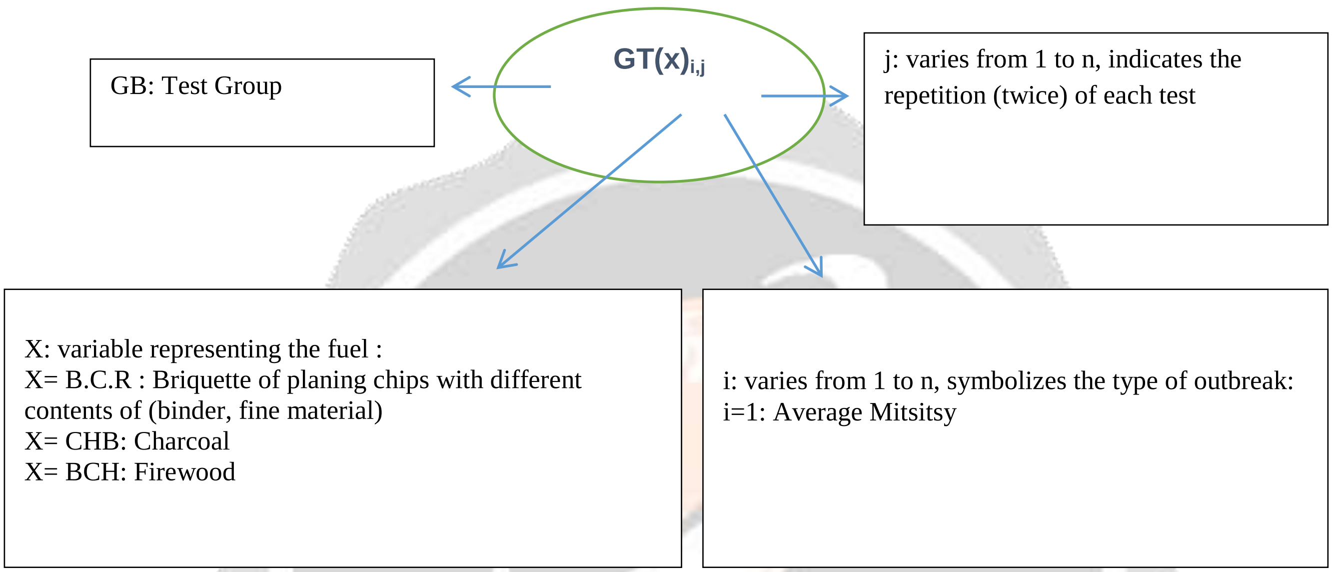

Figure 2: Planning Chip Test Group

These test groups [GT(x)i, j] are distributed as follows:

- The test group using the Planing Chip Briquette [GT(B.C.R) i, j] with the Mitsitsy furnace comprising: GT (B.C.R (5%))1, j composed by the two tests: GT (B.C.R (5%))1,1 to GT (B.C.R (5%))1,2.
- The test group using the Planing Chip Briquette [GT(B.C.R) i, j] with the Mitsitsy heater comprising: GT (B.C.R (7%))1, j composed by the two tests GT (B.C.R (7%))1,1 to GT (B.C.R (7%))1,2
- The test group using the Planing Chip Briquette [GT(B.C.R) i, j] with the Mitsitsy furnace comprising: GT (B.C.R (8%))1, j composed by the two tests GT (B.C.R (8%))1,1 to GT (B.C.R (8%))1,2
- The test group using the Planing Chip Briquette [GT(B.C.R) i, j] with the Mitsitsy furnace comprising: GT (B.C.R (10%))1, j composed by the two tests GT (B.C.R (10%))1,1 to GT (B.C.R (10%))1,2
- The charcoal test group [GT(CHB) i, j] with the Mitsitsy fireplace comprising: GT(CHB)1, j composed by the two tests GT(CHB)1,1 to GT(CHB)1,2
- The firewood test group [GT(BCH)i,j] comprising the:GT(BCH)1,j composed by the two tests GT(BCH)1,1 to GT(BCH)1,2

These tests are represented in the form of a matrix table as follows

Table 2: Matrix representation of the 6 test groups, fuels and fireplaces

Fireplace / Fuel	Mitsitsy Moyen Model (CNRIT)
B.C.R (5%)	GT (B.C.R (5%))$_{1,\,j}$
B.C.R (7%)	GT (B.C.R (7%))$_{1,\,j}$
B.C.R (8%)	GT (B.C.R (8%))$_{1,\,j}$
B.C.R (10%)	GT (B.C.R (10%))$_{1,\,j}$
CHB	GT(CHB)$_{1,\,j}$
BCH	GT(BCH)$_{1,\,j}$

According to this matrix table, the tests are made for 6 test groups with two replicates each,
b) Sawdust briquettes of: 5% and 10%.
The following figure summarizes the test group for sawdust

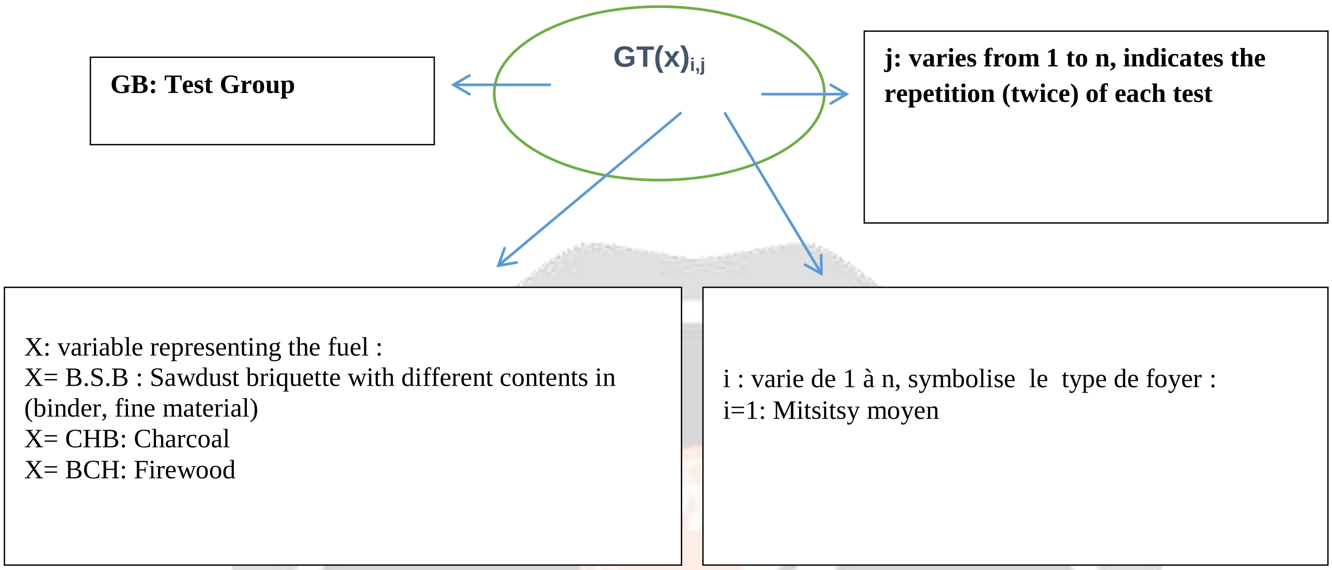

Figure 3: Sawdust Test Group

These test groups [GT(x)i, j] are distributed as follows:

- The test group using the Sawdust Briquette [GT(SBB) i, j] with the *Mitsitsy* fireplace comprising: GT (SBB (5%))1, j composed by the two tests GT (SBB (5%))1,1 to GT (SBB (5%))1,2.
- The test group using Sawdust Briquette [GT(S.B.B) i, j] with the *Mitsitsy* fireplace comprising: GT (S.B.B. (10%))1, j composed by the two tests GT (S.B.B. & at(7%))1,1 to GT (S.B.B. (10%)1,2
- The charcoal test group [GT(CHB) i, j] with the *Mitsitsy* fireplace comprising: GT(CHB)1, j composed by the two tests GT(CHB)1,1 to GT(CHB)1,2
- The firewood test group [GT(BCH)i,j] comprising the :GT(BCH)1,j composed by the two tests GT(BCH)1,1 to GT(BCH)1,2

These tests are represented in the form of a matrix table as follows
Table 3: Matrix representation of the 6 test groups, fuels and fireplaces

Fireplace / Fuel	Mitsitsy Moyen Model (CNRIT)
B.S.B (5%)	GT (B.S.B (5%))$_{1, j}$
B.S.B (10%)	GT (B.S.B (10%))$_{1, j}$
CHB	GT(CHB)$_{1, j}$
BCH	GT(BCH)$_{1, j}$

According to this matrix table, the tests are made for '4 test groups with two repetitions each.

2.2.1.5. Evaluation of the effectiveness and energy efficiency of briquettes made of sawdust and planing chips of different composition in (binder, fine) compared to an improved hearth of well-defined yield

(a) Calculation method for the determination of the fuel consumption (kg/h) of sawdust and shavings briquettes of binder and fine material composition as well as charcoal and firewood

The average fuel consumption (kg/h) shall be determined from the average values from the water boiling test groups [GT(x)i,j].

The formula used to calculate the average fuel consumption (kg/h) will be as follows:

AVERAGE FUEL CONSUMPTION = Fuel consumed: Duration of combustion $[\frac{Kg}{h}]$

FUEL CONSUMED = original fuel - fuel (uneaten + nested)

DURATION OF COMBUSTION = Boiling time + 1//4 of an hour

The average fuel consumption (kg/h) is therefore equal to the value of the ratio of the average quantity of fuel consumed to the average boiling time of water plus 15 minutes. Thus, each test group will have its own average fuel consumption per unit of time.

At each test, we will try to determine:

- The power of each fireplace by using sawdust briquettes or planning shavings of different binder composition;
- The efficiency or output of each fireplace by using briquettes of sawdust or planning shavings of different binding composition; o The efficiency or output of each fireplace by using briquettes of sawdust or planning shavings of different binding composition.
- the fuel consumption (in kg/h) of sawdust briquettes or planning shavings of different binding composition and that of charcoal and firewood.

The realization of each activity will depend respectively on the study materials, the raw materials (fuels, water) available and the technicians for the realization.

a) The capacity of each fireplace by using sawdust briquettes or planing shavings with a different binder composition

Power is defined as the derivative of energy with respect to time.

$$P(t) = \frac{dE(t)}{dt}$$

-In our case, it is a question of determining a constant heat output value. We can therefore write;

$$P(t) = \frac{Q}{t}$$

Where: Q: represents the useful energy, i.e. the energy transmitted from the hearth to the pot,
and "t": the time or total duration of the test.

The useful energy is a function of the amount of heat accumulated by the water between its initial temperature and boiling temperature and the latent heat of the evaporated water:

$$Q = C_{eau} \times M_{eau\,initiale} \times (T_{ébullition} - T_{initiale}) + L_{eau} \times (M_{eau\,initiale} - M_{restante})$$

And as a result:

$$P = \frac{C_{eau} \text{ x } M_{eau\ initiale} \text{ x } (T_{ébullition} - T_{initiale}) + L_{eau} \text{ x } (M_{eau\ initiale} - M_{restante})}{t}$$

Where:

C_{eau}	Mass heat of the water	4180 J/kg. °C
L_{eau}	Latent heat of vaporization of water	2260000 J/kg
$M_{eau\ initiale}$	Initial mass of water	2,5kg
$M_{eau\ restante}$	Mass of water remaining after the test	Kg
Q	Energy transmitted by the hearth to the kettle	Joule
t	Total test time	Seconde
P	Power of the hearth	Watt

b) The efficiency (yield) of each fireplace through the use of sawdust briquettes or planing shavings with a different binder composition

The evaluation of the efficiency of the household is based on the yield calculation.

By definition, the efficiency is the ratio between the energy transmitted from the furnace to the kettle and the energy contained in the fuel burned.

Let it be :

$$\eta = \frac{Q}{PC_{Combustible} \times P_{Combustible}}$$

$$\eta = \frac{C_{eau}\ x\ M_{eau\,initiale}\ x\ (T_{\acute{e}bullition} - T_{initiale}) + L_{eau}\ x\ (M_{eau\,initiale} - M_{restante})}{PC_{Combustible} \times P_{Combustible}}$$

3. RESULTS

3.1. Planing chip briquettes (BCR)

A-CALCULATION OF THE LOWER CALORIFIC VALUE (ICP)

This research work investigated the influence of two major factors influencing the ICP of planing chip briquettes: the binder and the fines.

3.1.1 Influence of binders (5%, 7%, 8% and 10%) on ICP chip briquette

According to the different binder contents (5%, 7%, 8% and 10%) of the planing chip briquettes, the PCI (min, max) per binder composition is summarized in the following table

Table 4: ICP (min, max) of different compositions when binding briquettes of planing chips

Binder (%)	PCI Min	PCI Max
5	5189,181	6897,666
7	5420,739	6354,306
8	5418,751	5982,750
10	6100,782	6404,0737

This table informs the ICP (min, max) of the planing chip briquettes according to the different binder contents.

a) ICP evolution curve according to binder content

The following figure gives the value of the ICP according to the different contents by binding

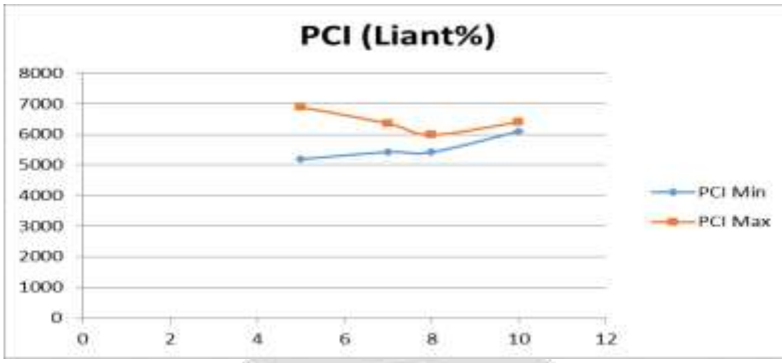

Figure 4: ICP value of planing chip briquettes

This curve shows that PCI is very important for a binder content of 5%.

b) Medium ICP planing chip briquettes according to binder content

According to the experimental tests carried out in the laboratory of the Energy Department of the National Centre for Industrial and Technological Research (CNRIT), the composition of each sample is not the same from one test to another, therefore, two values (minimum, maximum) were obtained for the result of : ICP

Table 5: ICP Average briquettes of planing chips (5%,7%,8%,10%) in binder

Binder (%)	PCI Min	PCI Max	PCI Moyen
5	5 189,18	6897,66	6 043,42
7	5420,73	6354,3	5887,515
8	5418,75	5982,75	5700,75
10	6100,78	6404,07	6252,425

This table also informs about the average minimum and maximum ICP of the planing chip briquettes.

3.1.2 Influence of fine composition materials (25%, 36%, 50%, 73% and 80%) on the ICP planing chip briquette.

For different contents of the fine particles making up the briquettes of planing chips, the results of the experimental tests in the laboratory are summarized in the following table

Table 6: Values of ICP min, max for different contents of fine material

Fine%	PCI Min	PCI Max
25	5189,18	6251,28
36	5420,73	6354,30
50	5627,73	6404,07
73	5418,75	5982,75
80	5740,20	6897,66

This table informs the ICP (min, max) of the planing chip briquettes according to the different fine material contents.

a) ICP evolution curve according to fine matter content

The following figure shows the evolution of the ICP according to the different fine matter contents.

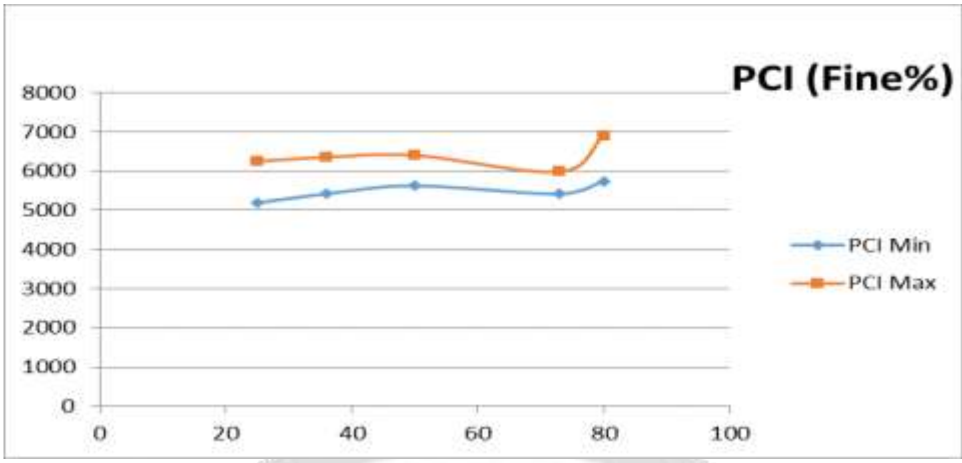

Figure 5: Evolution of ICP according to the different fine matter contents

This curve shows that the higher the value of the fine matter content, the higher the ICP. In this context, the fine matter content of 80% is the interesting value for a production that is competitive with wood energy.

(b) PCI medium briquettes planing chips according to fine material content

The values obtained in the different ICP determination tests are not the same from one test to another. The following table gives the average ICP values for each fine matter content.

Table 7: Average ICP for planing chip briquettes

Fine%	PCI Min	PCI Max	PCI Moyen
25	5189,18	6251,28	5720,23
36	5420,73	6354,30	5887,51
50	5627,73	6404,07	6015,9
73	5418,75	5982,75	5700,75
80	5740,20	6897,66	6318,93

This table shows the average ICP value according to the fine matter content.

B-CALCULATION OF THE GROSS CALORIFIC VALUE (PCS)

Two main parameters have been studied for the determination of the Gross Calorific Value. These two parameters studied are: the binder and the fine matter.

3.1.3 Influence of the binders (5%, 7%, 8% and 10%) on the PCS chip briquette

Four different binder contents were investigated to determine the PCS of planing chip briquettes. The following table summarizes the PCS value according to the binder contents.

Table 8: PCS value as a function of binder content

Binder (%)	PCS Min	PCS Max
5	6333,59	7254,40
7	6815,80	6832,55
8	6413,45	6450,11
10	7066,32	7084,64

This table summarizes the PCS value of the planing chip briquettes according to the change in binder content.

a) PCS evolution curve according to binder content

The following figure shows the evolution curve of the PCS according to the binder content.

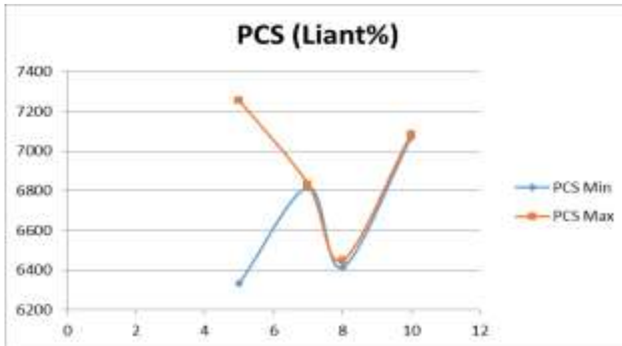

Figure 6: Evolution of PCS according to binder content

This curve shows that PCS is important for a binder content of 5%.

3.1.4 Influence of the fine composition materials (25%, 36%, 50%, 73% and 80%) on the PCS planing chip briquette

For different contents of the fine particles in the briquettes of planing chips, the results of the laboratory tests are summarized in the following table

Table 9: Values of PCS min, max for different fine material contents

Fine%	PCS Min	PCS Max
25	6333,59	6357,55
36	6815,8	6832,55
50	7066,32	7084,64
73	6413,45	6450,11
80	7232,17	7254,4

This table shows that the higher the fine matter content, the higher the PCS.

a) PCS evolution curve according to fine matter content

The following figure shows the evolution curve of the PCS according to the fine matter content.

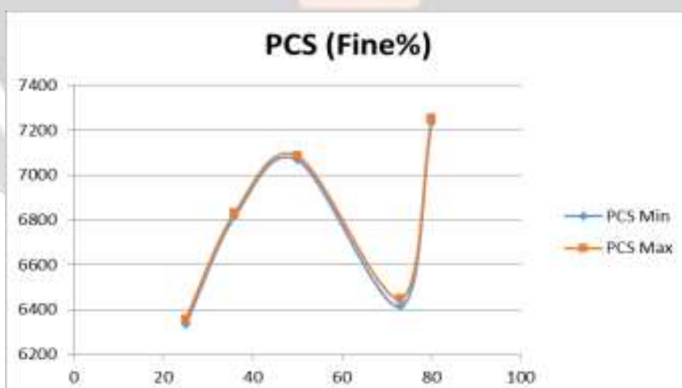

Figure 7: Evolution of PCS according to fine matter content

This curve shows the importance of a high fine material content for a high PCS.

b) PCS Average by fine matter content

For the different tests carried out, the values obtained are not identical. The following table summarises the mean value of PCS according to the fine matter content.

Table 10: Mean value of PCS according to fine matter content

Fine%	PCS Min	PCS Max	PCS Moyen
25	6333,59	6357,55	6345,57
36	6815,8	6832,55	6824,17
50	7066,32	7084,64	7075,48

73	6413,45	6450,11	6431,78
80	7232,17	7254,4	7243,28

c) Average PCS/PCI ratio by binder content

The following table summarises the PCS/PCI ratio according to binder content.

Table 11: Average PC/PCI ratio by binder content

Binders (%)	PCI Min	PCI Max	PCI Moyen	PCS Max	PCS/PCI
5	5 189,18	6897,66	6 043,42	7254,4	1,2
7	5420,73	6354,3	5887,515	6832,55	1,16
8	5418,75	5982,75	5700,75	6450,11	1,13
10	6100,78	6404,07	6252,425	7084,64	1,13

This table shows the ratio of the average SGP value to the average ICP value according to the binder contents. This ratio shows that the value of the PCS/PCI ratio is close to 1.16.

d) Average PCS/PCI ratio by fine matter content

The following table summarizes the PCS/PCI ratio according to fine matter content.

Table 12: PCS/PCI ratio in fine matter

Fine%	PCI Min	PCI Max	PCI Moyen	PCS Moyen	PCS/PCI moyen
25	5189,18	6251,28	5720,23	6345,57	1,11
36	5420,73	6354,3	5887,51	6824,17	1,16
50	5627,73	6404,07	6015,9	7075,48	1,18
73	5418,75	5982,75	5700,75	6431,78	1,13
80	5740,2	6897,66	6318,93	7243,28	1,15

This ratio shows that the PCS/PCI ratio is on average 1.15 for both binder and fine matter content.

3.2. SAWDUST BRIQUETTES (BSB)

A-CALCULATION OF THE LOWER CALORIFIC VALUE (ICP)

This research work investigated the influence of two major factors on the ICP of sawdust briquettes: the binder and the fine material. However, the results of the experimental tests proved that there is a correlation between the binder content and the fine matter content. We have therefore limited ourselves to the study of the fine material content. In further research work, the fine matter content was simply used.

3.2.1. Influence of fine material (25%, 50%, 75%) on ICP sawdust briquette

Depending on the different fine material contents of the sawdust briquettes, the ICP (min, max) per is summarized in the following table

Table 13: ICP (min, max) of different fine material compositions of sawdust briquettes

Fine%	PCI Max	PCI Min
25	5552,98	6464,98
50	6249,52	6817,37
75	4853,83	4981,72

This table informs the ICP (min, max) of the sawdust briquettes according to the different fine material contents.

a) ICP evolution curve according to fine material content

The following figure shows the ICP value for the different fine material contents of sawdust briquettes

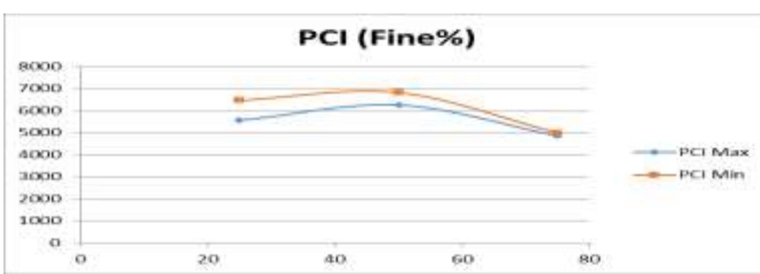

Figure 8: Evolution of ICP according to fine matter content

This curve shows that ICP is very interesting for a fine material content of 50%.

c) Average ICP of sawdust briquettes according to fine material content

According to the experimental tests carried out in the laboratory of the Energy Department of the National Centre for Industrial and Technological Research (CNRIT), the composition of each sample is not the same from one test to another, therefore, two values (minimum, maximum) were obtained for the result of : PCI

Table 14: ICP Average sawdust briquettes (25%,50%,75%) with binding agent

Fine%	PCI Max	PCI Min	PCI Moyen
25	5552,98	6464,98	6008,98
50	6249,52	6817,37	6533,445
75	4853,83	4981,72	4917,775

This table also informs about the average minimum and maximum ICP of sawdust briquettes.

B-CALCULATION OF THE GROSS CALORIFIC VALUE (PCS)

In accordance with the ICP calculation, in the case of PCS, we limit this research work to the influence of fine materials on the PCS of sawdust briquettes.

3.2.2 Influence of fine composition materials (25%, 36%, 50%, 73% and 80%) on the PCS sawdust briquette

For different contents of the fine particle content of the sawdust briquettes, the results of the experimental laboratory tests are summarized in the following table

Table 15: Values of PCS min, max for different fine material contents

Fine(%)	PCS Max	PCS Min
25	7160,01305	6237,2519
50	7674,40355	7622,13097
75	5693,688	5579,32976

This table shows that PCS is important for a fine material content of 50%. For a fine matter content exceeding 50%, the PCS has a low value.

a) PCS evolution curve according to fine matter content

The following figure shows the evolution curve of the PCS according to the fine matter content.

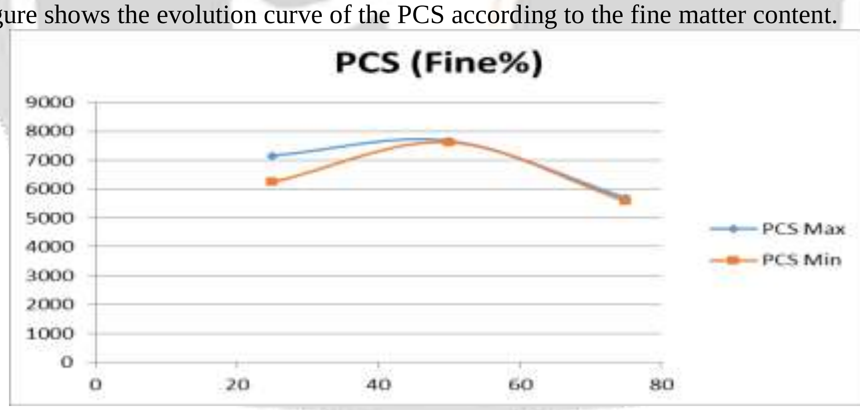

Figure 9: Evolution of PCS according to fine matter content

This curve shows that a fine material content of 50% is adequate for a high PCS.

b) PCS Average by fine matter content

For the different tests carried out, the values obtained are not identical. The following table summarises the mean value of PCS according to the fine matter content.

Table 16: Mean value of PCS according to fine matter content

Fine(%)	PCS Max	PCS Min	PCS moyen
25	7160,013	6237,251	6698,63
50	7674,403	7622,130	7648,26
75	5693,688	5579,329	5636,50

c) Average PCS/PCI ratio by fine matter content
The following table summarizes the PCS/PCI ratio according to fine matter content.
Table 17: PCS/PCI ratio in fine matter

Fine (%)	PCI Max	PCI Min	PCI Moyen	PCS moyen	PCS/PCI moyen
25	5552,98	6464,98	6008,98	6698,63	1,11
50	6249,52	6817,37	6533,445	7648,26	1,17
75	4853,83	4981,72	4917,775	5636,5	1,15

This table shows that the PCS/PCI ratio has an average value of 1.14 for each of the fine matter contents.

3.3 Energy efficiency of briquettes of planing chips and sawdust compared to charcoal and firewood

This section informs about the results of the different tests and the energy efficiency of briquettes of planing chips and sawdust compared to charcoal and firewood. The following table summarizes the results :
- of the fuel consumption test of briquettes of (shavings, sawdust) with different binder content ;
- of the power of each fireplace using the briquettes (chips, sawdust) with different binder content ;
- the efficiency of each furnace using briquettes of (chips, sawdust) with different binder content;

In addition, the table highlights the comparison of the performance of each fuel including planing chip and sawdust briquettes as well as charcoal and firewood.
Table 18: Summary of the results of the different tests: consumption, power, efficiency and transmitted energy

Fuel	Volatile matter (%)	PCI	PCS/PCI	Fuel consumption (kg/h)	Power (W)	Yield (%)
1) Planing shavings						
BCR (5%)	24,99	**6897,66**	1,20	0,40	**745,7**	**39,5**
BCR (7%)	29,52	6354,30	1,16	0,41	624,65	28,3
BCR (8%)	25,18	5982,75	1,13	0,39	657,92	29,7
BCR (10%)	18,95	6404,07	1,13	0,36	686,72	30,5
2) Sawdust						
BSB 5%	20,87	5782,12	1,08	0,45	632,43	24,1
BSB (10%)	15,37	6808,34	1,12	0,43	621,87	25,4
3) Charcoal		**6700**		**0,34**	636,23	**23,74**
4) Firewood				0,54	574,73	21,04

This table shows the results of different tests comparing the efficiency and energy efficiency of briquettes of planing chips and sawdust compared to charcoal and firewood. It highlights the performance of briquettes of planing chips compared to those of sawdust and obviously with wood energy. The briquette of planing shavings with a binder content of 5% is the most important from an energy point of view as it has a Lower Calorific Value (LCV) of 6897.66 Kcal/Kg, a Power of 745.7 W and an efficiency of 39.7% respectively. From an ecological point of view, although this briquette has a Volatile Matter content of 24.99%, it is better placed than the BCR 7% and BCR8% briquettes.

4. DISCUSSIONS

The results of this research work showed that depending on the parameters studied, influencing the ICP and PCS, which of these parameters is more influential: the binder or the fine matter content to be able to compete with wood energy. Thus, to compete with wood energy, it is necessary to take into account the ICP, the Volatile Matter Content because the latter is intended to dictate on a good or a bad fuel.

To answer our question: which of these two parameters is more influential? And among briquettes: planing chips or sawdust, which is better placed to substitute wood energy?

4.1. Which of these two parameters is the most influential on ICP?

To answer this question, it is necessary to compare the ICP/PCS of the two briquettes of planing chips or sawdust for the same binder or fine material content.

According to this research work, the binder and fine material content has a correlation, i.e. :

- the binder is an important parameter for a good fuel with a high ICP;
- a briquette with an adequate binder content ignites with a blue flame, i.e. combustion is complete and there is less loss. Having complete combustion means that the fine material composing the briquette is in good proportion and this proportion means the correlation between the binder content and the proportion of fine material.
- The very high binder content has an influence on the low ICP, i.e. there is no correlation between binder content and fine matter proportion.

In short, regardless of the parameter used: binder or fine material, each has almost the same influence.

4.2. Which of the two briquettes based on planing shavings or sawdust is better placed to substitute wood energy?

The summary table of the tests and energy efficiency of each fuel (briquette, coal, fuelwood) studied proves that the briquette of planing chips with a 5% binder content is the best placed to replace charcoal or fuelwood because this briquette has :

- Firstly, a Lower Calorific Value (6897.66 kcal/kg) higher than that of the average charcoal (6700 kcal/kg);
- Secondly, a high power (745.7 W) compared to other fuels;
- Thirdly, a very interesting efficiency compared to other fuels.

In short, to face the problem of the country's dependence on fossil resources, the application of the policy of diversification of energy sources is the best solution for non-oil producing countries, including Madagascar, with a view to reducing imports and developing alternative energy sources such as briquettes of vegetable waste.

4.3. Will the use of this 5% planing chip briquette by binding have any effect on the energy needs of households?

The average annual per capita consumption of charcoal is 100 kg/year/capita. The average size of a Malagasy household is 4.9 or 5 persons per household, i.e. in one year, a family consumes 100x5 = 500 kg/year/household. The substitution of charcoal by briquettes of planing shavings (5%) of a household will reduce charcoal consumption by: 2.86%, i.e. instead of consuming charcoal of 500 kg/year/household, this consumption will become 485.67 kg of briquette made from planing shavings.

CONCLUSION

It must be said that the initial objective set has been achieved. Combustible briquettes based on planing chips and sawdust are produced using a mixture with an appropriate proportion of binder and raw materials.

The methodology adopted is both qualitative and quantitative. Its eventual implementation requires a priori the following activities to be carried out in chronological order: the collection of bibliographic and webographic data on the theme and the study area, the descent into the study area to take a close look at the problems relating to this forest waste and the taking of samples for laboratory trials, the analysis and processing of the data collected and the drafting of this document.

The results of this research work are promising since :

- Firstly, forest waste can be recovered in the form of combustible briquettes made from planing shavings and sawdust ;
- Second, samples of briquettes based on planing chips and sawdust were produced with appropriate input mixtures;
- Thirdly, among the combustible briquettes produced, the one based on planing chips with 5% binder is the most efficient as it has a high Lower Calorific Value (LCP: 6897.66 kcal/kg), a power of 745.7 W, an efficiency of 39.5% in relation to the other fuels produced and studied.
- Fourthly, the PCS/PCI ratio has an average value of 1.14 and 1.16 for the fine matter and for the binder.

Much remains to be done, such as the search for the ideal mixture for a briquette based on a mixture of chips and sawdust.

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