ENERGY VALORIZATION OF THE AGRO-INDUSTRIAL WASTES: THE CASE OF PALM NUT FIBRES AND SHELLS

André Talla[*,1], Pierre Meukam[1], George Elambo Nkeng[2]
[1] Université de Yaoundé I, École Nationale Supérieure Polytechnique
Laboraoire d'Énergétique, de l'Eau et de l'Environment
[*] B.P. 16034 Yaoundé – Cameroun, e-mail : andre_talla@yahoo.fr
Tel.: (+237) 99 99 09 44 (Mobile) – (+237) 22 30 45 71 (domicile)
[2] École Nationale Supérieure des Travaux Publics
B.P. 510 Yaoundé – Cameroun

ABSTRACT**:** Since 1995, Cameroon has been witnessing energy crisis due to demographic and industrial growth. This is portrayed in the electricity sector by several power cuts in towns. Electrification rate is estimated at 25% at the national level, 46% in towns and less than 1% in the rural areas. The valorization of fossilized primary sources contributes to environmental destruction through the abundant emission of greenhouse gases. Wood remains the main source of energy in this country. Consequently, this contributes to deforestation. The current study addresses the issue of energy recovery from palm nut fibres and shells produced by oil mills. Mixed with binders like starch, ash, clay or lime, this biodegradable waste is conditioned in the form of briquettes. Their density, specific heat and lower calorific capacities are estimated. A comparative study of the various binders used shows a ratio of lower calorific power on the cost of the binder, which varies from 14,538 $kJ.m^{-3}$/(CFA franc) for starch to 55,736 $kJ.m^{-3}$/(CFA franc) for ash. An improved cooking hearth is designed and produced to supply a clean and economic energy solution. Concerning environmental impact, the substitution of charcoal with this combustible material enables us to save 784,100 tons of wood each year and to reduce the emission of methane into the environment by limiting the degradation of this waste product emitted carelessly into the open air.
Keywords: valorization of waste, energy, palm nut, fuel briquette, environment, fibres and shells.

1 INTRODUCTION

In Cameroon, biomass is available everywhere but is rather poorly valorized. Only carpenter workshops based in towns manage to get the most from their wastes by selling them to households who use them for cooking. However, in many countries, heat, vapour and electricity are produced from the combustion of waste because of the tariff incentives attached to the repurchase of cogenerated electricity [1] [2]. For example, Guadeloupe and Reunion Islands exploit extensively in cogeneration factories the combustion of bagasse whose energy efficiency is approximately 2.2 $kWh.kg^{-1}$ [3]. Similarly, the incineration of one ton of household refuse in industrialized countries enables to produce 300 to 500 kWh and many rubbish dumps use this energy to produce electricity and heat [3]. At the global level, it was estimated in 1998 that 155.10^9 kWh of electricity was generated from biomass and waste [4].

The valorization of primary fossilized sources contributes towards environmental destruction through the abundant emission of greenhouse gases. Moreover, in rural areas where more than 50 % of the Cameroonian populations live, less than 1 % of the inhabitants have access to this form of energy and barely 46 % in towns. Wood is therefore presented as the main source of energy in this country, its consequence being extensive deforestation.

Agro-industrial fuel wastes are however capable of restoring greater energy than the amount necessary for industrial needs. In a boiler which recovers heat and produces steam, hot water or electricity, agro-industrial fuel wastes are all the more interesting to burn given that their calorific power is relatively high.

A study carried out in Cameroon by Institut Technique Européen du Bois Énergie (European Technical Institute for Wood Energy) shows that although oil mills are major producers of huge quantities of fuel wastes, they hardly valorise the wastes. Less than 10 % of these wastes available are used in cooking nuts [5]. All oil mills produce wastes (stalks, fibres and shells) which some valorise partially. In Cameroon, an average of 484,000 tons of oil is produced each year. Oil represents approximately 20 % of the mass of bunches which contain on average about 12.5 % fibres [6]. It is therefore estimated in this country that 290,400 tons of fibres are produced on average yearly by oil mills.

Most of these biodegradable wastes are therefore abandoned without carelessly in open air. Under these conditions, they undergo the process of methanisation which releases, inter alia, methane, one of the most harmful greenhouse gases in the air. In addition, the lack of knowledge on the energy properties does not permit to consider a rational valorisation of these wastes.

In Europe, the fuel briquettes derived from the compaction of sawmill wastes, wood and dead leaves, fruit cores, barks and roots of trees replace wood by presenting some advantages to users such as zero dust, easy storage, easy conditioning and easy upkeep of fire [7].

The main aim of this work is to attempt the first solutions to this problem. It will involve determining the essential characteristics of oil mill wastes in particular the water content, the specific heat, the lower calorific capacity, the density and rate of mineral matter, on the one hand, and conditioning them in the form of fuel briquettes for easier transportation and use, on the other hand.

A prototype of improved furnace, intended for cooking food, is proposed to provide a first clean and efficient energy solution to the user.

2 NOMENCLATURE

ρ	density (kg.m^{-3})
η	hearth output (-)
θ	temperature (°C)
χ	mineral matter content of fuel briquette (%)
μ	water value (kg)
c	specific heat (J.°C^{-1}.m^{-3} or J.°C^{-1}.kg^{-1})
db	dry base
K	total coefficient of thermal losses (Wm^{-2} °C^{-1})
kgms	kilogramme of dry matter
m	mass (kg)
PCI	lower calorific power of fuel (J.kg^{-1})
S	heat exchange surface (m^2)
V	volume (m^3)
X	Water content of the sample (% kg.(kgdb)$^{-1}$)

Indices

0	initial moment
a	air or ambient
c	calorimeter and its accessories
e	water
f	final state of fuel briquette
h	wet state of fuel combustible
s	anhydrous state of fuel combustible
t	time t
ce	mineral matter of fuel briquette
e0	initial state of water
ec	hot water
ef	cold water
em	average state of water
er	remaining water
s0	initial state of the solid

3 THEORETICAL ANALYSIS

The characteristics of the fuel briquettes studied are given using experimental results coupled with mathematical simulation models.

3.1 Water Content

Water content X in dry base is one of the major properties of a fuel, given that it determines the other parameters. It represents the quantity of water contained in a sample by its anhydrous mass unit. A zero water content fuel is desirable to provide the best energy properties. However, it is difficult, in practice, to have a solid fuel whose mass is equivalent to its dry mass. The dry base water content Xt at the time t is given by the relation:

$$X_t = \frac{m_t}{m_f}\left(X_f + 100\right) - 100 \qquad (1)$$

where X_f is the final water content of the fuel briquette (in % kge.kgms^{-1})

m_t and m_f respectively represent the wet mass at the time t and the final mass of the sample (in kg).

3.2 Rate of Mineral Matter

The mineral matter of a fuel briquette (ash after total combustion) is that part of the fuel which remains unburnt after total combustion. The rate of mineral matter represents the proportion of this unburnt part in relation to the dry fuel mass. A good fuel has a low rate of mineral matter. The rate of mineral matter χ is given by the relation:

$$\chi = \frac{m_{ce}}{m_f}(X_f + 100) \qquad (2)$$

Where χ is the mineral matter content of the fuel briquette (in %)

m_{ce} is the mass of the mineral matter of the fuel briquette (in kg)

3.3 Density

The density of a solid body is proportional to the density of water. This parameter constitutes a major property of a solid fuel. Densification therefore increases the energy value of fuel in a given volume. Let us consider a fuel briquette with water content Xf intended for combustion, by neglecting the variation of the volume of this briquette in relation to its volume if the dry base water content is zero, the density is determined by the relation:

$$\frac{\rho_f}{\rho_e} = \left(\frac{X_f}{100} + 1\right)\frac{\rho_s}{\rho_e} \qquad (3)$$

with $$\rho_f = \frac{m_f}{V_f} \text{ and } \rho_s = \frac{100\rho_f}{\left(X_f + 100\right)} \qquad (4)$$

where m_f: mass of the fuel briquette (kg),

V_f: volume of the fuel briquette (m 3),

ρ_f: density of the water content of the fuel briquette X_f (kg.m^{-3}),

ρ_s density of dry fuel briquette (kg.m-3),

ρe density of water (kg.m-3),

3.4 Specific heat dry fuel

Specific heat represents the amount of energy necessary to raise one kilogramme of matter by one degree Celsius. The importance of this parameter resides in the evaluation of heat exchanges in connection with the variation of temperature. Although specific heat does not contribute to the classification of fuels in a combustion process, it contributes towards energy balance in a process which emphasizes the energy value contained in these fuels.

The measurement of the specific heat of the fuel residues studied is obtained through the calorimetric method. The heat balance carried out on the calorimeter enables to show, in equilibrium between water and fuel, that specific heat cs can be evaluated by the relation:

$$c_s = \frac{1}{m_s}\left[\left(m_e c_e + \rho_a V_a c_a\right)\left(\frac{\theta_e - \theta_{e0}}{\theta_{s0} - \theta_e}\right) + \frac{KS}{\left(\theta_{s0} - \theta_e\right)}\int_0^t\left(\theta_{em} - \theta_a\right)dt\right] \qquad (5)$$

With c_e: specific heat of water (J.°C^{-1} kg^{-1})

c_a: specific heat of air (J.°C^{-1} m^{-3})

The water value μ_c of the colorimeter is deduced through experiments by applying the relation obtained hereafter through the energy balance of the mixture of a certain quantity of cold water and hot water:

$$\mu_c = \left(\frac{\theta_{ec} - \theta_e}{\theta_e - \theta_{ef}} \right) m_{ec} - m_{ef} \qquad (6)$$

Similarly, the total coefficient of the thermal losses on the walls of the calorimeter is obtained by experiments, thanks to the heat balance, by applying the relation:

$$K = -mc_e p \qquad (7)$$

where p is the slope straight line:

$$\ln\left(\frac{\theta_e(t) - \theta_a}{\theta_{e0} - \theta_a} \right) = pt = -\frac{K}{mc_e} t \qquad (8)$$

3.5 Specific heat of wet fuel

The knowledge of the specific heat c_s of dry fuel enables to deduce the specific heat of the fuel having known water content. By neglecting the heat exchanges due to the presence of air and water vapour in the fuel in front of the calorific exchanges of the liquid and solid phases, the specific heat of the wet fuel c_h of water content X is estimated by the relation:

$$c_h = \frac{100 c_s + X c_e}{100 + X} \qquad (9)$$

with X: Water content of the sample (kge.kgms $^{-1}$)

3.6 Lower Calorific Capacity of Fuel Briquettes

The densification of palm nut fibres and shells studied is ensured by a manual press designed and produced for that purpose. This press enables easy operation and strong compression. The shape and dimensions of the briquettes are chosen to adapt to the hearths commonly used in households or the improved systems to be proposed.

The experimental estimation of lower calorific capacity (PCI) of the fuel briquettes studied is based on a combustion test on a brazier with water used as test body to be heated. The heat balance resulting from this test enables us to deduce this parameter using the expression:

$$PCI = \frac{1}{m_c \eta} \left[m_{e0} c_e \left(\theta_{eb} - \theta_{ie} \right) + L_v \left(m_{e0} - m_{er} \right) \right] (10)$$

with η : hearth output

Lv: latent heat of water vaporization (J.kg^{-1})

4 MATERIALS USED AND EXPERIMENTAL PROTOCOL

4.1 Materials used

The testing device is made up of:

- a manual metal press illustrated by figure 1 and made up of a cylinder 9 cm in diameter and 10 cm high, of a screw 80 cm long, an arm 70 cm long and a nut of 2 cm. This press is designed and produced for the densification of the fibres and palm nut shells studied,
- a ventilated drying oven whose temperature is regulated to determine the anhydrous mass of the fuel,
- a precision balance of 0.001 g to measure fuel masses,
- a calorimetric bomb containing the test-tubes to be tested,
- type K thermocouples connected to a computer through a data acquisition device (ALMEMO 2390-5) intended to measure the temperatures in the calorimeter,
- a graduated burette intended to measure the volume of water allowed in the calorimeter,
- a brazier used to test the combustion of the fuel briquettes produced,
- a stop watch to control, if necessary, the duration of a test,
- a calliper rule used to measure the test-tube dimensions of fuel briquettes.

4.2 Experimental Protocol

- Water Content

The palm nut wastes are densified and dried in the open air until equilibium with the environment. The state of equilibrium is recorded when the mass of the products stops decreasing. A sample of wet mass m_f is then taken and introduced into the ventilated drying oven where the temperature is maintained at 103 °C. After approximately 48 hours, the mass of the sample is stabilized at the value m_s which corresponds to its anhydrous mass. The application of the relation (1) then enables us to deduce the final water content of the fuel.

- Rate of Mineral Matter

To determine the rate of mineral matter, we do dry extract of a sample taken on a dried briquette until its final water content. The anhydrous mass m_s of this sample is subjected to complete combustion. The mass m_c of the fuel residue is then measured using a precision balance and enables to deduce the rate of mineral matter by applying the relation (2).

- Density

To determine the density of fuel briquettes, their mass is measured thanks to a precision balance and their volume calculated based on the geometrical dimensions measured using a calliper rule. These measurements enable to deduce the density of the briquettes by applying the relation (3).

The density of palm nut fibres is estimated by densifying, without a binder, the mass of the sample taken then by evaluating the volume occupied by these residues. The required density is equally deduced as before. This size, in this particular case, depends on the densification pressure.

As regards the density of the palm nut shells, a sample with a known mass is taken and introduced in a burette containing water. The measurement of the water volume moved by this test-tube enables to deduce the density of the palm nut shells.

• Specific Heat

A sample of fuel briquettes of mass m_h is heated beforehand until its anhydrous mass m_s, in a drying oven whose temperature is fixed at 103 °C. It is then plunged in the calorimeter containing a volume of cold water of mass m_e. The variation of water temperature in the calorimeter is recorded every 10s until its maximum value θ_e reached in equilibrium.

The heat balance between the initial time t_0 when the solid is introduced in the calorimeter and the final time t_f when the water in the calorimeter reaches the maximum temperature enables us to determine the specific heat of dry fuel by applying the relation (5).

Using the mixture of the mass of hot water $m_{ec.}$at the temperature $\theta_{ec.}$ and the mass of cold water m_{ef} at the temperature θ_{ef} in the calorimeter one can determine, using the heat balance and once the balance temperature θ_{eq} is reached, the water value of the calorimeter and its accessories by the relation (6).

As concerns determining the total coefficient of thermal loss, a mass of water sample m_e at the temperature θ_e contained in the calorimeter heat undergoes thermal exchanges with the external environment at the temperature θ_{has}, because of the difference in the thermal potential between the two media. The variation in the water temperature is due mainly to the thermal losses by conduction, radiation and convection. The heat balance on the calorimeter and its contents in relation to the environment enables to determine the total coefficient of exchanges using the relation (7).

• Lower Calorific Value of Fuel Briquettes

Using a burette, 1 liter of water at the room temperature is measured and poured in a pot. The brazier, a device used to test combustion, is loaded with the fuel briquettes to be tested. Combustion is started by means of 30 g of paraffin oil. A stop watch and a digital thermocouple display panel are used to record the variation of the water temperature in the pot according to the time. At the end of the combustion, the unevaporated mass of water in the pot is determined by weighing and the quantity of water which has evaporated is deduced. Through the energy balance and using the output of the combustion device, the lower calorific value is estimated by means of the expression (10).

• Choice of Binders

The binder is the substance which stabilizes palm nut fibres and shells in the form of fuel briquettes. Accessibility and the moderate cost of acquisition are the selection criteria for the binders to be tested. Hence, we retained for that purpose starch, lime, clay and ash.

Starch refers to a white and odourless compound which is marketed for other purposes (clothes treatment), in the granulated or powder form. It is a complex glucide of formula $\mathbf{(C_6H_{10}O_5)_X}$, abundant in the grains of cereals, bulbs and cassava tubers in particular. The starch used in our work is extracted from cassava tubers, accessible in several localities across the country. Its retail price, on average, is 900 CFA francs for a bottle of 1.5 l (600 g) on the Cameroonian market.

Lime is a solid, white caustic substance when it is pure. It is obtained by calcinating limestone and other calcium carbonate shapes. Pure lime, also called quicklime or caustic lime is made up of calcium oxide (CaO). Traditionally, lime is intended for preparing cement and mortar, as well as for neutralizing acid lands in agriculture [8]. Its use as binder stems from the fact that it hardens quickly after drying. Another traditional use is devoted to the dyeing of dresses. It is retailed at 500 francs CFA per kilogramme on average on the Cameroonian market.

Clay, a plastic, impermeable and resistant rock when soaked with water, irreversibly hardens when cooked. The irreversible hardening of clay during heating and its plasticity are properties which prompted us to use it as binder. For tests carried out within the framework of our work, the clay used is extracted from a marshy area in the suburbs of Yaounde.

Ash on its part is a powdery solid residue from combustion. It is an entirely mineral matter during complete combustion. Wood ash or ash from a similar plant matter is mainly made up of sodium carbonate and potassium carbonate [8]. This mineral matter was tested as binder in a feasibility study of waste valorisation including a mixture of sawdust, shells of paddy rice and dry grass by brickwork in Niger [9]. The ash used in our tests is borrowed from the boiler of an oil palm production industry in the suburbs of Yaounde using nut wastes as fuel.

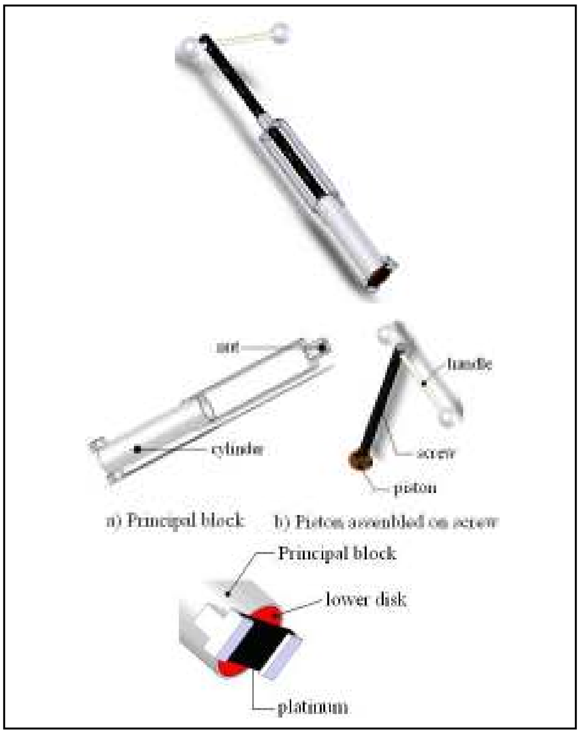

Figure 1: Diagram of the designed press and its main components

5 RESULTS AND DISCUSSIONS

5.1 Densification of Fuel Briquettes

Using binders described earlier and measured out in various proportions, we produced fuel briquettes with palm nut fibres and shells. Figure 2 shows a sample of manufactured briquettes.

Figure 2: Photographs of a sample of manufactured briquettes

Figure 3 shows that the density of fuel briquettes increases in a quasi linear manner with the binder concentration. It can be noted that, for the same binder concentration, the density is higher in the case of lime. In particular, considering a binder concentration of 200 g for 300 g of fibres, the density of lime briquettes is approximately twice greater than the density of briquettes produced using other binders. In addition, apart from clay briquettes where the rupture during the withdrawal was observed at a concentration of 100 g of the binder for 300 g of fibres, the briquettes produced using other binders undergo rupture at a concentration of 50 g of the binder for 300 g of fibres. It was also noted that in relation to the diameter of the mould which is 9 cm, the diameter of briquettes vary between 9 and 11 cm. This is explained by the spongy character of fibres. Based on these results, one could, as the first classification following the density criterion and by order of importance, choose lime, starch, clay and finally ash.

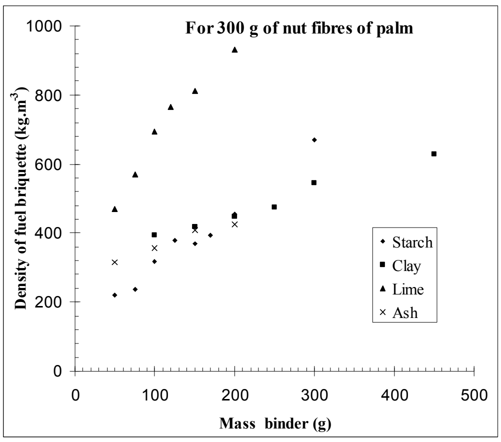

Figure 3: Example of density of fuel briquettes manufactured according to the binder concentration in 300 g of palm nut fibres

5.2 Density of Fibres and Shells

Using the procedure for determining the density of fibres and shells described above, we obtained, on the basis of four tests bearing a mass 300 g of fibres and 150 g of shells, an average density of 744 kg.m^{-3} for fibres and 1277 kg.m^{-3} for shells. As one could have anticipated, the density of fibres for example is far greater than that of briquettes whose fibres are densified using binders (at rupture at the withdrawal, of 220 kg.m^{-3} for starch at 469 kg.m^{-3} for lime approximately). An explanation would be the low porosity of fibres compressed without binders compared to fuel briquettes.

5.3 Specific Heat, Water Content and Rate of Mineral Matter

Specific heat, water content and the rate of mineral matter are determined for each binder by borrowing a sample of fuel briquettes produced and dried in the open air until balance. We are also contemplating a water value of the calorimetric bomb of 60 g and a total coefficient of thermal transfer of 0.563 W.m^{-2}.°C^{-1} obtained after several tests based on the experimental protocol established above [10].

For the particular case of determining the specific heat of the fuel, figure 4 illustrates, as an example, the variation in water temperature in the calorimeter after introducing the sample being studied. One can note temperature rise of up to a maximum value reached in equilibrium between water and the test-tube. The various results are recorded in **Table I**. In equilibrium with the ambient air, water content varies from 15.00 % kge.kgms^{-1} for briquettes conditioned with ash at 31.12 % kge.kgms^{-1} for lime briquettes. The mineral matter content increases by 9.72 %, the lowest value for starch briquettes, at 64.14 % for ash briquettes. As concerns specific anhydrous heat, the lowest value of 964.04 J.kg^{-1}°C^{-1} for starch briquettes and 1113.50 J.kg^{-1}°C^{-1}, the highest value for lime briquettes is observed. By comparing the parameters evaluated for fibres and bricks containing palm nut fibres, the tendency evolves as anticipated. For example, one can note the smallest value of 9.72 % of the rate of mineral matter in briquettes of fibres conditioned with starch against 9.24 % when the fibres are not conditioned.

The purpose for recovering energy from waste palm nuts is to provide a fuel which can replace wood or charcoal. However, it does not suffice to determine previous major characteristics to propose a suitable and economic way of conditioning these wastes. To get there, it is necessary to consider the lower calorific capacity and evaluate the cost of conditioned briquettes.

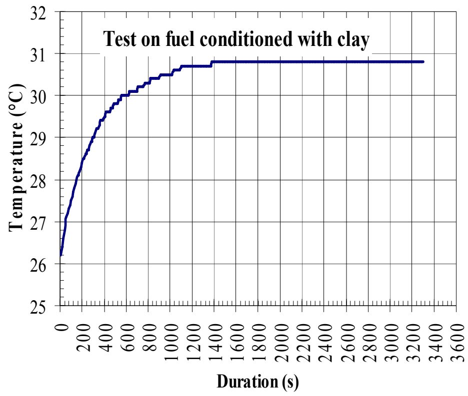

Figure 4: Example of curve showing the variation in water temperature depending on the time for fuel briquettes conditioned with clay

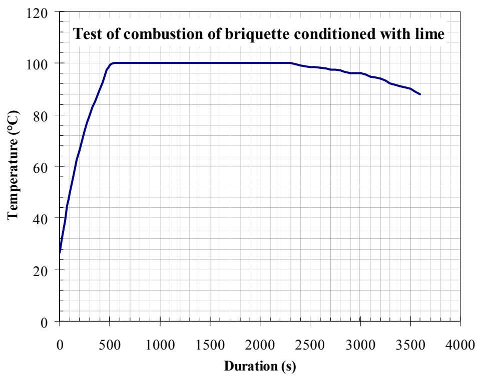

Figure 5*:* Example of **v**ariation according to the time of the temperature of the water heated with a fuel briquette conditioned with lime

Table I: Some thermo physical parameters of fuel briquettes produced with palm nut fibres

	Nature of the binder				Fibres	Shells
	Ash	Clay	Lime	Starch		
Water content (% kge.kgms $^{-1}$)	**15.00**	17.23	31.12	20.16	20.05	15.40
Rate of mineral matter (%)	61.14	58.65	49.30	**9.72**	9.24	38.31
Density (kg. m $^{-3}$)	426.25	447.23	569.90	455.30	743.42	1277.18
Anhydrous Density (kg. m $^{-3}$)	370.65	381.5 0	**434.64**	379.02	619.32	1107.00
Specific heat (J. kg $^{-1}$ °C $^{-1}$)	**1374.63**	1455.26	1794.85	1497.90	1357.25	1493.64
Specific heat anhydrous (J. kg $^{-1}$ °C $^{-1}$)	979.42	980.05	1113.50	**964.04**	810.50	1067.70

5.4 Lower Calorific Capacity and Cost of Fuel Briquettes

The experimental estimation of the lower calorific capacity of conditioned briquettes is done by means of a device described earlier which comprises a brazier and its accessories. The energy efficiency in the hearth of this device is estimated at 30 % [9]. Figure 5 illustrates, as an example, the variation in temperature of water heated using fuel briquettes conditioned with lime during a combustion test intended to determine the lower calorific capacity. This approach is in conformity with the experimental protocol and the application of the theoretical correlations developed earlier. During the test, the atmospheric pressure is maintained on the water surface. Figure 5 shows the rise in water temperature up to 100°C, corresponding to the boiling point at the atmospheric pressure. This temperature is then maintained constant for some time before it starts dropping; which implies the end of the combustion.

As concerns the cost of the conditioned fuel briquettes, we took into account labour cost and the cost of the binder. We suppose that the worker is paid as manufacturers of earth bricks in Cameroon, i.e. 2 000 CFA francs on average per day of 9 working hours. In addition, the manufacture of a fuel briquette requires 15 minutes on average i.e. 56 CFA francs. This cost could reduce considerably by developing a more effective densification technique. As for the cost of the binder, it is mainly made up of transport charges and the purchase cost itself. All the binders tested within the framework of this work are accessible near the densification unit (Ferme Suisse, palm oil industry used as sample for our studies); ash is taken from one of the boilers of this oil mill. Transportation cost under these conditions is minimal. Retailed starch is bought at 1 077 CFA francs per kilogramme and lime at 500 CFA francs for the same mass. Taking into account, for each type of binder, the concentration likely to guarantee better stability of fuel briquettes, we record in **Table II** the characteristic properties resulting from the combustion test.

Based on the ratio of the lower calorific capacity on the cost of the fuel briquette, preference would be given to ash-conditioned briquette. However, there could be inadequate supply of such a binder in case of large scale manufacturing of briquettes. Due to this potential disadvantage, we advocate the production of fuel briquettes conditioned with lime as binder with a concentration of 75 g for 300 g of palm nut wastes.

In addition, we noted through the combustion tests that 300 g of briquettes with 75 g of lime could replace 80 g of coal sold on the Cameroonian market at 100 francs per kg. The average lower calorific capacity of this fuel is estimated at 33,700 $kJ.kg^{-1}$ [10]. However, 300 g of briquettes with 75 g of lime contain about 154 g of fibres. In other words 1 kg of densified palm nut fibres containing lime could replace approximately 0.54 kg of charcoal.

Table II: Costs of fuels and characteristic properties during combustion

	Ash (200 g)	Clay (200 g)	Lime (75 g)	Starch (200 g)
Estimated PCI ($kJ.kg^{-1}$)	8 421	5 923	8 925	10 433
Duration of start of boiling	6 mn 50 s	6 mn 10 s	7 mn	6 mn 20 s
Duration of boiling	23 mn	17 mn 20	16 mn 40 s	30 mn
Estimated PCI ($kJ.m^{-3}$)	3 121 199	2 259 666	3 879 210	3 954 357
Estimated cost (CFA franc)	56	56	94	272
PCI/cost ($kJ.m^{-3}$/ CFA franc)	**55 736**	40 351	**41 268**	14 538

Figure 6*:* Photograph of prototype of improved hearth

6 CONCLUSION

In Cameroon, it is estimated that on average 290,400 tons of fibres are produced each year by oil mills. On the basis of the equivalence established earlier, the densification of 290,400 tons of fibres produced on average each year in Cameroon would enable to substitute approximately 156,820 tons of charcoal. The charcoal results from carbonization which produces 1 kg for 5 kg of wood [11]. It results therefore that the valorisation of palm nut fibres could save each year 784,100 tons of wood taken from the forests and savannas. In addition, the densification of palm nut wastes from oil mills on the production site would contribute in reducing the quantity of unvalorised biodegradable wastes dumped in the open air. Such a solution would limit the atmospheric emission of greenhouse gases, in this case methane, and ensure long-lasting energy supply. Moreover, such a solution would contribute significantly towards environmental protection by limiting deforestation. The prototype of improved hearth designed and constructed for a suitable and economic use of fuel briquettes produced constitutes a concrete contribution to the energy problem in connection with sustainable development (e.g. **Figure 6**).

7 ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to the Energy, Water and Environment Laboratory of the National Advanced School of Engineering of the University of Yaounde I and the National Advanced School of Public Works of Yaounde for their invaluable collaboration.

8 REFERENCES

[1] J.M. Charpin, B. Dessus et R. Pellat - Étude économique prospective de la filière électrique nucléaire. Rapport au premier Ministre de la République Française, (2000).

[2] D. Mayer et F.P. Neirac - La production répartie d'électricité : techniques et perspectives dans le contexte européen. GEVIQ'2002, (2002), Marseille, pp. 48-54.

[3] EDF et les énergies renouvelables. Document EDF, (2000).

[4] B. Manoha - WEC Commitee on The Performance of The Generating Plant. Work Group Renewable Energy, BEA Workshop London, (2001).

[5] Itebe - Dossier Cameroun, Bioénergie International, Newsletter, (2007), France, on : http://www.itebe.net/cgi-bin/newsletter/mail.cgi/archive/itebe_fr/20071005113924

[6] S. L. Nengom - Amélioration du procédé de production de l'huile de palme dans une huilerie artisanale, Mémoire d'ingénierie, spécialité génie industriel, ENSP, (2007), Yaoundé, p. 86.

[7] Itebe - Briquettes, Bioénergie International, 2007,France, On : http://www.bioenergieinternational.com/index.php/post/2007/09/21/mise-a-jour-de-la-charte-qualité-ITEBE_briquettes

[8] Microsoft Encarta - Dossier liants naturels, Microsoft Corporation, (2007).

[9] Einstein - Foyers en image3, (2006), on : http://www.gtz.de/de/dokumente/fr-foyers-en-images1-1995.pdf.

[10] P. Meukam - Valorisation des briques de terre stabilisées en vue de l'isolation thermique de bâtiments, thèse de doctorat, Université Yaoundé I, (2004).

[11] B. Benabdallah, J. Carré, S. Khennas, L.F. Vergnet et P. Ossoukaii - Guide biomasse – énergie, Collection Etudes et filières, (1994).