ISSN (e): 2250 – 3005 || Volume, 06 || Issue, 06|| June – 2016 ||
International Journal of Computational Engineering Research (IJCER)

Experimental Study of Some Agro-Industrial Residues Targeted As Partial Substitutes to Fuel-Oil Conventional Burnt Into the Clinker Kiln of Onigbolo-Cement-Complex (Benin)

Sanya Emile A[1], Chaffa Gédéon[2], Houngbédji F. Martin[3], Djima M.A.Bassitou[4]

[1] *Laboratory of Applied Energetic and Mechanics (LEMA) – Polytechnic School of Abomey-Calavi (EPAC) - University of Abomey- Calavi (UAC) 01 POB: 2009 Cotonou, BENIN*

[2] *Laboratory of Applied Energetic and Mechanics (LEMA) – Polytechnic School of Abomey-Calavi (EPAC) - University of Abomey- Calavi (UAC) 01 POB: 2009 Cotonou, BENIN*

[3] *Cement-Complex of Onigbolo (CCO) - SCB-LAFARGE Cement Company of Bénin, POB: 61 Pobè, BENIN. Tel: +229 20 25 04 25 - Fax: +229 20 25 03 02*

[4] *Benin Petro s.a., Cotonou, BENIN, Tel. +22921 311 671 Fax. +229 21 311 673*

ABSTRACT

Cement industry belonged to the largest energy consumers' factories in Benin. The Cement Complex of Onigbolo (CCO) had particularly undergone the disconcert effects of petroleum blaze costs of last years. This paper dealt with experimental investigations on agricultural/industrial wastes as fractional substitutes of the 7,000 L/h fuel-oil burnt in CCO-clinker furnace. Combustion of about 58 tons of five targeted agro-wastes and worn-tires, up to now ignored or forsaken in situ, even incinerated in open-air because unwieldy, made it possible saving more than 1.5 MF(CFA) in only 100-hours running. Experimental results also showed how far the cement process could contribute to towns/villages/cities cleanup (environmental problems reduction) combined with energy needs fulfillment. Among the studied agro-wastes and in expectation of adequate control and optimization of the convenient pretreatment for improving worn-tires' combustion, results revealed that wood-sawdust was the alternate-fuel technically and economically well adapted to this tested furnace, better than cottonseeds-hulls preferred by CCO-authorities. Compatibility of the burnt wood-sawdust with cement quality characteristics, relatively high calorific value, availability and abundance throughout the year at existent sawmills, technically justified its choice. Conversely, results furthermore proved that no significant substitution rate can be reached, using only one kind agro-waste: therefore cottonseeds-hulls can be combined to sawdust.

Keywords: *alternate-fuels, cotton-fibers waste, cottonseed hulls, clinker kiln/furnace, worn-tires, wood-chips, wood sawdust.*

I. NOMENCLATURE

a: correction constant necessitated by acids formation;
b: correction constant necessitated by combustion heat of the firing or igniting wire;
c: temperature correction constant necessitated by exchange heat with outside (zero if using adiabatic jacket),
C: carbon symbol (carbon content of any considered fuel *i* in %);
CODA-Benin s.a: Oil-mill Complex of Agonvy (an Anonym Society located at Ikpinlè (South-West Benin)
COFRAC: French Accreditation Committee;
CCO: Cement Complex of Onigbolo, a factory located at Pobè (South-West City of Benin);
E: calorimetric bomb water equivalent, accessories and contained water (g);
ε_r: waste to fuel-oil equivalent ratio (no unity);
Fludor-Benin s.a: Anonym Oil-mill Company (Centre Benin);
H: hydrogen symbol, hydrogen content of any fuel *i* (%);
HHV: Higher Heating Value also called Higher Calorific Value (HCV) (kcal/kg);
IBCG: Fats Industry of Benin (an Oil-mill) located at Cotonou;
INSAE: National Institute of Statistics and Economic Analysis of Benin;
kF: kilo-Franc, MF (CFA): mega-Franc, both money unities of African Financial Community (CFA):
L/h: liter per hour (fuel-oil flow unity);
LHV: Lower Heating Value also Lower Calorific Value (LCV) (kcal/kg);
M: mass of sample (g);

ONAB: National Wood Office of Benin;
Q: mass flow-rate (kg/h) or ton/hour (t/h)
SHB: Oil-mill Society of Benin located at Bohicon (center of Benin);
SOCOR s.a: French Company Control and Receiving Combustibles at Douai (France)
SODECO: Cotton Development Corporation (Benin)
SONACOP: National Society of Petroleum Products Marketing (Benin);
σ_r: substitution ratio (%);
th/t (= kcak/kg): thermal per ton (industrial unity: 1 th = 1.163 kWh);
T: temperature (°C) with respective indexes: initial (T_{in}) and maximal (T_{max});
W_W (*i*): water content of crude sample *i* (%), W_D (*i*): water content (%) of dry agro-waste sample *i*.

II. INTRODUCTION

The primary goal of any industrial business is to increase productivity, whilst minimizing energy consumption, for ensuring competitive products and achieving greater profitability. This vision is shared by leaders of Onigbolo-Cement-Complex (CCO), a big energy consumer Company of Benin. Indeed, energy was and remains the major cost factor in cement production: 40-60% [1, 2, 3, 4, 5, 6]. The required temperature, for conversion of the raw materials, consisting mainly of limestone, clay and shale (in powder form), into clinker that gives access to cement, is around 1450 °C [1, 2, 3, 4, 5]. The difficulties for petroleum fuels and electricity supply oblige to take into account some cautions. If nothing is done, this important factor of production might penalize the company in its quest for competitiveness. Dependency on foreign petroleum products, including diesel fuel with transport difficulties and introduced uncertainty by instability of purchase costs, especially the recorded latest outbreaks, combined to daily load shedding, have stimulated industrial glimpse for alternate energy solutions [6, 7, 8]. Onigbolo-Cement-Complex managers are now fond of redefining their company's energy strategy. So, they've decided to search for alternate combustibles for partially substituting the classical fuel-oil. Some agricultural and industrial residues were chiefly targeted. However, every fuel substitution requires removal of some constraints which consist on providing clear answers to general, technical and technological, financial and socio-economical questions [9, 10, 11]. Substantially, analysis of general context concerns the search for adequate solutions to various expressed issues such as: whether or not to use the selected residue(s) in clinker-furnace, acceptance of choice by industrial unit authorities and workers, availability of the targeted residue(s) for short, medium and long terms, the chosen fuels location (concentrated in one place or dispersed), initial use and prospects of residue(s) producers, number of potential users, competitors or suppliers and fluctuations related to their supply, collection and acquisition conditions (seasonal or continuous). Technical and technological aspects chiefly are based on physicochemical and energetic analyses of the targeted alternate combustibles. Particular attention shall be paid to control of the required pre-treatment/modifications linked with adoption of any agro-residue. Final choice is specifically based on criteria that are: compatibility of combustion products of the selected residue with chemical composition and quality of the manufactured clinker, a high value of the lower calorific power of the adopted agricultural / industrial residue, its ability to develop a combination of spontaneous and rapid combustion (high heat provider), collection, storage and easy handling.

This article is focused on development of the performed technical experiments by proceeding to true combustion of each of the targeted agro-waste and worn tires in the clinker furnace of CCO. Apart from the difficulties inherent in the handling of different residues tested, the quality of cements obtained was compared to that of standardized reference 2004 actually used to date.

III. MATERIALS AND METHODS

3.1. Materials

The explored agro-wastes derived from three vegetable species (cotton, oil-palm tree and wood) to which was added one imported residue as worn-tires. The targeted agro-wastes consisted of the cotton by-products as fibers, seeds-hulls, cotton fibers waste and entire seeds, the oil-palm tree empty bunches, the wood chips and sawdust. Of these, the effectively reported six (06) tested combustible residues in this paper included the cotton fibers waste supplied by industrial cotton-gins plants in Benin, cottonseed hulls from Fludor-Benin oil-mill, wood chips and wood-sawdust delivered by Saclo sawmill industry of Bohicon (Center Benin), empty bunches of oil-palm tree recovered at CODA-Benin oil-mill of Pobè and the worn tires collected from various cars in Cotonou and Porto-Novo, two great cities of Benin, added to those belonging to the CCO motorized vehicles.

Chemical and energetic characterization of the studied agro-wastes was performed using PARR Instrument Carbon and Hydrogen Analyzers from SOCOR laboratory at Douai in France. This latter is an agreed and specialized society, holder of ISO-17025 accreditation awarded by the French Accreditation Committee.

All the performed experimental combustions were really done using these targeted agro-wastes in the rotating clinker kiln of CCO industrial cement entity. Chemical constituents of the ensued clinkers were determined with the aid of fluorescence X-rays Spectrometer of CCO integrated laboratory [2-6, 23]. This apparatus usually allowed for online data monitoring on the produced cements quality in accordance with cement industry standards. In view of well ensuring quality for the obtained cements, mortar specimens from resulting cements were also realized and submitted to resistance evaluation, mainly for breaking strength, in classical compression testing.

3.2. Methods

3.2.1. Wastes energetic characteristics. Determination of energetic characteristics was done on only two (02) samples per each of all those selected agricultural and industrial wastes. The reasons were linked, not only with the well reproducibility of tests results, but also to the high unit cost. The realized analyses focused on determination of respectively, the carbon C(*i*) and hydrogen H(*i*) contents (in samples weight percentages) according to standard NF-M03-032, the moisture content W(*i*) according to European EN-14346-PR standard, the higher calorific value HCV(*i*) on dry matter basis and the lower calorific value LCV(*i*) on dry and also wet matter bases of each alternate combustible (*i*) according to NF-ISO-1928 standard. The HCV(*i*) at constant volume and the deduced LCV(*i*) at constant pressure were generally calculated by means of equations similar to those of the followed respective expressions [9,10,11,12,13, 23, 29]:

$$HCV(i) = 100 \times W(i) \times \left[(4.1868 \times E) \times (T_{max} - T_{in} + c) - (a + b)\right] / \left[M \times (100 - W(i))\right] \quad (1)$$

$$LCV(i) = HCV(i) - 25.1 \times \left[\left(8.937 \times W_{W(i)} \times (100 - W_{D(i)})/100\right) + W_{D(i)}\right] \quad (2)$$

in which **E** signified the equivalent water capacity of bomb calorimeter, accessories and the contained water (g), T_{in} initial temperature (°C), T_{max} maximal temperature (°C), **a** correction constant necessitated by acids formation, **b** correction constant necessitated by the ignition wire combustion heat, **c** temperature correction constant necessitated by exchange heat with exterior (zero, if adiabatic jacket was use), **M** mass of sample ***i*** (g), $\mathbf{W_W}$(i) gross moisture of sample ***i*** (%) and $\mathbf{W_D}$(*i*) water content of dry waste sample ***i*** (%, NF-M03-037).
The SOCOR laboratory also used an analogous approximate equation for LCV calculation from the measured HCV-value by bomb calorimeter and the obtained mass percentages of carbon (%C), hydrogen (%H) and humidity (%W). These chemical contents of the studied agro-wastes were determined using a (C, H, W)-Parr Analyzer. The adopted values were arithmetical mean of the two results for HCV(*i*) on dry, in one side, and the LCV(*i*) on crude, on the other. The LCV(i) values on crude basis have finally been chosen pursuing the current investigation for simply accounting for the fact that, all the testing alternate combustibles truly burned in situ, in their raw state, because no treatment was applied.
As it's clearly known, the produced heat from combustion must be sufficient for covering the needs in heat for cooking clinker, including that part for preheating raw material, from the disposed cyclones upstream of furnace which, under the nominal running conditions, consumed about 7,200 L/h of fuel-oil [1, 7]. For that reason, it's convenient to prior choose a target of a partial fuel-oil substitution and secondly adopt usage of a higher alternate waste ratio as possible, in order achieving a significant reduction of the petroleum products consumption rate by furnace. Subsequently, the experimental procedure itself had consisted effectively on introducing each of the chosen waste/residue into the clinker furnace, at the same time as continuing to provide a compulsory permanent proportion of the classical fuel-oil as balance. Corresponding fraction of fuel-oil mass flow-rate (Q_{AFOF}), to be added to that of a selected agricultural residue/waste (Q_{AW}), could then be calculated from the established heat balance between the two combustibles kinds. The derived equation was expressed as following:

$$Q_{AFOF} = \left[LCV_{FO}\left(Q_{FO} \cdot \rho_{FO}\right) - Q_{AW} \cdot \rho_{AW} \cdot \left(LCV_{AW} / LCV_{FO}\right)\right] \quad (3)$$

The selected agro-waste quantity (Q_{AW}, kg/h), owning a lower calorific value (LCV_{AW}, kcal/kg) and loose state density ρ_{AW} (kg/m^3) which combustion must generate the same heat quantity as that provided by the classical fuel-oil quantity Q_{FO} (=7,200 L/h) of density ρ_{FO} (=0.86 kg/L) and LCV_{FO} (=9,700 kcal/kg), had been simulated using equation (3). This allowed us to deduce the corresponding added fuel-oil flow-rate fraction (Q_{AFOF}, kg/h).

3.2.2. Substitution rate estimation. The substitution rate (σ_r) was defined as percentage ratio, built on basis of the supplied heat quantity by a chosen alternate combustible only to that delivered by the use of combined agro-waste and fuel-oil (equivalent to furnished normal fuel-oil heat quantity),. It's expressed by the derived following equation from the heat balance:

$$\sigma_r = 100 \cdot \left(Q_{AW} \cdot LCV_{AW}\right) / \left[\left(Q_{AW} \cdot LCV_{AW}\right) + \left(Q_{AFOF} \cdot LCV_{FO}\right)\right] \quad (\%) \quad (4)$$

It was also important to notice that, effective implementation for testing worn-tires conducted to major changes in the furnace feeder, as made choice was un-pretreated entire tires use into it. Then, a tires' conveyor-lift system coupling to an adequate control locks reassuring the furnace feeding was designed and built.

3.2.3. Achieved cements quality. Two important parameters have been exclusively evaluated for quality testing of the reached cements using these targeted agricultural and industrial residues.

3.2.4. Cements mechanical resistance. It's important that the derived cements be mechanically certified. The breaking strength measurement, through standardized compression, was the elected mechanical method of evaluation applied to normalized mortar specimens from the achieved cements from these studied agricultural/industrial wastes/residues. Mortar specimens of 40x40x160 mm dimensions have been realized and conditioned according to NF-EN196-1 standards. Natural sand of 2,600 kg/m^3 absolute density interred the specimen's realization on weight basis of 1,350 g for 450 g of cement and 225 g of water (ratio Water/Cement=0.50). Built specimens were submitted to compression test exploiting the Universal SATEC MKIII-60TVL press type having maximal capacity 5,000 N, belonging to Civil Engineering Research Entity of LEMA.

3.2.5. Cement's quality at composition's point of view. The X-fluorescence spectrometry (FX), reference for nondestructive elemental analysis in many applications, such as cement, mining and food products, was used in this study. Percentages of various components of the produced cements from the selected agricultural wastes and worn tires were determined. A comparison has finally been realized between these different percentages and that of classical cement produced without any incorporation of agricultural waste or worn tires, but simply on basis of the applied production practices at CCO until there, i.e., according to the standardized reference of 2004.

IV. RESULTS AND DISCUSSION

The realized physicochemical and energetic analyses, on different studied agro-wastes and industrial residues, have yielded the constituents percentages and LCV-values gathered in Table 1.

Table 1- Physicochemical and energetic characteristics of the studied wastes and references

Parameters	**Carbon**	**Hydrogen**	**Humidity**	**Others** *	**LCV (kcal/kg)**
Viewed wastes	(% mass)				
Cotton-fibers waste	33.7	4.57	6.15	55.58	**2,814**
Cottonseeds waste	52.4	7.09	6.8	33.71	**4,784**
Cottonseeds hulls	46.8	5.58	10.9	36.72	**3,738**
Wood-sawdust	51.55	6.12	11.6	30.74	**4,271**
Wood-chips	51.7	6.05	8.7	33.55	**4,279**
Cotton fibers	44.7	6.11	6.2	42.99	**3,953**
Oil-palm bunches	As determined by authors [10, 16]				**3,000**
Worn-tires	with textile reinforcement [17]				**8,600**
Worn-tires	with feeble metallic reinforcement [17]				**8,500**
Worn-tires	with high metallic reinforcement [17]				**5,900**
Gas oil (Sonacop)	As determined by authors [10, 11, 21]				**10,300**
Heavy fuel-oil n°2	As determined by authors [10, 20, 21]				**9,700**

* Values in labeled column as "Others" are those deduced from 100 % after summing values of measured constituents that not interred the LCV expression

In the last two rows of Table 1 were indicated the LCV-values of conventionally used heavy fuel-oil and diesel (gas oil) at CCO factory. Finally, apart from tests on tires, that have lasted up to 48 hours continuously, the done others on the agro-wastes were not as long: experimental times ranging from 02 hours 30 minutes to 06 hours. The reasons of these limitations were particular, either to the small amount of stored agro-wastes for investigation or to the recorded poor performance during some experiments which have been stopped sooner than stipulated. This fact was also justified by the associated difficulties with the storage means of these identified residues (chiefly the lack of storage spaces) and technical problems, essentially due to the occurred failures on combustible forklift and furnace's feeder-valve during these done tests.

4.1. Cotton-fibers wastes

Results from the performed energetic analyzes for cotton-fibers waste revealed an average LCV-value of 2,813kcal/kg. This was very low in comparison with the furnished classical LCV-values respectively for fuel-oil 9,700kcal/kg and diesel or gas-oil with 10,300kcal/kg. These accomplished practical tests in situ showed that the cotton-fibers could be burnt in cement furnace but more elevated quantity must be provided for reaching the same heat capacity level as that of classically used fuel-oil. It then remained how to ensure the availability, required quantity and sustainability of the cotton-fiber wastes. Indeed, the recorded data on evolution of the produced cotton-crops in Benin, during different cotton campaigns, from 1995 to 2015, were depicted on Figure 1.

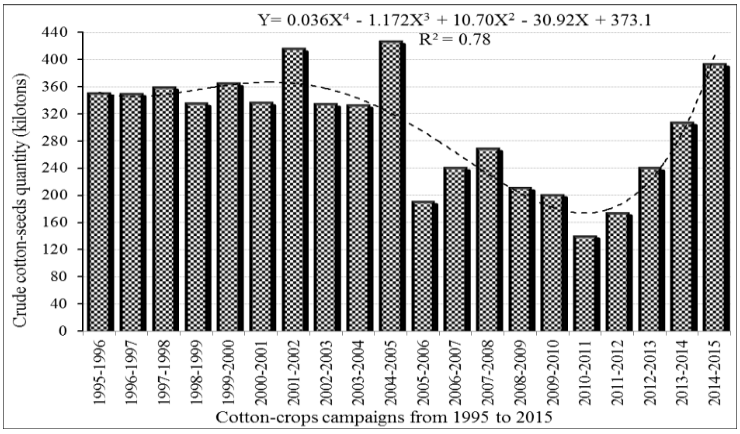

Figure 1- Evolution of the produced cotton crops from 1995 to 2015 campaigns in Benin (Inter professional Cotton Association of Bénin: http: //www.aic.org.bj)

Analysis of evolution of the produced cotton-crops data (Figure 1) reveals a polynomial tendency with feeble regression coefficient (R^2 = 0.78). These shown data let us known about the existing very unstable situation in cotton production in Benin. Cotton-crops production restarts with new rise, from only the three last campaigns, without however reaching the greatest value ever obtained up to now: that of 2004-2005 campaign. This raw material (crude cotton in seeds) underwent the first industrial transformation in, at means, fifteen cotton-gins spreading on all the national territory. All these cotton-gins factories spit two (02) kinds of cotton-wastes: the fiber wastes for about 0.5% of yearly crops and the gin-mot for 2%, both these two residues amount being of 2.5% of yearly crops. Average quantities of the combined two cotton-wastes kinds, on basis of the determined 2.5% cotton-crops values, from 1995 to 2015 campaigns, were those listed in columns 2 and 4 of Table 2.
The mean-value of the produced cotton-fibers waste in Benin, from 1995 to 2015 cotton-crops campaigns, was then estimated to 6,146±1,802 tons/year. It must be underlined that, such the shown annual quantities of cotton residues were truly underestimated. These wastes/residues amounts have been usually released in the surround environment if not incinerated outdoors. A relative small or insignificant part of these cotton-waste kinds was often recovered by mattress makers for manufacturing their sold various articles. These cotton-fibers waste continued to suffer a decline at the same rate as done the annual crude cotton crops from 2004-2005 seasons. This same tendency was also observed in all the West African sub-region. In recent years, the cotton market had fluctuated and the effects were severely felt by African producers. Despite the initiated stimulus by Beninese government towards the cotton producers and creation of the Cotton Development Corporation (SODECO), the downward tendency seemed unlikely to change, especially because of the low cotton price on international market. In other words, there existed an effective energy source in cotton-fibers waste, but not sufficient for supplying the clinker furnace. In addition, it was spread over the existent fifteen ginning machines on national territory and availability also seasonal. A large stock of cotton-fibers waste was therefore needed for covering peak periods. However, if this possible, through efforts to enhance cotton-seeds production, increasing the amount of fibers-waste should rather reflect poor quality of the global produced cotton-crops. Such a thing could not be desired by actors of the cotton sector.

Table 2- Estimated quantities of cotton-fibers wastes (tons) by campaigns from 1995 to 2015 in Benin

Campaigns	**Cotton-Fibers wastes**	**Campaigns**	**Cotton-Fibers wastes**
1995-1996	**7,356**	2005-2006	**4,000**
1996-1997	**7,340**	2006-2007	**5,049**
1997-1998	**7,543**	2007-2008	**5,641**
1998-1999	**7,037**	2008-2009	**4,424**
1999-2000	**7,651**	2009-2010	**4,215**
2000-2001	**7,062**	2010-2011	**2,940**
2001-2002	**8,723**	2011-2012	**3,654**
2002-2003	**7,015**	2012-2013	**5,040**
2003-2004	**6,981**	2013-2014	**6,447**
2004-2005	**8,951**	2014-2015	**8,253**
Mean-value of estimated quantity of cotton-fibers wastes: 6,146 ± 1,802 tons/year			

It followed nevertheless that, the fibers-waste could then be supplemented by another residue type: cottonseeds-hulls. The latter ensued from cottonseeds crushing at oil-mills. It was quantitatively more important than fibers-waste and certainly as appropriate as fibers for the clinker furnace feeding.

4.2. Cotton-seeds hulls

Results from chemical and energetic analyses of cottonseeds hulls were shown in line 4 of Table 1. It must be noticed that these obtained values were consistent with those found in literature [9, 10, 11] and in Fludor-Benin archives [12]. In fact, the shell (hull) represented 19% by weight of fresh cotton-seed, had a density of 130-160 kg/m^3, provided a LCV-value of 3,895kcal/kg and contained 3.4% of minerals. Cottonseeds-hulls were energetically best than that of cotton-fibers waste with 3,738 kcal/kg against 2,813 kcal/kg. Already used for feeding boilers at Fludor-Benin s. a Company, these shells/hulls could also be efficiently used in the clinker furnace. In fact, the seeds were considered as the by-products or wastes of cotton ginning. But, the cottonseeds constituted the raw material for crushing plants like those of Fludor-Benin s. a, the Benin Oils Society at Bohicon (SHB) and the Benin Fats Materials Industry (IBCG) at Cotonou. Annual excesses of cottonseeds-hulls, which represented the difference between the real quantity of hulls from the crushed seeds and the reserved part for internal self-consumption of these companies (exclusively devoted to boilers and livestock feed mill units), were estimated to 35,000 t for Fludor-Benin [12] and 40,000 t for SHB [13,14] and therefore judged substantial. These values did not integrate that of cotton-whole-seeds resulting from the excess uncrushed quantity of oil-mills which was usually rejected in the open air.

4.3. Wood-chips and wood-sawdust

The recorded results from chemical and energetic analyses of the wood-sawdust and wood-chips were those gathered in the respective lines 5 and 6 of Table 1.
It could be observed that the LCV-value of wood-sawdust was of the same order as wood-chips, two considered wastes from the same wood substance: 4,272-4,279 kcal/kg. Both these two results showed that, values of LCV of the wood wastes were higher than those of cotton-fibers / cotton-fibers wastes (3,953 / 2,814 kcal/kg) and cottonseeds-hulls (3,738 kcal/kg), but not that of entire cottonseeds (4,784 kcal/kg). Of course, the noticed differences linked with the fact that the cottonseeds or seeds-hulls contained relative oil percentages which consisted on hydrocarbon substances known as veritable fuel. Knowledge of these data offered the advantage for helping guide the eventual choice towards wood-wastes (chips or sawdust) at the expense of cotton-wastes. Indeed, respective quantities of the really tested wastes or residues (Q_{AW}, column 2) and those of equal fuel-oil (Q_{FO}, column 4), for generating the same heat power (column 3), have been experimentally evaluated. The results were also expressed in form of the called equivalent ratios **(ε_r)** which values gathered in Table 3 (column 5, accompanied with inverse 1/ε_r in brackets). It could be underlined that, for producing the same heat energy amount as that of commonly used fuel-oil in the clinker kiln, approximately 9,700 kcal/kg, it must be consumed 2.40 tons of wood-sawdust against 4.20 tons of cotton-fibers waste or 2.03 tons of cottonseeds-hulls. The wood-sawdust and wood-chips were two residue types from wood sawing and wood planning processes respectively. The sawmill plant of Saclo (Bohicon) at the National Wood Office of Benin (ONAB), operated eight (08) hours per day and delivered approximately 2,000 m^3 of wood. The generated residues consisted of falling trunks and branches of trees, wood-chips and wood-sawdust. Quantity of these residues had been reasonably estimated to about half of the wood total production: 1,000 m^3 a day.

Table 3- Calculated equivalent ratio from each quantity of the tested wastes and that of the burnt fuel-oil

Studied Alternate Agro-Wastes / Industrial Residues (As Combustible)	**Used Waste Quantity (Tons)**	**Produced Energy Quantity (Kwh)**	**Equivalent Fuel-Oil (Tons)**	**Ratio** $\varepsilon_r = \frac{Q_{FO}}{Q_{AW}}$ **(1/Er)**
Worn Tires	**18,654**	173,557	15,385	**0.82** (1.21)
Cotton-Fibers Waste	**13,56**	36,398	3,226	**0.24** (4.20)
Cotton-Whole Seeds	**5,40**	30,042	2,663	**0.49** (2.03)
Oil-Palm Bunches	**8,17**	28,496	2,526	**0.31** (3.20)
Wood-Sawdust	**12,195**	57,782	5,122	**0.42** (2.40)

Falling logs were retrieved and used as wood or charcoal in cooking. The wood chips and sawdust spilled loose near the sawmill site. According to existent literature, the amount of sawdust averaged 12% of initial volume of the wood residues against 32% for the finest particles of the woodworks [9]**.** At Saclo sawmill, the excess teak sawdust alone was estimated at 3,500 m^3 per year. A tiny amount, not as much as 0.5% of previous value, was recovered by local residents for domestic usages [9, 10, 23]. The energetic valuation of the remnant sawdust, through an industrial kiln, required that annual stock higher than estimated and conditioning to dry.

4.4. Oil-palm bunches
Literature provided globally the LCV-values of 1,100 - 3,800 kcal/kg for oil-palm wastes [11, 15]. The oil-palm bunches at Agonvy displayed an average LCV-value 3,996 kcal/kg, for annual production amount of more than 8,000 tons [16]. In this study, we've chosen to adopt an average value of LCV 3,000 kcal/kg. The use of oil-palm bunches had led to difficulties for conducting the kiln. It effectively caused a slight production decrease due to the generated lower combustion temperatures linked to the trouble burning of palm bunches at the kiln entrance. In other words, the amount of produced heat by the oil-palm bunches failed compensating the connected fraction to the fuel-oil reduction. This poor combustion of oil-palm bunches was due, not only to waste kind higher humidity and ashes contents, but also to the residue handling difficulties and especially congestion of feeder airlock, all things leading to a very low exchange ratio. It was also suitable to emphasize the required delicacy for oil-palm bunches storage. In reality, the storage required not only, availability of an important heat source for drying bunches, but also subsequent realization of suitable devices without which breakdown was unavoidable.

4.5. Worn tires testing
Determination of LCV value of the used worn tires in the current investigation had not been realized. The reasons are related to diversity of the collected tires for this experiments campaign, but also at high cost of analysis and at insufficient of financial resources. In the absence of such analysis, indicative data on tires LCV values were taken from literature [17].
The results on Figure 2 clearly showed that the published values for the Lower Calorific Value of cars' tires varied as function of tires constitution, including mainly the types of structure reinforcements.

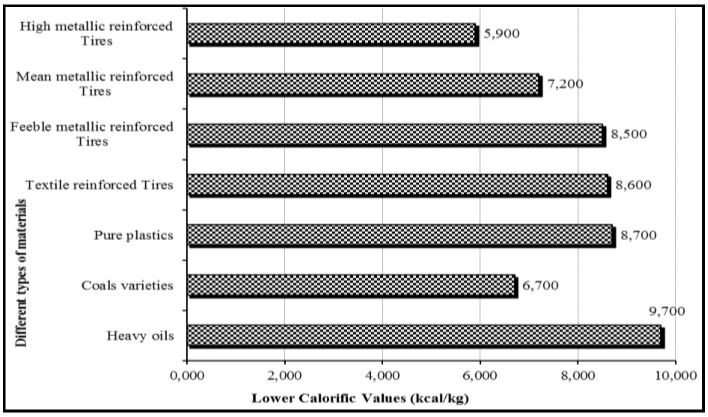

Figure 2- Values of LCV (kcal/kg) for some materials showing that worn tires LCV vary according to structural reinforcement types [17]

Table 4- Indicative data on mean-values for chemical composition of the cars worn-tires [17]

Constituents	Proportions	Unity
Carbon	70	%
Iron	16	%
Hydrogen	7	%
Oxygen	4	%
Zinc oxide	1	%
Sulfur	1	%
Nitrogen	0.5	%
Stearic acid	0.3	%
Halogenious	0.1	%
Cuprifer links	200	mg/kg
Cadmium	10	mg/kg
Chromium	90	mg/kg
Lead	50	mg/kg
Nickel	80	mg/kg

Depending on whether the tires belonged to ordinary cars, buses and heavy equipments, the metallic reinforcement, expressed as a percentage of tires mass, changed from respectively, less than 5%, between 5 and 25%, to over 25%. As part of this investigation, a mixture of different tires kinds was used. Thus, the considered LCV value for this work was arithmetic mean of those from the four (04) tires varieties shown in Figure 2:

7,550kcal/kg. It outcame that, this adopted tires LCV-value was not very far from the often cited one in literature: 8,000kcal/kg. If excluding, from Figure 2, the data relating to the high metallic reinforced tires that belonging to heavy equipments (less interesting tires category for feeding the tested clinker kiln), reached average LCV value of 8,100 kcal/kg then fairly closed to that of literature: 8,000 kcal/kg.
Indicative values on chemical composition of the motorcars overall tires were depicted in Table 4. These shown components values in table 4 truly proved that, the worn tires, due to their high carbon and hydrogen contents, constituted a very usable energy source in the cement process for the required cooking of clinker.

4.6. X-Fluorescence Spectrometry Analyses

Basic chemical constituents of the burned alternate combustibles could produce ashes and other by-components that might contribute to changes some of the cementing indexes, such as the alumina-ironic modulus (AFM) and silicate modulus (SM) provided respectively by their iron and silica contents. Such the changes exerted effects, not only on the quality of clinkers, but also on energetic consumption and the tenacity of refractors bricks for the furnace's inner isolation [25, 27, 28]. The alkaline degrading attacks of refractory bricks, due to N_a and K components, might be recorded. Increasing of the thermal conductivity of isolating bricks, that provoking excessive heating of furnace envelop, could sometimes be observed under diffusion and attacks from defined salts like N_aCl, KCl and K_2SO_4. To discomfit this possible occurrence, results of the performed X-fluorescence spectrometry analyzes, on the one hand (Figure 3) and those from the compatibility study of the burned tires and wood-sawdust with the obtained cements quality, on the other hand, clearly showed that the chemical compositions of resultant clinkers were not significantly affected by combustion of added worn tires, cottonseeds wastes or oil-palm bunches in clinker furnace. When comparison is made with the current reference 2004 in cement field, one can clearly observe and satisfactorily, that the obtained values, for different constitutive oxides of the produced clinkers using the selected wastes or residues as alternate combustibles to fuel-oil (Figure 3), are truly consistent with the technical normative values. Everything that ensures process feasibility and justifies of the best quality of the derived clinkers from agricultural and industrial waste valorization in cement filed.

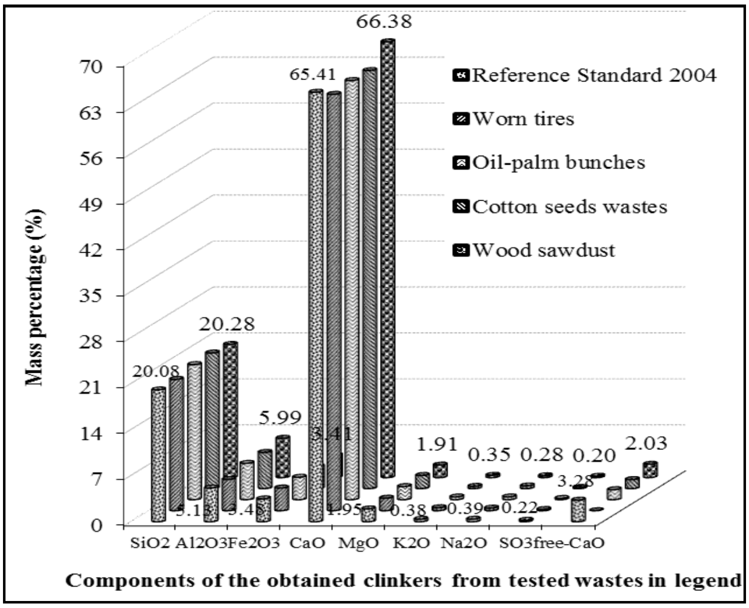

Figure 3- Chemical compositions of obtained various clinkers from the studied alternate wastes (legend) using X-fluorescence spectrometer analysis compared to standardized reference 2004

The noticed slight differences in monitored values could be attributed to low free-C_aO contents of the produced cements from the burnt wastes in comparison with that of Reference standard 2004. In fact, free-C_aO values of 1.38±0.90 to 1.59±0.05% cement mass proportions have been quantified contrary to about 3.28±0.50% for the standardized reference 2004, excepted for that of wood-sawdust which showed more important value of 2.03%. At this level of chemical composition, these recorded data on the resulting cements characteristics from the selected wastes led to the conclusion that they were as good quality as the reference standard 2004.
This furnished chemical behavior really justified the found complementary and practical chosen mechanical analysis. As said and its methodology described above, the adopted mechanical measurement was that of compression testing on built mortar specimen from obtained cements using the mixes of agro-wastes and fuel-oil burned in clinker furnace.

4.7. Mortar specimens' breaking strength

In order to better confirm the previous chemical quality of the derived cements, standard specimens of cement mortar have been realized and submitted to compression testing for breaking strength determination. The results of the performed mechanical tests, using obtained respective cements from combustion of worn-tires on one hand, and wood-sawdust on the other, attested of their very good resistances in compression test. Indeed, the recorded data from mechanical measurements showed very interesting resistance values for the ensued cements which effectively exposed, at only two (02) days old, respectively compressive strength values of 22±0.64 MPa and 25.79±0.11 MPa. For a brief comparison, usually published values, at 28-days old, were of order of 15-18 MPa [2-6, 24, 26]. The explanation attempt to this developed behavior by obtained cements from the burnt wastes had not yet been completed. It's first thought that these monitored higher values of breaking strength were linked with iron content and derived constitutive metallic oxides from tires reinforcement. In that, they could probably contribute to reinforcing of resultant materials and thus justified the observed favorably high difference at contrary to produced cement-mortar specimens using classical fuel-oil alone. The performed analysis on constitutive oxides of these clinkers clearly proved that all of their metallic oxides mass percentages were practically of the same values order: 3.35 to 3.48 for Fe_2O_3, 4.76 to 5.99 for Al_2O_3 and 1.91 to 2.0 for MgO. However, apart from the wood-sawdust for which CaO (66.38%) and free-CaO (2.03%) percentages were fairly of the same order values as for standardized reference ones (65.41%) and (3.28±0.50%), those from the obtained other cements seemed slightly feeble (63.42 to 63.86%) and (1.38±0.90 to 1.59±0.05%), Further analysis of the recorded data revealed that carbon components as C_2S, C_3S, free-C_3S, C_3A and C_4AF of cements from the burnt wastes were relatively higher than those for standardized reference 2004. Finally, the noticed high resistance for cement-mortar specimen in compression had therefore been attributed to higher values of cements contents relative to their carbon components and free-CaO. These technical results were considered sufficiently relevant, inspiring and encouraging to rather convincing the CCO authorities to put their first choice on worn tires at expense of the other targeted agro-wastes, as it was possible to have quantitatively tires. Seeing the amount of consumed fuel-oil by the clinker kiln, it could a priori assume that the available quantity of tires in the long term was very low or insignificant to meet energy needs. In fact, worn tires from cars or other moving equipments were non-biodegradable industrial wastes. No statistics on available worn-tires currently existed on their end use limited in Benin. The assessment of effective annual quantity of damaged tires was not really possible without knowledge of habits of the vehicle owners. However, it could be estimated to hundreds of thousands of tons scattered mainly in the big cities of country where worn tires were cluttered including some sidewalks and roundabouts where vulcanization handicrafts worker installed. Some of these damaged tires often, but in very insignificant quantity, also served as ballasts to the local built canoes in lagoon areas. For a developed country, such as France and Germany, the average rate of wear tire was about one (01) tire per/car/year. Under the pressure of motor vehicles and reshaped tires markets, one could reasonably adopt, for West African sub-regional countries, a status of order of 0.5 worn tires per car yearly. This estimation did not preclude the use of additional import tires, if the make choice was for sustainable supply of the kiln. It would then remain solutions to problems of tires collection, mainly from existing sprinkled locations to factory destination.

V. BRIEF ECONOMIC ANALYSIS

In the Table 5 were gathered results from the realized experiments on clinker furnace using the cited wastes, their regular attained substitution ratios, the produced energy and expensed financial costs, equivalent and corresponding fuel-oil costs that allowed us deducing financial and fuel-oil equivalent quantity reductions.

Table 5- Recorded data from experimental combustion of different targeted alternate agro-industrial wastes in rotating clinker furnace of Onigbolo Cement Complex

Targeted alternate wastes types	Burned wastes quantities (tons)	Obtained substitution ratio (%)	Produced energy (kWh)	Expensed agro-waste costs (kF)	Equivalent fuel-oil costs (kF)	Financial reduction per ton of waste (kF)	Fuel-oil equivalent quantity (tons)
Worn-tires	18.65	5.2	173,557	1,879.90	2,540.71	34,43	4.002
Cotton-fibers waste	13.56	4.8	36,398	440.80	532.75	6,78	0.557
Whole cottonseeds	5.40	6.8	30,042	427.40	439.77	2,29	0.075
Oil-palm bunches	8.17	4.6	28,496	258.96	417.15	18,51	0.916
Wood-sawdust	12.20	9.5	57,782	337.75	845.86	41,682	3.078

From those technical and economical recorded data, it ensued that the wood sawdust constituted the potentially most important alternative agro-waste convenient for rotating clinker furnace of Onigbolo Cement Complex. The production of thermal energy from 12.195 t of wood sawdust, at substitution rate of about 9.5%, allowed generating a financial economy of 508.31 kF (CFA) corresponding to 3.08 t of equivalent fuel-oil in only 8.5 hours testing. The figure 4 disclosed the results of the comparative analysis made on basis of the reached substitution rates for different experimented agro-wastes. It's also shown the corresponding reduction values of financial cost looking upon to the burned classical fuel-oil. Indeed, these reductions expressed the equivalent fuel-oil quantities that have been economized on various wastes at these shown substitution ratio levels. A more high value of substitution ratio of 11.97% had also been attained for the wood-sawdust, at flow-rate value of 1.86t/h and 3 hours 30 min experimental running. The limited stock of available wood sawdust in furnace site did not allowed pursuing the flow-rate increase for this alternate agro-waste. It's clear that, other waste kind should be associated to wood-sawdust for obtaining higher substitution rate than the one actually reached: cottonseeds or cottonseeds-hulls might be combined to wood-sawdust.

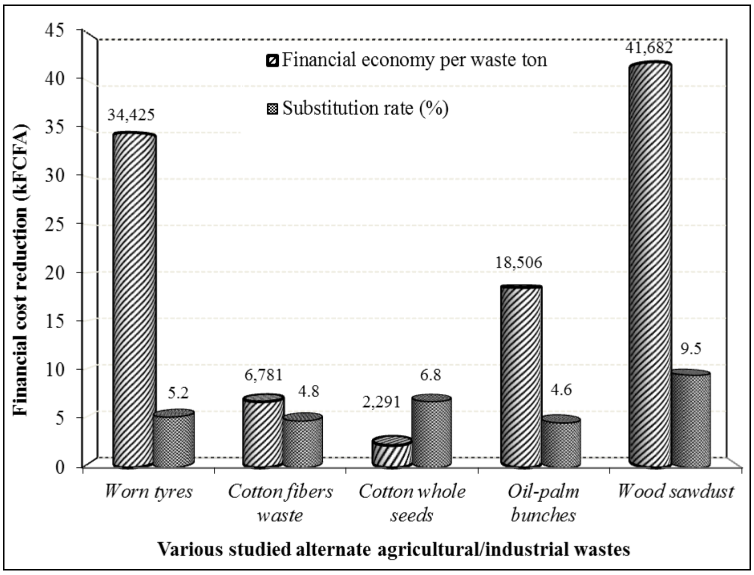

Figure 4- Financial costs reduction for each ton of the tested alternate agro/industrial wastes (kF/ton) and corresponding reached substitution ratios (%).

The production of thermal energy from 18.654 t worn tires, at substitution ratio of minus 5.2%, permitted of course an economy of 660.81 kF(CFA) corresponding to 4.002 tons of equivalent fuel-oil for 48.5 hours testing. It's also clear that, an appropriate pretreatment should be applied to the worn-tires, for combustion improvement, like cutting them into particles of very small sizes against their actual use in the whole state.

V. WASTES COLLECTION

The supply of alternative wastes to clinker kiln should not be steady if an effective strategy for collection was not established. This could be developed in two phases: the agro-industrial residues (cotton, wood, shells and stalks) on the one hand, and worn tires, without forgetting the waste oil from draining engines and gearboxes, on the other hand.

6.1. Selected agro-industrial wastes

The problem was relatively easy to solve in case of industrial agro-wastes for wood, cottonseeds and oil-palm bunches. In principle, the signing of partnership agreements for the removal of wastes and residues between the Cement Complex of Onigbolo and the waste generators might be sufficient. One indexed the wood sawmills of Saclo, the cotton ginning and seeds crushing factories, without ignoring the oil-palm mills of Agonvy and Hinvi added to the generated wood sawdust by small private sawmill units. The transport was then managed by the CCO sales department. After delivery of cement, the latter should directed its trucks towards wastes/residues pick-up points, on returning to the cement factory location.

Another type of usable residue as complementary was one consisting on shells from oil-palm kernels with a LCV value 3,500 kcal/kg. These shells were generated by Agonvy and Hinvi oil-palm mills: 17.5 tons/week/plant. Part of this kind oil-palm waste, added to a mixture of dry cakes and fibers, was classically used for autonomously feeding boilers of the mills [15]. In addition, there was a third type of cotton residue, the stems, non-targeted in this work. It was available in Benin as by-products [18, 19] and its LCV-value of 4,108 kcal/kg indicated that it was energy recoverable [9-11, 20, 23]. However, the use of cotton stems in clinker kiln was much more difficult compared to the selected two previous cotton wastes. These underlined difficulties for stems were related to the rods shape, their collection (because widely dispersed) and especially their handling which required pretreatment as cutting before being introducing in the kiln feeder. The average annual production of cotton stalks, on the basis of unit weight of dry stem (23.8 g/stem) [18] and the covered area over the past decade (320,000 ha) [19], was estimated at 460,000 tons. Based on recorded statistics on the cotton marketing from 1995 to 2011, the annual amount of stems essentially recoverable by energy way could be estimated at 280,000 tons.

6.2. Worn tires collection

For deteriorated worn tires, the collection management was a far more difficult to solve. Here, the abundance of tires was necessary but insufficient for warranting the sustainable supply of clinker furnace. Appropriate awareness campaigns towards populations were then needed to get them joining organization for the collection of this industrial type waste. Involvement of the governing class was pleasing at this level to ensure that the existent worn tires have been effectively delivered to CCO factory for the kiln feeding. It was only after such an accession that the responsibility for organizing the collection might be entrusted to an efficient private company.

VI. CONCLUSION

Consumption's reduction of petroleum products in cement industry, through the substitution of agricultural or industrial residues, had been studied. The energetic analyzes results of residues, on the one hand, and testing in the cement furnace, on the other hand, showed that the cement process was conducive to energy recovery from wastes. The recorded data, on the lower heating values of studied residues, were all often low compared to that of reference fuel-oil. It followed that the amounts of required waste to sustainably producing an equivalent energy quantity to that of fuel-oil were relatively huge and also depended on the types of residues. These results proved that none of the tested alternative combustibles could alone be sufficient to meet the needed energy for the process. A significant substitution ratio was then possible by combining different kinds of residues with the fuel-oil, especially since some residues were seasonal, cases for cotton-wastes and oil-palm bunches. However, results of post-manufacture analyses, mainly by spectrometry X-fluorescence and compression test, for quality certification of obtained various cements, showed that no significant change was detected in the composition of the obtained clinkers compared to the normative value, on the one hand, and very good resistances in compression testing, with respectively 22±0.64 MPa from worn tires and 25.79±0.11 MPa for sawdust, on the other. Used worn-tires or wood-sawdust in addition induced a significant and beneficial effect on short-term strength of the ensued cements. An improvement in this achieved good performance with worn-tires was feasible and could be linked to a pre-cut into particles of convenient small sizes. Attained technical and economical performances led to conclusion that wood-sawdust remained the best alternate agro-waste to burn in the CCO rotating clinker furnace as substitute to fuel-oil prior to the tested other wastes. Experimentations, using depleted oils, as well as the extracted ones from non-food crops, such as Jatropha oil, constituted a perspective study. The cement manufacture, through effective use of the selected residues in clinker furnace, could greatly contribute to pollutants reduction and subsequently help to improve environment cleaning.

ACKNOWLEDGEMENTS

The authors express their gratitude to the authorities of Cement-Complex-Onigbolo, for allowing and then physically accompanied effective realization of these life-size experiments in their clinker-furnace and recruitment of Mr. Houngbédji Martin at CCO, following this research work.

REFERENCES

[1]. F.L. Smith. Fours à voie sèche. Document Technique, 1-51, 1978.
[2]. Lawrie, E., Word Cement. The Cement Technical Journal, 29(7):45–57, 1998.
[3]. F. Paulin. Word Cement. The Cement Technical Journal, 29(7):81–84, 1998.
[4]. J.A. Rosenhøj. International Cement Review. May, 30–36, 1993.
[5]. W.H. Duda. Cement Data-Book. Tome 1, International Process Engineering in the Cement Industry, Bauvelag GmBh Wiesbaden und Berlin, 3d Editions, 1985.
[6]. E. Mecum VaD. Corporate Technical Services. Cement Proc. Eng., 1-130, 2000.
[7]. P. Bruneau. Documents techniques de formation des opérateurs de fours à clinker, 6-47, 2005.
[8]. E. Ngo-Ndjella and Z. Okiri. La gestion de l'énergie dans une cimenterie: application à la Société des Ciments d'Onigbolo. Mém. Ing. Trav. CPU. Bénin, 19-86, 1996.
[9]. J. Carré, B. Ben Abdallah, S. Khennas, L-F Vergnet and P. Ossukail. Guide Biomasse - Energie. Edition Academia, 108-320, 1994.
[10]. J. Hébert. Contribution à l'étude de la valorisation énergétique des résidus végétaux par la densification. Ph.D Thesis, FSA Gembloux, 37-154, 1988.
[11]. Y. Lahaye. La valorisation des sous-produits de l'agro-industrie camerounaise. OCBCE. Bruxelles, 13-79, 1986.

[12]. M.V.V. Goubali. Etudes technique et économique de la production d'électricité par valorisation énergétique des coques de graines de coton à Fludor– Bénin s.a. Mém. Ing. Trav. CPU, Bénin, 1-85, 2004.

[13]. H. Kottin. Valorisation énergétique des coques de graines de coton à la Société des Huileries du Bénin. Mém. Ing. Trav., CPU Bénin, 18-66, 2003.

[14]. F.R. Zannou and J.M. Zinsalo. Etude des échanges thermiques dans le processus d'extraction d'huile par solvant en vue d'une réduction des pertes d'hexane à la SHB. Rapp. Lic. Pro., Iut-Lok. Bénin, 21-84, 2006.

[15]. M. Soglo. Etude et analyse critique du système autonome de production d'énergie de l'huilerie du Grand Agonvy. Mém. Ing. Trav. CPU, Bénin, 19-87, 1995.

[16]. A.M. Toni. Production d'énergie électrique par gazéification: étude et réalisation des équipements d'une centrale pour une valorisation des rafles de palmiers à huile dans le sud du Bénin. Mém. Ing. Trav. CPU, 15-76, 2003.

[17]. Anonyme, http://www.umweltschweiz.ch/impercia/md/content/abfall/altpneu.f.pdf/, visité le 17 Mars 2010.

[18]. H.P. Assogba. Etude de la faisabilité d'un projet d'électrification par gazéification de la biomasse: Application aux tiges de coton pour l'électrification de l'arrondissement de Founougo (Banikoara). Mém. Ing. Trav. CPU, Bénin, 17-98, 2003.

[19]. D.R.F. Adandédjan. Etude de faisabilité d'un projet de valorisation énergétique de la biomasse: étude de cas des tiges de coton pour la production de briquettes combustibles. Lic. Pro. IUT-Lok, Bénin, 1-80, 2008.

[20]. P. Lequeux, J. Carré, J. Hébert, L. Lacrosse and Y. Schenkel. Energie – biomasse: la densification. Press. Agro. Gembloux, 1-188, 1990.

[21]. A. Guillermic. Caractéristiques des combustibles, problèmes de combustion, de corrosions, de pollution atmosphérique. In Le chauffage par les combustibles liquides: Tome 1. Technip, 107-130, 1980.

[22]. J-C. Jacquemard. Le palmier à huile. Agricultures Tropicales en Poche. Collection Quae, 1-240, 2012.

[23]. M. Houngbédji and B. Djima. Vers une utilisation des combustibles alternatifs dans le four rotatif du Complexe Cimentier d'Onigbolo. Mém. Ing. Trav. CPU. Bénin, 22-98, 2003.

[24]. S. Ghabezloo. Comportement thermo-poro-mécanique d'un ciment pétrolier. Paris-Est/Ecole Nationale des Ponts et Chaussées Ph.D Thesis, 43-204, 2008.

[25]. R. Bastier, A. Bogan, B. Gilbert and A. Regnault. Fours de cimenterie - Ateliers de cuisson du clinker. Technique de l'Ingénieur. Fascicule BE8844. TI-B209DUO, 2000.

[26]. F. Dupray. Comportement du béton sous fort confinement: étude en compression et en extension triaxiales à l'échelle mésoscopique. Ph.D Thesis, Univ. Joseph Fourier, Grenoble I (France): 1-192, 2008.

[27]. T. Chappex and K.L Scrivener. The influence of aluminum on the dissolution of amorphous silica and its relation to alkali silica reaction. Cement Conc. Res., 42(12): 1645–1649, 2012.

[28]. M. Xian-Wei, C. Hu-Xing and W. Pei-Ming. Effect of CuO on the formation of clinker minerals and the hydration properties. Cement Conc. Res., 40(12): 1681–1687, 2010.

[29]. ISO-1928. Combustibles minéraux solides- Détermination du pouvoir calorifique supérieur par la méthode de la bombe calorimétrique et calcul du pouvoir calorifique inférieur. ISC: 75.160.10, 13-61, 2009.

[30]. F. Alemayehu and S. Omprakash. Minimization of Variation in Clinker Quality. Advances in Materials, 2 (2): 23-28, 2013. (doi: 10.11648/j.am.20130202.12).