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Energy Contribution of Oil Cakes Used as Fuel in Waste Boilers: Case of an Oil Mill in Côte D'ivoire

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Abstract: Côte d'Ivoire is the second palm oil producer country in Africa. The oil mills are generally located near the farms which are in rural areas. In fact, Côte d'Ivoire is self-sufficient in electricity; but the electric distribution network is not wide enough. So that it is difficult to access public electricity for most of rural areas. Therefore, to produce electricity traditional fuels group are used. Moreover, the cost of electricity production by turbo-alternators using traditional fuel such as DDO is higher than the cost of electricity produced by the national electrical company. The principal aim of this study is to show that the use of the waste produced by the oil mill can be used as fuel for the production of electricity in order to satisfy the energy needs. Solid waste from a palm oil mill is used as fuel for boilers. Three types of composition are carried out: solid waste only (Fuel 1), oil cake only (Fuel 2), a mixture of solid waste and oil cake (Fuel 3). Physicochemical and energy studies of these fuels have been made. And that allows giving the contribution of oil cake in energy production (superheated steam, electric power) in agro industrial unit.

Key words: Energy, oil cake, waste boiler, fuel, oil mill

INTRODUCTION

Côte d'Ivoire is the second palm oil producer country in Africa, with an annual production of 276 000 tons (Jacquemard, 1995). Fifteen tons of mode of palm can give, in average conditions, more than 3.5 tons of oil (Ribier and Rouzière, 1995; Département de l'agriculture, 1991). Thus, residues resulting from the transformation are about 906 857 tons for this country. This waste can be used for energy production apart from what they can be used as feeding stuffs or elements of compost. Various technologies exist which make it possible to transform this waste into energy. These technologies are usually gathered in first and second generation (FAO, 2008; Clashausen, 2007).

Wastes resulting from transformation of fruits of the palm tree in oil (seeds) are used as fuels (Fuel 1) in boilers in order to produce electricity for the oil mill. The nuts (almond) obtained after the production of the palm oil were sold in the state. Given the increase of oil price and concerns related to global warming. The production of energy from biomass is in full revival both in developed and in developing countries (Uwe, 2007; Jürgen, 2007). In Côte d'Ivoire for example, operators of sector of oilseeds started to transform nuts which they sold rough, to extract oil. The added-value of such operation is in a ratio of 4.6 (nuts initially sold to 100 euros/ton whereas the oil of almond is sold to 461.54 euros/ton). However, this transformation involves residues made up of hull and oil cakes, by-products which can be used as fuels in the boilers of the oil mills. These residues made it possible to implement Fuel 2 and Fuel 3. These fuels are composed for Fuel 2 exclusively by oil cakes (by-product of the transformation of the almond) and Fuel 3 is a combination of Fuel 1 and 2.

The object of this study is to evaluate the energy contribution of two new fuels and compare them to Fuel.

MATERIALS AND METHODS

In Côte d'Ivoire, the oil mills are usually installed in isolated agro-industrial areas (Tounon, 1996). To achieve their objectives, they need to produce energy, usually steam. This study was conducted from March 2006 to July 2009.

The produced vapour is partly used for production of electrical energy necessary to machinery of the factory and this starting from turbo alternators groups. The other part is used for specific operations such as palm bunch, fruits mixing, palm oil clarification and the drying of fibre, nuts, almond, hulls used as fuel in the boilers (Graille *et al*., 1981).

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Production of vapour and electricity in the oil mill Boiler: A boiler with a water pipe type BABCOCK SFMV 1157 ensure the production of superheated steam at 20-22 bars; 255-275°C. A set of equipment (water balloons, lateral collector screen, rear collector screen, super heater, fans of primary and secondary air, fan of pulling, fireplace, chimney sweep, power supply fuel) contribute to its optimum operation. In general bad combustion (excess of air) and thermal losses of the boiler are mainly due to the malfunctioning of the chimney sweeps and equipment to remove the ashes.

Turboalternators: The production of electricity of the oil mill is ensured by two turboalternator groups. They are equipped with steam turbines with a single wheel (single stage) and a back pressure. This back-pressure is at the origin of the racking of superheated steam at the exhaust. The vapour obtained at the exhaust is cooled until 2.5-3 bars ≈130°C to be used in the machining process (sterilization, mixing, clarification and then drying of solid waste).

Each turbine is coupled to a mechanical reducer which reduces the speed of its shaft (6000-7000 rpm). This allows the alternator shaft to turn at a speed of 1500 rpm.

Thus alternators convert mechanical energy into electrical energy distributed by the power station of oil mill. At start-up, in the event of call of significant loads, two generators CUMMINS provide additional electrical energy.

CHARACTERIZATION OF THE FUELS (SOLID WASTE, OIL CAKE)

Characteristic of fuel (solid waste) used in boilers

Components: Solid waste resulting from the treatment of palm bunches is the main fuel used in boilers of the oil mill. It is a mixture of fibres, hulls and fragment, representing on average 24% of the weight of the fresh bunch of palm trees (12% of fibres resulting from some pulp, 7% of hulls and 5% of fragment of palm-kernel resulting from palm nut) as shown in Fig. 1.

The components of this fuel are hydrogen, carbon, oxygen, sulphur and ash. Table 1 shows the mass composition of each component of the fuel used.

Mass composition: Three samples taken from the fuel are used in interval of 8 h.

Having weighed and sorted out them manually (separation components) we found that the fuel is composed by an average of 94.65% of fibres, 3.54% of hulls and 1.81% of fragment.

The drying of these three samples for 12 h at a temperature of 105°C provides a moisture (% H_2O) average of 30.9% after a double weighing (before and after steaming).

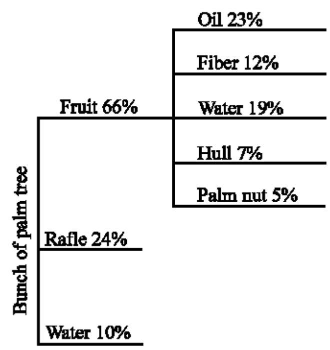

Fig. 1: Mass composition of the bunch and granulate of palm tree

Table 1: Mass composition of each component of fuel

	Components (%)				
Fuel	Carbon	Hydrogen	Oxygen	Sulphur	Ash
Fibres	46.8	6.6	41.7	0.4	4.5
Hulls	53.0	6.0	38.6	0.4	2.0
Debris	53.0	6.0	38.6	0.4	2.0

Table 2: Summary of the characteristics of three (3) samples of fuel

Samples	Mass before stoving (g)	Mass proportion (%)	Mass after stoving (g)	% H_2O	% H_2	PCS* (kcal kg^{-1})	PCI (kcal kg^{-1})
Sample 1							
Fibres	449	92.39	303.972	32.00	6.60	4600.00	2564.00
Hulls	26	5.35	22.386	13.90	6.00	4800.00	3725.40
fragment	11	2.26	9.471	13.90	6.00	4800.00	3725.40
Total 1	486	100.00	335.829	30.90	6.55	4615.20	2650.00
Sample 2							
Fibres	491	96.09	331.425	32.50	6.60	4600.00	2553.60
Hulls	11	2.15	9.042	17.80	6.00	4800.00	3514.80
Debris	9	1.76	7.398	17.80	6.00	4800.00	3514.80
Total 2	511	100.00	347.865	31.92	6.58	4607.83	2590.17
Sample 3							
Fibres	337	95.47	233.878	30.60	6.60	4600.00	2652.40
Hulls	11	3.12	9.427	14.30	6.00	4800.00	3703.80
Debris	5	1.41	4.285	14.30	6.00	4800.00	3703.80
Total 3	353	100.00	247.590	29.86	6.57	4609.07	2698.86

*The superior calorific power

Calorific value: The energetic potential of fuel is given by its lower caloric power. It depends on water content (% H_2O) and hydrogen (% H_2) in the fuel. The Lower Caloric Power (PCI) is determined by using Lucien Delaplace relation (Delaplace and Philipe, 1972):

$$PCI_{balance} = \sum_{j=1}^{3} \left(PCI_{combj} \times \%combj \right) \quad (1)$$

where, PCI_{combj} represents the lower caloric power of fuel of constituent j expressed in kcal kg^{-1}, % combj represents the mass of constituent j in the fuel mixture.

$$PCI_{combj} = \frac{PCS(100 - \%H_2O) - 600(\%H_2O + 9\%H_2)}{100} \quad (2)$$

The tests performed on fuel samples taken at intervals of 8 h a day of machining have shown the performance table as shown in Table 2.

From the relation Eq. 1 and previous sampling results, the average lower calorific value of the fuel mixture is determined by relation Eq. 3. It is 2646 kcal kg^{-1} compared to those of ethanol and of the gas oil which are respectively 6096 and 10191 kcal kg^{-1} (Guibet, 1997). The difference between the first value and the two others is certainly due to the water content.

$$PCI_{average} = \frac{PCI_{sample1} + PCI_{sample2} + PCI_{sample3}}{3} \quad (3)$$

Impacts of the residues of combustion of the mixture used in the boilers of the oil mill: The formation of slag, derived mainly from the fusion of ashes resulting from combustion of fuel mixture (fibres, hulls, debris) plugs the grids and spray tubes of the boiler.

This formation is even so accentuated that the operation of the chimney sweepers and system of cleaning of ashes is defective.

The photographs of boiler furnace, one month after the general maintenance during the peak period of the factory show the real impact of slag on boiler equipment (Fig. 2, 3).

Fig. 2: Slag formed on the tubes

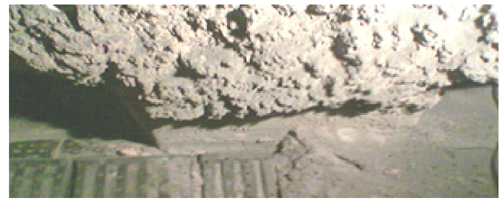

Fig. 3: Slag formed on the refractory bricks sprays

Characteristic of the oil cake: The oil cake is a solid residue obtained after oil extraction from almonds of palm fruit. With an oil content of about 9%, it is dry and gritty (Fig. 4).

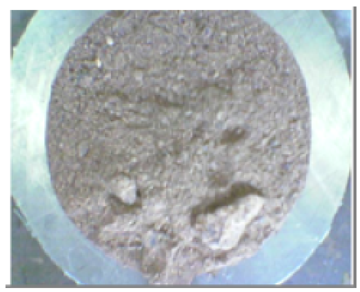

Fig. 4: Photograph of a sample of oil cake

The agronomic studies show that oil cake constitutes, after cereals, the second class of animal feeds (IE - Groupe Economie du Bétail, 2008). The analyses carried out in one of the laboratories of an oil mill of Côte dIvoire (Iboké) make it possible to affect to them a humidity (%H_2O) of 5%, a lower calorific value (PCI) of 4000 kcal kg^{-1} and a content of oil (% oil) of 9.66%. The humidity of oil cake was determined by double weighing, as previously.

The Lower Calorific Value (PCI) of oil cake was determined from Lucien Delaplace formula (1), superior calorific values and the hydrogen content of 4200 kcal kg^{-1} and 6.6%, respectively provided by the documentation of the management of the council and industrial Development (DCDI) of oil mill.

As for the content of oil, by the extraction process solid-liquid (oil cake-hexane), it was noticed that 30.523 g of oil cake provide 2.948 g oil of palm-kernel, or an oil content of 9.66%. Using the oil cake as fuel, this residual oil contributes among others to slag formation. The knowledge of the characteristic content of oil is a necessary data for the conduct of boilers.

RESULTS AND DISCUSSION

Comparative study of the energy contribution of the fuels (solid waste, oil cake, mixture): In this part, we present the results of the energy balance of the use of three types of fuel:

Table 3: Quantities of fuel for boilers

Months	Quantity of freshly treated regimes (t)	Produced quantity (ton)		
		Fuel 1	Fuel 2	Fuel 3
Jan	7449	1341	573	1914
Feb	8279	1490	641	2131
March	12478	2246	1037	3283
April	13692	2465	1230	3695
May	13926	2507	1178	3684
June	9947	1790	915	2705
July	7210	1298	672	1970
Aug	6129	1103	602	1705
Sept	5817	1047	561	1609
Oct	6770	1219	652	1870
Nov	5341	961	553	1514
Dec	6468	1164	598	1762
Total	103506	18631	9212	27843

- Fuel 1 is essentially consisted of solid waste only
- Fuel 2 is only oil cake
- Fuel 3 is the mixture of oil cake and solid waste

This study allows to determine:

- The fuel availability
- The total quantity of superheated steam produced (depending on the efficiency of boilers)
- The quantity of electrical energy which can be produced (depending on consumption of turbo alternators)

The energy balance of fuel depends on efficiency of boilers and the specific consumption of turbo alternators. Thus the lower calorific values only, determined in the previous part, are not sufficient to compare the energy inputs.

Fuels availability: The analyses of monthly production of palm bunches of agro industrial units available in Côte d'Ivoire permit to determine the quantities of Fuels 1, 2 and 3.

Total quantity of Fuel 1 produced by a single unit out of ten is equivalent to 18% (by mass) of the total regime treated.

The rate of extraction of palm oil is 43% (in mass), the total quantity of Fuel 2 is equivalent to 57% (in mass) of the total quantity of palm produced. Palm-kernels are available from four units.

As for Fuel 3, it results from the sum of the total quantities of Fuel 1 and Fuel 2.

Investigations on the production units of a year are recorded in the results of Table 3 and shown on Fig. 5.

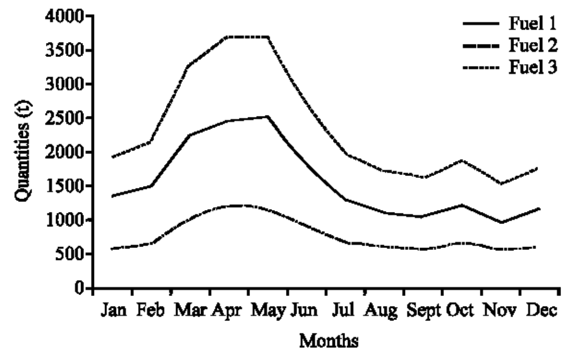

Fig. 5: Monthly quantities of fuel

Amount of steam to be produced

Boiler efficiency of oil mills: The boilers used in oil mills type BABCOCK SFMV 1157. Their performance can be calculated according to the Eq. 4.

$$\eta_{boiler} = \frac{q_{vap} \times \Delta H}{q_{fuel} \times PCI_{fuel}} \tag{4}$$

Where:

q_{vap} : The mass flow of steam (tons h^{-1})
ÄH : The mass enthalpy variation between mass superheated steam and water supply (kcal kg^{-1})
q_{fuel} : The mass flow of fuel (tons h^{-1})
PCI_{fuel} : The average lower calorific value of fuel (kcal kg^{-1})

These parameters are evaluated with daily data of machining during a month of high production (month of May.

Mass flow of steam produced (q_{vap}): It is calculated by Eq. 5:

$$q_{vap} = \frac{E_{TA} \text{ x } C_{STA}}{t_{TA}} \tag{5}$$

Where:

E_{TA} = 15492 kwh as mean energy delivered by the turbo alternators
C_{STA} = 24 kg kwh^{-1} as specific consumption of turbo alternators
t_{Ta} = 24 h as operating time

A mass flow rate of 15.492 t h^{-1} of steam produced by the three boilers of the agro industrial unit.

Variation of enthalpy mass (ΔH): Water supply of boilers, levied at 70°C is superheated to 22 bars/265°C; its variation of enthalpy is 630 kcal kg^{-1} (Goodall, 1981).

Mass flow of fuel used (q_{comb}): It takes into account total mass in tons of treated fresh regime (M_r), the mass ratio (% Comb) of fuel elements of treated regimes and the operating time (t_p) in hours presses:

$$q_{comb} = \frac{M_r \times \%comb}{t_p} \quad (6)$$

The 635.86 tons of fresh regimes containing 18% of fuel are treated daily for 20 h. This provides a mass flow of fuel of 5.72 t h^{-1}.

The efficiency of boilers used in agro industrial units is estimated at 64.5%.

Mass flow of steam to produce: The quantity of superheated steam produced by ton of fuel (Q_{Tfuel}) is function of (Delaplace and Philippe, 1972):

- The mass enthalpy variation between superheated steam (H_{vap}) and water (H_{water}) supply of boilers (ΔH)
- The efficiency of boilers (η_{boiler})
- Lower calorific value of fuel considered

It is calculated by the Eq. 7:

$$Q_{Tfuel} = \frac{PCI_{comb}\ x.\ \eta_{boiler}}{H_{vap} - H_{water}} \quad (7)$$

Water supply is taken at 70°C, its enthalpy is 70 kcal kg^{-1}.

The Fuel 3 is a mixture, its calorific lower value is given by the formula of the balanced calorific value (1). It depends on the mass proportions of Fuel 1 and Fuel 2 from the analysis of Table 3.

100%Fuel 3 = 67% Fuel 1 + 33% Fuel 2

Thus, the lower calorific value of Fuel 3 is estimated at 3092.82 kcal kg^{-1}.

The quantities of superheated steam produced by ton of fuel are respectively:

- 2.708 tons of Fuel 1
- 4.094 tons of Fuel 2
- 3.166 tons of Fuel 3

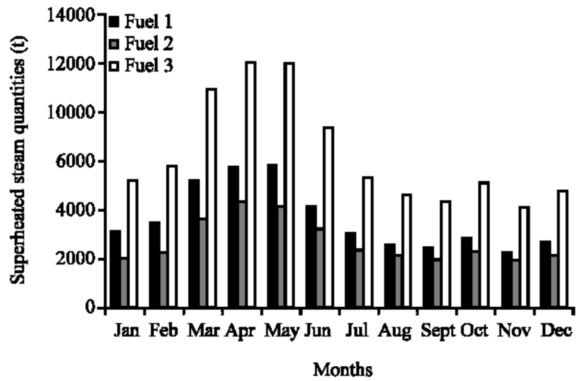

Fig. 6: Monthly quantities superheated steam which can be produced by tons of each fuel

Table 4: Quantities of superheated steam which can be produced in the boilers of the oil mill

	Quantity of steam		
	Fuel 1	Fuel 2	Fuel 3
Months	(ton)		
Jan	3631	2348	6060
Feb	4036	2623	6746
March	6083	4245	10392
April	6675	5036	11696
May	6789	4821	11663
June	4849	3746	8564
July	3515	2751	6236
Aug	2988	2464	5398
Sept	2836	2299	5092
Oct	3300	2667	5920
Nov	2604	2264	4794
Dec	3153	2448	5579
Total	50459	37712	88139

Figure 6 which results from Table 4 shows the monthly quantities of superheated steam likely to be produced per ton of fuel.

Quantities of electricity which can be produced

Specific consumption of turbo alternators of the oil mill: The yield (data manufacturer) of turbine and the reducer is 0.97 and that of the alternator is 0.96. Thus, the turbo alternator has a yield of 0.90.

The states of steam in admission are 20 bars and 260°C and exhaust 3 bars and 150°C. The variation of enthalpy (ΔH) is 40 kcal kg^{-1} (Goodall, 1981).

The energy unit (Eu) provided by the turbo alternators is the kilowatt-hour (860 kcal). Their specific consumption (C) calculated from the Eq. 8, gives a value of 24 kg kwh^{-1}.

$$C = \frac{Eu}{\eta_{turbo} \times \Delta H} \quad (8)$$

Quantity of electrical energy to produce by the oil mill: The low value of the efficiency of boilers is mainly due to the dysfunctions previously stated.

Table 5: Estimated quantification of electrical energy produced by turbo alternators of the oil mill of Iboké (2006)

	Quantity of energy produced (kWh)		
Months	Fuel 1	Fuel 2	Fuel 3
Jan	151305	97820	252490
Feb	168165	109294	281068
March	253455	176873	433015
April	278114	209836	487325
May	282868	200890	485964
June	202045	156065	356834
July	146450	114642	259823
August	124493	102682	224910
Sept	118156	95778	212165
Oct	137513	111114	246670
Nov	108488	94319	199735
Dec	131379	102001	232433
Total	2102431	1571314	3672432

The total quantities of electricity that could be produced by Fuel 1, 2 and 3 in the waste boilers of palm oil mills of Iboké in Côte d'Ivoire are listed in Table 5.

The results in Table 5 show that the production of electricity by the oil cake (Fuel 2) only is not a viable option. Indeed Fig. 5 shows that the electrical energy produced by the oil cakes (Fuel 1) is lower than that of Fuel 2. In addition, the current use of Fuel 1 requires the addition of generators to cover the needs of the Agro Industrial Unit (IAU).

About the Fuel 3, it can produce an electrical power of 3672432 kWh. This production exceeds the needs of the agro industrial unit, which was 3611142 kWh in 2006.

Combustion tests

Experimental furnace: Early we showed the energy contribution of Fuel 1, 2 and 3. In order to supplement this study, combustion tests were carried out in an experimental furnace at the oil mill. These tests aim to examine the conduct of the burning of different fuels studied to compare with previous results.

To this end, an experimental furnace was developed by modifying an oven for cooking. Figure 7 shows the different views of the cooking oven before the changes.

This cooking oven presented:

- Cooking area (second stage) with walls
- Fireplace linked to a chimney (Fig. 7)

Changes made (Fig. 8) on the kitchen oven are:

- Replacement of the plate separating the cooking area of the fireplace by a grid. This grid allows removing the ash and also allows supplying the oven with primary air
- Installation of a chimney communicating with the cooking area by its higher wall
- Installation of pipelines (equipped with shutters), one of which leads to a nozzle located in the cooking area (secondary air) and the other to the original location of the chimney (primary air)

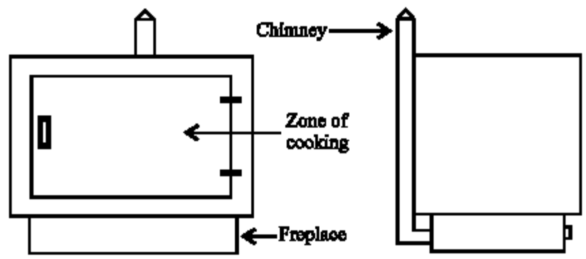

Fig. 7: Diagram of front and profile views of the cooking oven

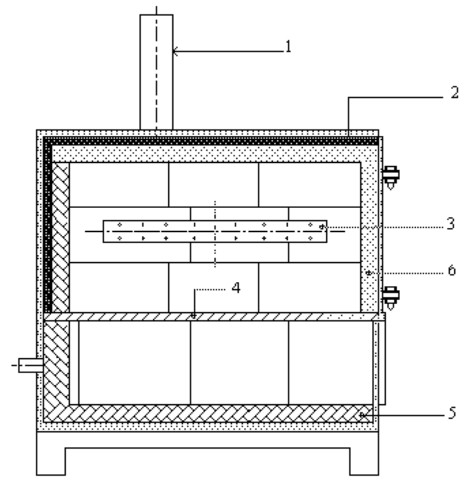

Fig. 8: Shows changes made on the oven cooking. 1: Chimney, 2: Insulator, 3: Secondary base of air, 4: Grid of health, 5: Refractory bricks and 6: Dorr of the hearth

Combustion tests: The experimental furnace made it possible to test the combustion of studied fuels (Fuel 1, 2 and 3). The tests are carried out in the same conditions (5 kg of each fuel, primary and secondary air flows are identical). Combustion temperature was measured with infrared thermometer. The colour of the exhaust gas of the experimental furnace was observed. The results of these tests are shown in the Table 6.

Comparing temperatures of smoke is like comparing those of the fireplace because the combustion gas route is very short. The data in Table 6 show that the fireplace of Fuel 1 reached the highest temperature (309°C).

It burned with a suitable quantity of air because there are no unburnt residues and smoke is clear grey. The sample of this fuel was consumed faster than the others and generated the smallest quantity of ash.

Table 6: Temperatures of combustion of the various fuel samples

	Smoke temperature after a few min of combustion (°C)											
Ech.	5	10	15	20	25	30	35	40	45	Total duration of combustion (min)	Mass of ash (kg)	Observations
Fuel 1	250	262	309	278	232	176	85	-	-	35	0.351	Smoke is clear grey in color
Fuel 2	185	194	200	220	242	230	219	173	96	70	0.766	Smoke is black + + unburnt residues
Fuel 3	256	226	215	233	248	219	176	90	-	45	0.439	Smoke is dark grey + unburnt residues

The operating conditions of furnace did not make it possible to keep the oil cake (Fuel 2) in suspension during the combustion. This one was consumed in heap (black smoke and unburnt residues). By putting it in suspension using a metal bar (the furnace door opened), the oil cake burns very quickly by causing a sharper flame.

The bad conditions of its combustion probably justify the low temperatures of smoke recorded and the long time for its total combustion.

As Fuel 3 (3.35 kg of Fuel 1 plus 1.65 kg of Fuel 2), it is noted that its combustion requires more air. Despite of the bad conditions of its combustion, the smoke temperatures are higher than those of the oil cake. In addition, the quantity of ash is quite low.

CONCLUSION

This study has highlighted the energy potentialities of oil cake. The analysis and tests allowed giving their contribution as fuel for boilers waste. Countries such as Côte d'Ivoire, which have oil mills of palm have a great potential in biomass. The recovery of the oil cakes to produce energy could contribute to reduce the use of the petroleum products. It could also help to reduce production costs of agro industrial units.

Simultaneously, this recovery would help reduce the negative effects and degrading environment which the activities of the oil mills generate.

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