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Effect of Preheating Temperature and Extraction Pressure on Combustion Characteristics of Cake from Whole, Kernels and Crushed Jatropha Seed

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Abstract: The Low heating value, reaction time, burning temperature and gas emission of jatropha seed cake respectively from whole, kernel and crushed seeds preheated at 25°, 50°, 75° and 100°C temperature and under 8400, 15000 and 19500 pounds pressure levels were assessed. At this effect, the combustion process consisted in introducing 20 g of each cake sample type into a one liter volume burning chamber and 130 g of water also into one liter water compartment of a designed combustion unit. The main results were as follow. The highest lower Heating value (21,51±93,64 MJ/kg) was obtained with the cake from crushed seeds preheated at 100°C and under of 15000 pounds pressure. The highest reaction time (1072,66±153,44 seconds) was registered with cake from kernel seeds also preheated at 100°C but with 19500 pounds pressure. The highest burning temperature was recorded from the whole jatropha seed cake. The highest carbon monoxide level ( ) was recorded during crushed and whole seeds cake combustion while the carbon dioxide level was the highest with the kernel seed cake.

Keywords: Extraction Conditions, Cake, Lower Heating Value, Reaction Time, Burning Temperature, Carbon Dioxide, Carbon Monoxide

1. Introduction

Oil seeds are considered to be one of the most promising alternative renewable energy sources [1, 2]. Their energy production is mainly focused on oil extraction for biofuels production [3, 4, 5]. The oil extraction procedures consist in crushing, dehulling, preheating and hydraulic pressures [6, 7]. The cake as a result of oil extraction process can still be used for additional energy production due to their content in residual oil, protein, cellulose and carbohydrate. It is expected that the cake energy potential and valorization should be influenced by the oilseed nature, oil extraction procedures and also by the energy process like combustion, pyrolysis, gasification and anaerobic digestion. Scientific literature on cake combustion is still limited. Cake densification and airflow are mentioned as the two main factors affecting its combustion performance [8, 9]. Hence, high densification pellets and high airflow significantly increase the reaction time and the burning temperature respectively [10, 11]. The general objective of this work is to contribute to the elaboration of a optimal protocol of valorization of oilseeds and more particular jatropha cake. Jatropha curcas is the main oilseed used as a source of renewable energy production [2]. Therefore, our research is aimed at assessing the effect of seedform under four levels of temperature (25°, 50°,75° and 100°C) associated to three levels of extraction pressure (8500, 1500 and 19500 pounds) on the cake combustion characteristics namely Lower Heating Value, reaction time,

Burning temperature, Gas emission.

2. Materials and Methods

2.1. Obtention of Cake from Whole, Kernels, Crushed Jatropha Seeds

20 kg of Jatropha seeds used for the study was obtained from local farmers of Soudano Guinean zones of Cameroon with the following geoclimatical characteristics of production area (LN 5°36'-5°44', LE 9°85'-10°66'), 1500 m altitude, ferrolateritic soil type, 2000-2500mm average rainfall, 25-30°C average temperature and 60-80% humidity). The jatropha seeds were sundried till 2% water content. 6 kg of jatropha seeds was respectively used as whole, kernel and crushed. The whole was used as such. kernel was obtained using a manual rotary disk machine to dehull whole seed and crushed (3-3.7 mm size particle) seeds was obtained by grinding 6 kg whole seeds using a 2 kWh electric motor machine. Each of the three seed type obtained were respectively and separately preheated during five minutes at the following levels of temperatures 25°; 50°; 75° and 100°C. Each of the above jatropha seed samples were respectively and separately submitted to 8400, 15000 and 19500 Pounds extraction pressures to obtain oil and cake using a mechanical hydraulic press. Each of the above cake type samples were weighed, packaged in the plastic bags and stored in a desiccator for two weeks. The bromatological characteristics of cake (dry matter, volatile matter, residual lipids and cellulose) were determined according to [12]. Each of the above cake type was then submitted to the combustion process. The experimental diagram is summarized by the figure 1.

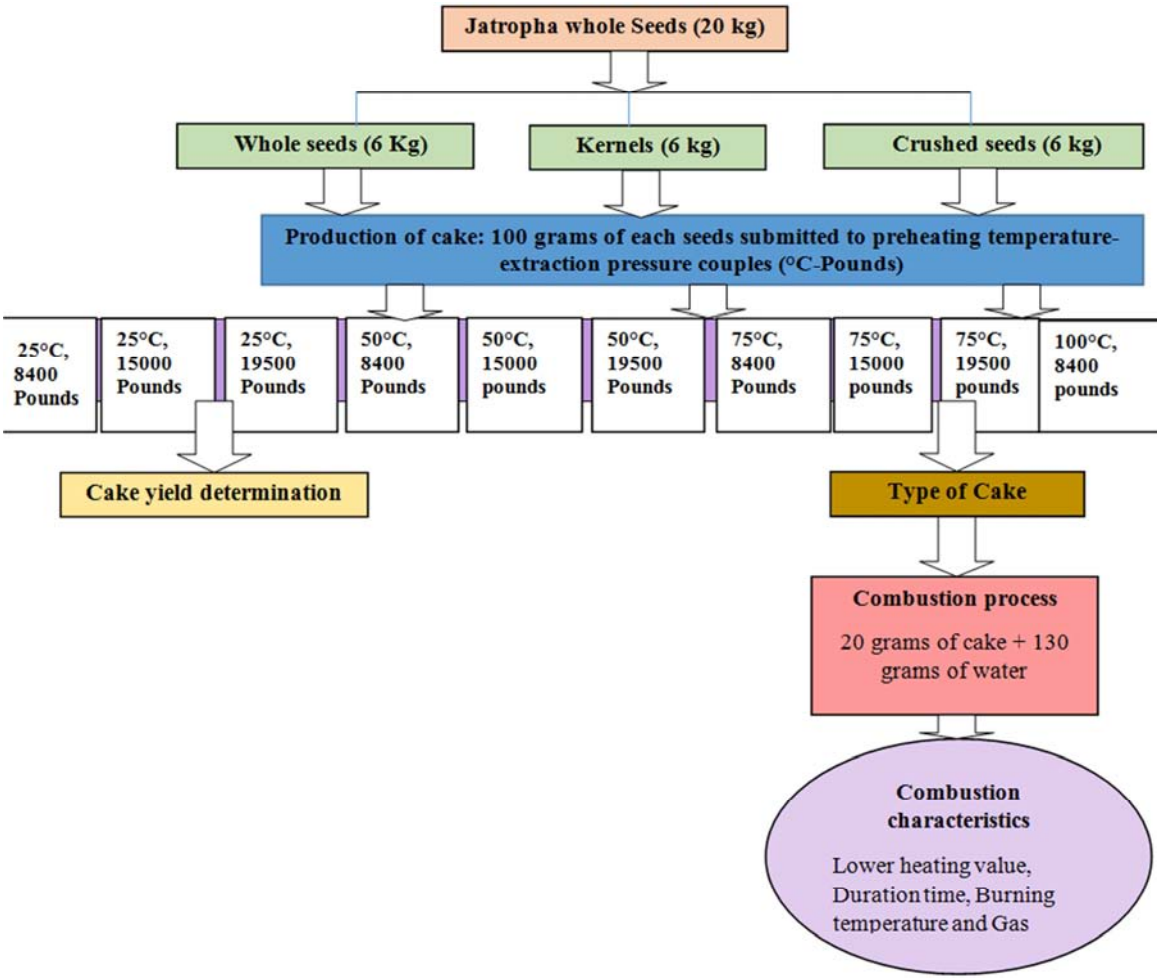

Figure 1. *Experimental scheme or diagram.*

2.2. Determination of Cake Type Samples Combustion Characteristics

Respective combustion process of different cake type samples was carried out according to [13]. At this effect, a combustion unit (figure 2) was designed. It consists of two staggered cubic form compartments with a total height of 20 cm made of stainless steel material of 3 mm thick. The bottom compartment or combustion chamber (1 liter volume) to receive cake type sample while simultaneously the above (1 liter volume) is to receive water. A 5 mm diameter galvanized pipe chimney was fixed to the rear of the combustion chamber at a height of 2 cm for flue gas exhaust. Four gas sensors (CO, CO_2, H_2 and CH_4) were attached to the end of the chimney.

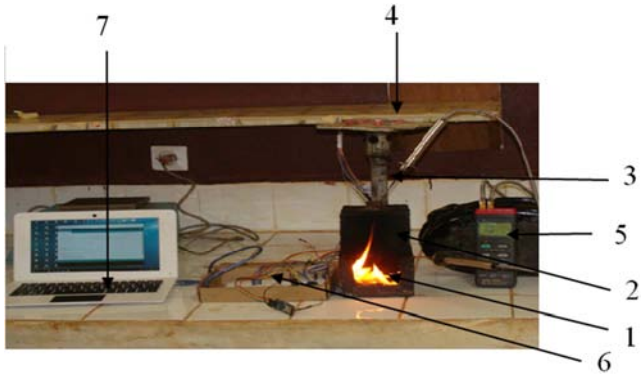

Figure 2. *Combustion process unit.*

1: combustion chamber; 2: water compartment; 3: chimney; 4 gas sensors; 5 Thermocouple with two probes; 6: Arduino issue; 7: computer for collecting gas data.

The combustion process consisted in introducing respectively 20 g of each cake type sample + 130 g of water into bottom and above compartments of a designed combustion unit. The amount of water and cake were selected and adjusted based on a pre-test showing that combustion of 20 g of cake was able to raise the water temperature at 100°C. A 0.2 g of propane as a source of activation into the cake mass was used. The reaction time was determined using a Nikson brand stopwatch started at the beginning and stopped at the end of the flame. In addition, a thermocouple with two probes was used to collect the temperature every 30 seconds in the water compartment and combustion chamber. At the end of the combustion, residual ash was collected and weighed using an electronic balance (0.001 g accuracy) in order to determine the calorific value of the cake. Each treatment and procedure was in three replicates.

The calorific value was determined using the following Equations below.

$$\text{LHV} = \frac{\text{Qt}}{\text{initial cake mass} - \text{final ash mass}} \quad (1)$$

LHV : Low Heating Value (kJ/kg); Qt: total quantity of heat produced during combustion (kJ); intial cake mass (kg); final ash mass (kg).

$$Qt = Qw + Qb \quad (2)$$

$$Qw = Mw * Cw * (\Theta f - \Theta in) \quad (3)$$

$$Qb = mbCb\ (\Theta fin - \Theta ini) \quad (4)$$

Qt: total quantity of heat produced during combustion (kJ); Qw : quantity of heat accumulated in water (kJ); Qb : quantity of heat accumulated in the boiler (kJ); Mw : mass of water introduced in the boiler; Cw: water mass heating capacity (4 180 kJ/kg/°C); Cb : boiler heating capacity (0,44 kJ/kg/°C); Θ: initial and final temperature (°C).

3. Results and Discussion

3.1. Cake Yield as a Function of Seed Form, Preheating Temperature and Applied Pressure

Independently of the seed form, the applied pressure and the preheating temperature, the significantly highest cake yield (Table 1) was obtained with crushed seeds preheated at 50°C and at the applied pressure of 8400 pounds and the lowest yield with the kernels preheated at 100°C under the highest pressure (19500 pounds). Whatever the seed form and the preheating temperature level, the cake yield decreases logically with increasing applied pressure. The differences in cake yield between seed forms can be explained by the particle size.

Table 1. *Cake yield (%) as a function of seed form, preheating temperature and applied pressure.*

seedforms	Extraction pressure (pounds)	Preheating temperature 25°C	50°C	75°C	100°C
Whole seeds	8400	86,67 ± 0,51bA*	82,93 ±3,59bA*	84,03 ± 2,68bB*	81,90 ± 0,58bC*
	15000	76,33 ± 0,51bA**	76,10 ± 1,25bA**	76,53 ± 0,60bB**	75,23 ± 1,55bC**
	19500	75,03 ± 0,85bA***	73,63 ± 1,70bA***	72,40 ± 0,70bB***	71,80 ± 2,36bC***
Kernels	8400	70,53 ±0,51cA*	69,63 ±3,59cA*	66,90 ±2,68cB*	61,33 ± 0,58cC*
	15000	60,63 ±0,51cA**	62,10±1,25cA**	56,10±0,60cB**	54,50 ± 1,55cC**
	19500	56,10 ±0,85cA***	59,03 ±1,70cA***	54,63 ± 0,70cB***	51,50 ± 2,68cC***
Crushed seeds	8400	88,36 ± 0,32aA*	89,26 ±0,80aA*	88,20±1,21aB*	84,80 ±0,26aC*
	15000	81,40 ± 0,69aA**	83,30 ± 1,30aA**	83,00 ± 3,55aB**	78,26 ±0,66aC**
	19500	77,53 ±0,25aA***	77,20 ±1,76aA***	74,80 ± 0,80aB***	76,06 ±1,79aC***

a, b, c: means with the same letter on the same column are not significantly differents (p>0,05).
A, B, C:means with the same letter on the same line are not significantly different (p>0,05).
*: means with the same number of star in the same column are not significantly different (p>0,05).

3.2. Cake Lower Heating Value

The highest calorific value (table 2), regardless of preheating temperature, applied pressure and seed form, was obtained with cake from crushed seeds preheated at 100°C under 15000 pounds applied pressure. The lowest value was obtained in cake from non-preheated kernels extracted at 19500 pounds pressure. No significant difference (P>0,05) was found neither between the preheating temperature nor the applied pressure levels. The heating value of the cake, irrespective of the seed form, preheating temperature and the applied pressure, is in the range between 12 and 21 MJ/kg. These values are in the range of 18 and 20 MJ/kg mentioned by [3, 14].

Table 2. *Low Heating Value (kJ/kg) of the different cake.*

cake provenance	Extraction pressure (pounds)	Preheating temperature 25°C	50°C	75°C	100°C
Whole seeds	8400	18699,44 ± 649,76bB**	15668,68 ± 48,28bA**	16092,36 ± 71,90bAB**	17513,48 ± 275,64bB**
	15000	18340,92 ± 327,14bB*	19642,80 ± 976,58bA*	16852,36 ± 114,47bAB*	19106,60 ± 35,58bB*
	19500	19149,16 ± 26,75bB**	18065,60 ± 680,32bA**	18957,28 ± 679,47bAB**	16682,24 ± 139,08bB**
Kernels	8400	16143,04 ± 449,12cB**	17527,80 ± 527,30cA**	16261,92 ± 328,88cAB**	17000,72 ± 168,54cB**
	15000	15987,44 ± 140,64cB*	19373,56 ± 1034,73cA*	15224,60 ± 108,37cAB*	16648,60 ± 136,02cB*
	19500	10033,68 ± 241,76cB**	18057,60 ± 483,03cA**	14922,36 ± 352,56cAB**	10903,00 ± 203,31cB**
Crushed seeds	8400	17580,84 ± 109,45aB**	19253,24 ± 606,89aA**	19011,96 ± 192,73aAB**	14968,20 ± 712,04aB**
	15000	19002,88 ± 438,50aB*	19116,92 ± 1127,88aA*	19973,36 ± 257,51aAB*	21513,76 ± 93,64aB*
	19500	21150,36 ± 759,43aB**	19483,64 ± 219,95aA**	20415,00 ± 263,58aAB**	21359,00 ± 785,66aB**

a, b, c: means with the same letter on the same column are not significantly differents (p>0,05).
A, B,:means with the same letter on the same line are not significantly different (p>0,05).
*: means with the same number of star in the same column are not significantly different (p>0,05).

The seed form has a significant influence on the calorific value. The highest calorific value was registered by the cake from crushed jatropha seeds extraction. This could be explain by the seed particle size. Indeed, heat transfer is known to be faster in small particles [13] associated with a high oxygen diffusion in the particles, would contribute to a significant production of heat.

3.3. Reaction Time

The highest reaction time (table 3), regardless of preheating temperature, applied pressure, and seed form, was recorded with cake from kernel extraction preheated at 100°C under 19500 pounds applied pressure. The lowest reaction time was obtained with cake from the cru shed seeds preheated also 100°C with 8400 pounds applied pressure. No significant difference (p>0,05) was observed either between the preheating temperature and the applied pressures. Reaction time was comparable between whole seeds and kernel obtained (P> 0.05).

Table 3. *Effect of cake type on the reaction time (seconds).*

Cake provenance	Extraction pressure (Pounds)	Preheating temperature 25°C	50°C	75°C	100°C
Whole seeds	8400	722,66 ± 57,83aA*	794,00 ± 99,05aA*	675,00 ± 33,45aA*	821,33 ± 116,33aA*
	15000	953,00 ± 302,59aA*	898,33 ± 395,26aA*	898,33 ± 59,18aA*	898,33 ± 92,85aA*
	19500	764,00 ± 18,73aA*	650,00 ± 102,19aA*	703,00 ± 95,89aA*	658,33 ± 13,01aA*
kernels	8400	987,66 ± 74,04aA*	919,33 ± 76,74aA*	724,66 ± 4,041aA*	866,66 ± 99,42aA*
	15000	766,66 ± 8,73aA*	753,66 ± 45,82aA*	713,00 ± 65,02aA*	688,66 ± 49,41aA*
	19500	817,00 ± 51,56aA*	880,66 ± 70,02aA*	1038,33 ± 361,03aA*	1072,66 ± 153,44aA*
Crushed seeds	8400	582,33 ± 185,01bA*	582,33 ± 162,17bA*	645,00 ± 85,15bA*	413,66 ± 305,17bA*
	15000	704,33 ± 197,72bA*	579,00 ± 242,50bA*	644,00 ± 37,16bA*	699,33 ±103,36bA*
	19500	609,00 ± 101,83bA*	724,66 ± 126,61bA*	543,33 ± 69,97bA*	672,66 ± 116,50bA*

a, b, c: means with the same letter on the same column are not significantly differents (p>0,05).
A: means with the same letter on the same line are not significantly different (p>0,05).
*: means with the same number of star in the same column are not significantly different (p>0,05).

Reaction times (12 and 21 minutes) obtained in our work are lower compared to the 25 and 27 minutes using densified jatropha seed cake were used [10]. Contrary to expectations, the reaction time of cake from kernels extraction is higher than that of whole and crushed seeds. One might thing that devolatilization is slow in kernels because of low cellulose content and higher content in residual lipids compared to complete and crushed seeds. A high cellulose content promotes ignition and rapid decomposition of lignin, since cellulose is composed of polysaccharides in chains without aromatic compounds that volatilize more rapidly at low temperatures [15].

3.4. Evolution of the Burning Temperature

The evolution of the combustion temperature (figure 3) was generally comparable between the seed form and whatever the preheating temperature and applied pressure.

Regardless the combustion period considered, the highest burning temperatures were recorded in the cake from the whole seeds under the following respective combination of preheating temperatures and applied pressure: 50°C-8400 pounds; 50°C-15000 pounds; 75°C-8400 pounds; 75°C-19500 pounds; and 100°C-19500 pounds. The combustion temperature provides information on the reactivity level of a fuel [16]. Whatever the seed form, preheating temperature and extraction pressure, the temperature range of 25 to 700°C was slightly lower than those mentioned in the literature where combustion were carried out under controlled airflows and pressures [11, 17].

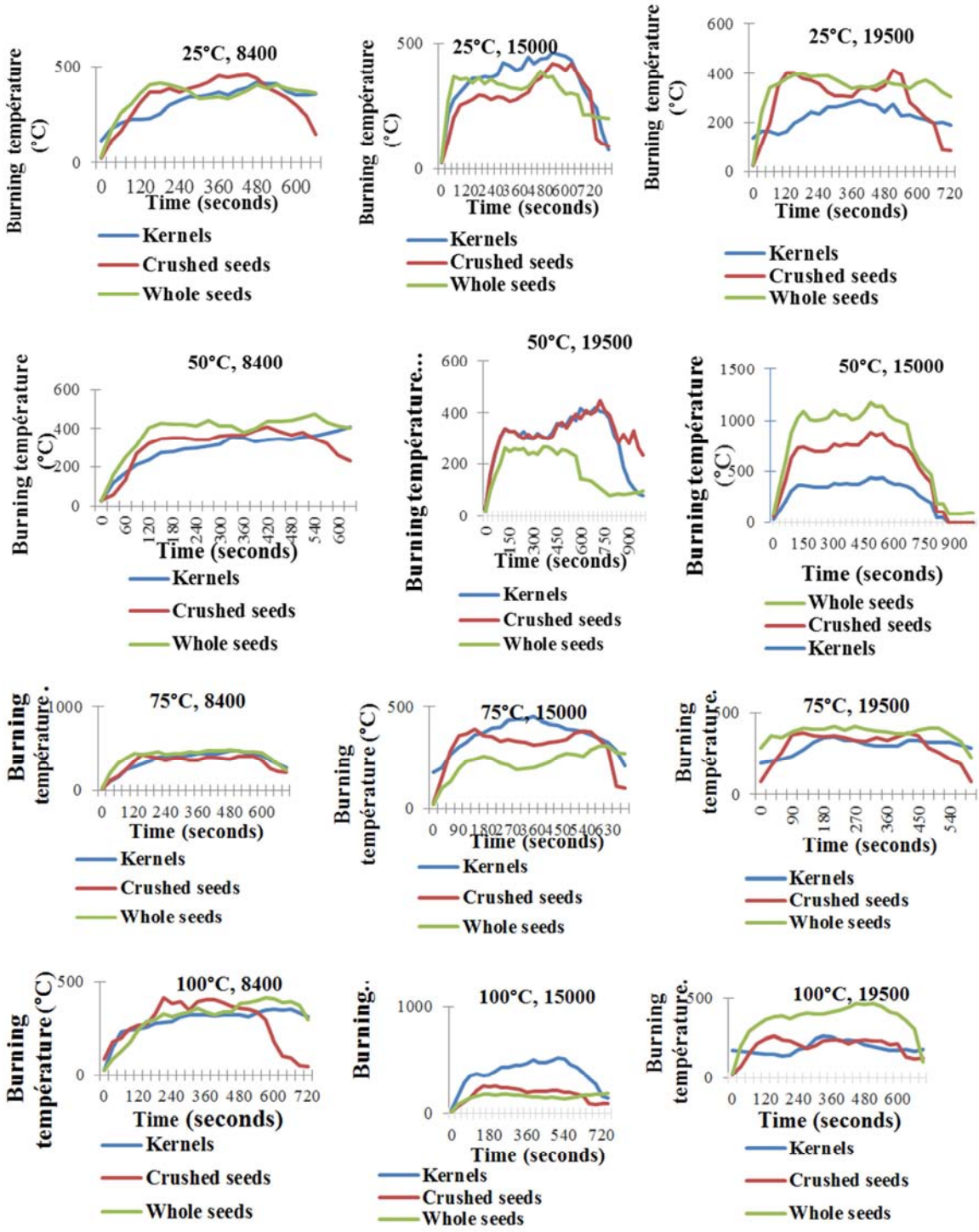

Figure 3. *Evolution of burning temperature in the combustion chamber.*

3.5. Gas Emission

The evolution of the carbon monoxide content was generally comparable between the seed form and whatever the preheating temperature/extraction pressure combination. Regardless of the time duration and the preheating temperature and applied pressure, the highest carbon monoxide (figure 4) levels were obtained with cake from kernel extraction. Independently of preheating temperature and applied pressure, the highest carbon monoxide levels was registered in the cake from complete and crushed jatropha seeds. The lowest carbon monoxide levels were registered with the cake from whole seeds preheated at the following combination of preheating temperatures and applied pressures 25°C/8400 Pounds and 19500 pounds; 50°C/8400 pounds and 15000 pounds; 77°C/8400 pounds, regardless of seeds form. The value of carbon monoxide was the lowest with the cake from crushed seeds compared to other seed cake type samples at the following respective preheating temperature combined to applied pressure: 25°C/15000 pounds; 50°C/19500 pounds;

75°C/15000 pounds and 19500 pounds; 100°C/8400 pounds, 15000 pounds and 19500 pounds.

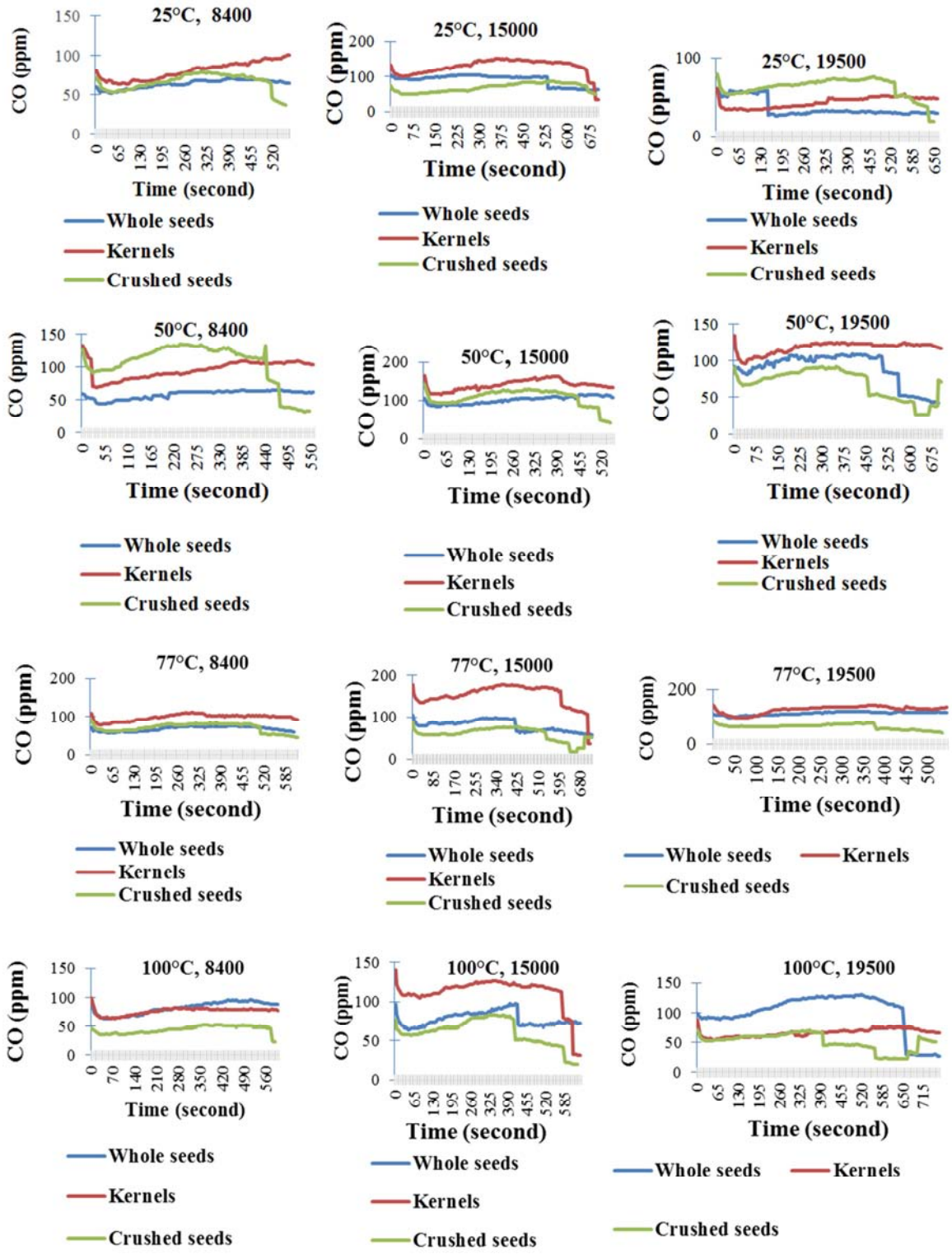

Figure 4. *Monoxyde carbone percentage as a function of time.*

The evolution of carbon dioxide level (Figure 5) was comparable between treatments and regardless of the preheating temperature/applied pressure.

The highest carbon dioxide level was recorded with the kernel cake except for the following preheating temperature/applied pressure couples 25°C/8400 pounds and 19500; 50°C/8400 pounds and 100°C/19500 pounds. In general, the combustion of kernel cakes, whatever the preheating temperature and the applied extraction pressure, produced the highest carbon monoxide level. A negative correlation was found between the combustion temperature and the carbon monoxide content. Kernel cake registered the

lowest burning temperatures. These results are similar to those found by [18, 19] who also obtained the highest carbon monoxide levels at the lowest temperatures during the palm kernel nuts combustion.

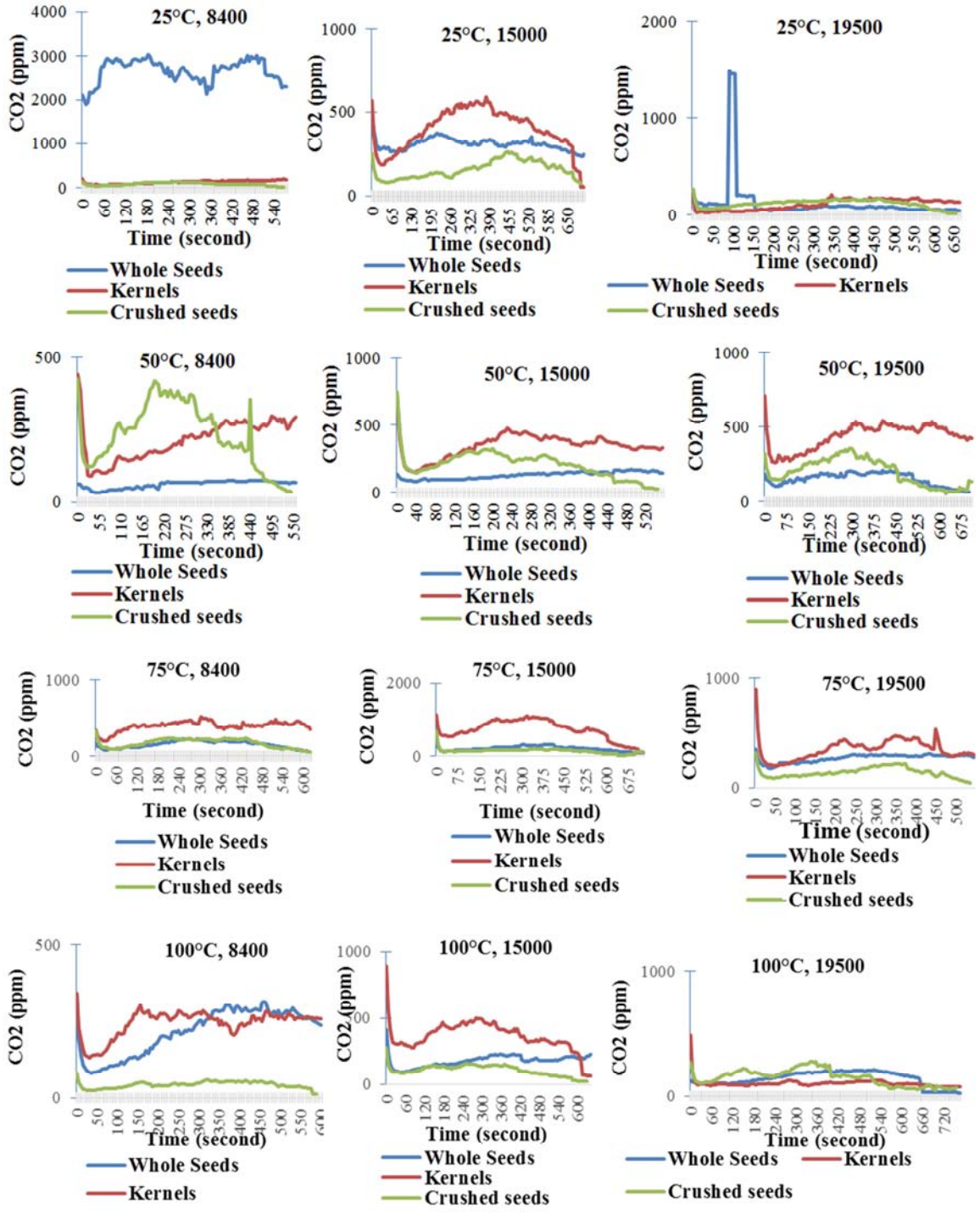

Figure 5. *Carbon dioxide as a function of time.*

4. Conclusion

From the study aim assessing the effect of seedform, preheating temperature and applied pressure on the Cake yield, Lower heating value, Burning temperature, Reaction time, and Gas emission, the main conclusion were as follows: Cake yield was significantly affected by the seed form. The cake yield decreases with increasing applied pressure. The calorific value was only significantly affected by the seed cake but not by the combined preheating temperature/applied pressure. Thus the highest calorific value was recorded with crushed seeds preheated to 100°C under 15000 pounds applied pressure.

The reaction time and burning temperature were only significantly affected by the Seed form. Indeed, they were higher

with kernel cake. The carbon monoxide level was influenced only by the seed form. Its lowest value was recorded with cakes from whole seeds. A negative correlation was found between the combustion temperatures and the carbon monoxide level.

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