Biomass Combustion Chamber for Cashew Nut Industry

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ABSTRACT
Brazil is rated number four among the leading producers of raw cashew nut. As it is known its shell (CNS, i.e., the Cashew Nut Shell) comprises around 50% of the weight of the raw nut, the kernel representing 25% and the remaining 25% consisting of the natural Cashew Nut Shell Liquid (CNSL), usually obtained during the cooking of the raw nuts and their kernel separation by roasting. Cashew nut production industries use its main waste, the CNS, as fuel, thus avoiding the need of sanitary landfill. Notice that burning is the best way of eliminating solid residues, for this process leads to a one thousand fold reduction in volume and, if performed under a well controlled mechanism, it may lead to a minimum of residues which may be extracted with the gaseous flow using cyclones and gas washing devices. This work discusses the use of a fluidized combustion chamber with air as its fluidizing agent (instead of sand), to properly burn the CNS. This technique has been shown to improve the overall combustion efficiency to 85% as compared to values around 50% achieved with the use of fixed bed combustion chambers normally used to burn this fuel.

Keywords: Solid waste combustion, CNS (cashew nut shell) combustion

1 INTRODUCTION

Brazil is rated number four among the leading producers of raw cashew nut, behind India, Vietnam and West Africa only (Figure 1). The Northeast Region of the Country, which is its largest cashew nut producer, intends shortly to improve the country's position through the use of new processing technology and the proper introduction of the precocious dwarf cashew tree in the market.

Figure 1: The Cashew: Brazil is rated number four producer in the World

The Northeast of Brazil possesses an area of nearly 680 thousand ha dedicated to this culture, with circa of 70 million cashew trees corresponding to a production of 150 thousand ton of shelled nuts (the state of Ceará leading this overall effort with a share above 80 thousand ton), meaning an overall production of 30 thousand ton of clean nuts and a US$ 140 million profit for Brazil, whose overall production which is second to India only in the world market.
The cashew tree (*anacardium occidentale L.*) is considered one of the most important items with a wide distribution in the tropical regions. It seems that the cashew tree is native of Brazil, the northern part of South America and part of the Caribbean.

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Table 1 – Cashew Fruit Mean Weight Distribution (apple excluded):

Size	Whole fruit (g)	Nut (g)	Raw Shell (g)	CNSL (g)	Shell (g)
Small	3.190	1.003	2.187	0.798	1.389
Medium	6.220	2.062	4.158	1.555	2.603
Large	9.460	2.528	6.932	2.365	4.567
Extra Large	10.479	2.684	7.795	2.620	5.175

As it can be seen in Table 1 the Cashew Nut Shell Liquid (CNSL) weight distribution lies between 23 and 25 % of the Cashew whole fruit, while the mean weight of the Shell following the CNSL extraction is around 47% of the whole fruit weight [1]. This way, one ton of whole fruit (the apple excluded) yields on the average 470 kg of "dry" Shells, 280 kg of clean nuts and 250 kg of CNSL

2 PROBLEM DESCRIPTION

Therefore, an yearly production of a 150 thousand ton of shelled nuts, means, on the average, a shell yield of 70.5 thousand ton, 42 thousand ton of nuts and 37.5 thousand ton of CNSL. Nearly all of this nut production, once processed, is exported, while the CNSL destiny is either the overseas market if the price is convenient, or used internally as fuel, if the international price is low. Actually the country should bet in the aggregated value of the CNSL, which, in natura, consists of a mixture on the average, of 70 % of anacardic acid, 18% of cardol, and 5% of cardanol, the remaining consisting of other phenols and less polar substances. CNSL resins find a multitude of uses, among them in the manufacture of friction resistant components such as brake and clutch linings [2]. However, while the CNSL international price is around US$300/ton, cardanol is worth US$ 3000/ton in the world market. Therefore it is obvious that it is worth to aggregate value to the CNSL by using it to manufacture cardanol. As for the shell destiny, it will be either burnt in industrial furnaces or deposited in sanitary landfills. However the first option leads to a drastic reduction of the inner furnace lining lifetime and its consequent maintenance cost increase, for the residual content of the CNSL in the shell will generate phenols known to attack the furnace refractory bricks.

3 PROPOSED SOLUTION

A way of avoiding the combustion chamber deterioration is to make it of iron or steel and to perform the shell burning process in a floating bed where the fuel (individual shells) actually float immersed in the combustion air stream. Iron is impervious to phenols so that the combustion chamber lifetime is improved, besides simplifying the heat transfer process if steam generation is desired.

This solution can be used not only in large industrial plants but also in smaller facilities such as bakeries and family run cashew fruit processing facilities.

This meets the energy conservation modern philosophy and also the one of using biomass as energy source in the way of avoiding a costly environmental problem (the deposit in sanitary landfills) and indirectly increasing the local employment level. This burning, under controlled conditions, will not harm the environment, becoming an asset within the self sustained development concept.

This is also an economic factor for the states of the northeast region of Brazil, for their energy matrix will become less dependent on the gas and electricity distribution. For the small and medium size industry this is an option less expensive than either gas or electricity. Notice that one might choose to burn a mix of cashew shell and gas, or only gas, if there is a lack of shell in the market.

Table 2 displays some mean fuel and chemical properties of the CNS. Notice that its dry heating value of 18.87MJ/kg places the CNS right in the middle of the biomass fuel mean range (14-21 MJ/kg)[3] . The mean stoichiometric air/fuel ratio for the burning of the CNS is 4.912 kg_{air}/kg_{shell}. For the floating bed burning process it is essential to estimate the terminal mean shell speed. The air blown through orifices with a speed larger than the terminal shell speed will push the shells upwards, lifting them, to be brought down by gravity, in an up and down motion, promoting a better contact between the shell (fuel) and the air(oxidant). This better contact between fuel and oxidant, as expected, leads to a better combustion process, increasing the combustion efficiency.

Table 2 – Cashew Nut Shell CNS) Chemical and Fuel properties

I –Heating Values	II – Proximate Analysis (% wt)	III – Ultimate Analysis
High: 5056 kcal/kg	1 – Humidity: 8.85 %	1 – Carbon: 46.08 %
Low: 4516 kcal/kg	2 - Volatiles: 68.03 %	2 – Hydrogen: 3.88 %
	3 – Ashes: 2.00 %	3 – Nitrogen: 0.21 %
	4 – Fixed Carbon: 21.12 %	4 – Sulphur: NIL
		5 – Humidity: 8.85 %
		6 – Ashes: 2.00 %
		7 – Oxygen: 38.98 %

A solid fuel burning process is usually done in two stages: First the fuel is burned in a fixed bed or grid. Next the gases generated in the first phase are further burned (that is, gases like CO and some CH like unburned hydrocarbons). The combustion chamber floating bed design mass flow rate, $\dot{m}_{tot}$, can be found recalling that the fuel mass flow rate, $\dot{m}$, can be written as

$$\dot{m} = \frac{P_{tot}}{\Delta h} \quad (1)$$

Where P_{tot} is the needed total fuel thermal energy per unit time and Δh is the enthalpy change needed to achieve the required mass flow rate. Thus the air mass flow rate is

$$\dot{m}_{air} = \dot{m}\,(A/F), \quad (2)$$

Where (A/F) is the air to fuel mass ratio
Hence,

$$\dot{m}_{tot} = \dot{m} + \dot{m}_{air} \quad (3)$$

Upon calculating the combustion chamber volume one should be aware of the environmental restraints on solid residues burning rules. Among them, it is essential that one must have at least a two second furnace gas residence time. The residence time, $t_{R,}$, may be estimated as

$$t_R = \int \frac{dV}{q} \cong \frac{V}{q}, \quad (4)$$

Where V is the furnace volume and q is the furnace gas volume rate, q = v A, v being the furnace gas mean speed and A the furnace cross section. Hence,

$$\dot{m}_{tot} = \int \rho\, v\, dA \cong \rho\, vA = \rho\, q = \frac{qP}{RT} \quad (5)$$

Where ρ, P, T and R are the furnace gas mean density, pressure, absolute temperature and the specific gas constant, respectively. Then,

$$t_R = \frac{VP}{\dot{m}_{tot} RT} \quad (6)$$

Therefore the combustion chamber volume can be estimated as:

$$V = \frac{t_R \dot{m}_{tot} RT}{P} \quad (7)$$

The specific gravity of the shell at 30^{o}C ranges from 0.950 to 0.970. Shaped roughly like a kidney, its maximum drag coefficient can be taken conservatively as C_D = 1.2. The shell terminal speed, v_t, can be also conservatively estimated as

$$v_t = \sqrt{\frac{2mg}{C_D A\rho}} \quad (8)$$

so that the blowing of air into the furnace with a speed larger than v_t, will lead the shells to lift and to be brought down by gravity, in an up and down motion, promoting a better contact between the shell (fuel) and the air(oxidant), improving the combustion efficiency.

Therefore, to estimate the proper air blowing velocity into the combustion chamber, one makes sure that such value will be larger than the CNS terminal speed so that floor holes are opened to attend this need. This way, i.e., having the air entrance speed larger than the shells terminal speed will guarantee that the shells will be thrown upwards. The diameter of these holes must be large enough to prevent clogging due to ashes as well as in sufficient number to cover the whole combustion chamber floor. The expression

$$\dot{m}_{air,hole} = C_{Di}\rho v A\,, \qquad (9)$$

yields the air mass flow rate through each orifice (where $v > v_t$ and C_{Di} is the discharge coefficient usually taken as 0.80). Hence the total number of holes, N_{hole}, will be:

$$\frac{\dot{m}_{air}}{\dot{m}_{air,hole}} = N_{hole} \qquad (10)$$

A prototype (Patent pending) has been built with the above described technique. Air is admitted through the combustion chamber floor holes so that the shells will float as in a regular fluidized bed facility. The combustion chamber side walls are built with a 45^{o} slope so that the shells being returned to the main stream will keep revolving and actively participating in the combustion process. Figure 2 displays the front view of this combustion chamber from where the air input orifices can be easily seen. This facility (Figure 3) fully meets the needs of a medium size bakery.

Figure 2: Front view of the combustion chamber prototype

Figure 3: Prototype in Operation

A much larger unit can be built for higher power demands, the limiting factor being the amount of CNS (the fuel), available for burning. Nowadays there are not enough shells to attend the needs of large industrial plants. However, the potential contribution of this material to the Brazilian energy matrix is not negligible, besides solving the problem of proper disposal of an unwelcome residue which would end up unbalancing the ecology of cashew nut producing regions. This is also convenient for small and medium size industries leading them to become less dependent of the conventional electrical grid. As it is well known energy supply reliability is a major aspect in industry management.

4 CONCLUDING REMARKS:

Finally, it is worth mentioning the following aspects of the present work:

a – Combustion chambers fueled by cashew nut shells can be used not only by nut processing facilities but also by small and medium size unities such as bakeries. As this burning technique saves up to 50% as compared to a fixed bed unit, besides being a lot less pollutant than the later, it might be possible to count on saving shells to attend the demand of external clients (i.e., other small size facilities).

b – This burning technique is applied, in general, to biomass burning, its main difference, as compared to other burning systems, is the fact that here the cashew shell combustion process takes place in a floating bed, so that the CNS has very little contact with the furnace floor (the grid), preserving it. When the combustion chamber walls are built with refractory tiles, these components are attacked by the phenols generated by the burning of the CNS due to their CNSL residual content. Here the combustion chamber is built of iron or steel, both materials impervious to phenols, leading to larger life time and requiring less maintenance. The burning process performed in a floating bed under controlled conditions, minimizes pollutant emission, smog formation and CO emission. Besides, as the mean chamber temperature is below 900^oC, there is no thermal NO_x, one of the pollutants well known as responsible for acid rain formation. Therefore one attains here an environmentally clean burning process.

c –Although the fluidized bed combustion process is well known, these authors are not aware of its use for the burning of CNS. Besides, the technique described here is not a fluidized bed combustion process, for there is no fluidizing material (such as sand in the fluidized bed classical combustion process). In the prototype described here, the fluidizing takes place due to the air flow only, using the terminal speed concept.

d – The potential market for this development is located in the northeast of Brazil, mainly in the states that process and export cashew nuts.

e – Being a clean burning technique, this equipment meets the ideal of self induced environmentally proper development. Besides the obvious conventional power saving, it offers an inexpensive and reliable energy source and, in a non direct way, it is an employment factor, for this saving might lead the small and medium local industries to expand their businesses.

f – The project which led to this development is integrated to the University of Fortaleza with the partnership of “Fábrica de Castanhas CASCAJU”, a major cashew nut processing plant in the state of Ceará, Brazil.

g – Measurements showed that this technique improves the overall combustion efficiency to 85% as compared to values around 50% achieved with fixed bed combustion chambers normally used to burn the CNS.

h – Last but not least, special care has to be taken with the CNSL production. This ingredient, important for its use as starting material for organic synthesis, maybe found dissolved in the vapors leaving the cooking pans (if not completely held by the gases washing units), will be deposited in the chimney walls and thrown to the environment as a black and dangerous pollutant. Therefore, if proper care is taken to deal with the above mentioned shortcomings, the CNS is an excellent fuel, its overall behavior competitive with coal and natural wood.

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