

PRELIMINARIES FAST PYROLYSIS TESTS WITH WHOLE SUGARCANE

Luis A. B. Cortez¹, Juan M. M. Perez², Henry R. M. Mesa³, Rodrigo A. Jordan⁴,
Ricardo Baldassin Junior⁵; José D. Rocha⁶

Abstract

This work shows a preliminary study the use of whole sugarcane (crushed and dry) in a thermoconversion process (Fast Pyrolysis in Fluidized-Bed Reactor). Being one of the first experiences using this type of biomass in the fast pyrolysis plant (PPR-200), the initial objectives were limited to appraise the suitability of a feed chopper/grinder (business technology) in biomass pre-treatment and to appraise the suitability of biomass to the pyrolysis process. In the chopping and grinding process, it was found a good performance of the equipment used. The biomass was dried in the sun (naturally), without complications. About the pyrolysis process, the experiments were conducted without significant changes in normal operation. To evaluate the quality of the generated products, proximate and ultimate analysis of bio-oil produced were performed. The high heating value (HHV) obtained for the bio-oil of whole sugarcane was 23 MJ.kg⁻¹, with fixed carbon content of 8.03% (dry basis), production yield of 23% and energy conversion efficiency of 41%. Comparing these results with the bio-oil produced from sugarcane trash, there were not significant differences related to the values of the HHV, fixed carbon content and production yield (HHV = 24 MJ.kg⁻¹, fixed carbon content = 7,92%, production yield = 24%).

Keywords: bioenergy, bio-oil, proximate analysis, ultimate analysis, production yield.

1. INTRODUCTION

Despite of the efficiency production from the Brazilian sugar-alcohol agroindustry be in a satisfactory level, concerning the ethanol production (fermentative pathways), the entire production chain shows inefficient, therefore less than 30% of primary energy is given as input in ethanol production. This fact happens because the actual model of ethanol production only contemplates the use of sugar, that represents only 1/3 of energetic content sugarcane, being the remaining 2/3 in the fibers (“*palhiço*” and bagasse).

If the assessment of the energy conversion efficiency of this pathways (ratio between the energy produced as ethanol fuel and the primary energy of whole sugarcane) the value found is near of 25,7%. Considering that the primary energy of one ton of sugarcane is distributed in straw (2500 MJ), in bagasse (2500 MJ) and in sugar (2400 MJ) (LEAL, 2007), 85 liters of ethanol are produced per ton of stalks (CGEE e BNDES, 2008), with a Lower Heating Value (LHV) of 22,36 MJ.l⁻¹, i.e., 1900,6 MJ are produced as ethanol fuel.

¹ School of Agricultural Engineering, State University of Campinas, Campinas-SP-Brazil, cortez@feagri.unicamp.br

² Bioware Technology, Campinas-SP-Brazil, juan@bioware.com.br

³ Bioware Technology, Campinas-SP-Brazil, henry@bioware.com.br

⁴ School of Agricultural Engineering, State University of Campinas, Campinas-SP-Brazil, rodrigo.jordan@feagri.unicamp.br

⁵ School of Agricultural Engineering, State University of Campinas, Campinas-SP-Brazil, ricardo.junior@feagri.unicamp.br

⁶ EMBRAPA, Brasília-DF-Brazil, jose.rocha@embrapa.br

The “*palhiço*”, wrongly called straw (sugarcane trash), is characterized by the remain material over the surface after the sugarcane harvest process, being this formed by green leaf, dry leaf, tips and stalks fractions. In mechanized harvest, it is added, eventually, the roots and soil particles (RIPOLI e RIPOLI, 2004).

Nowadays, according BRAUNBECK *et al.* (2008), the use of straw (sugarcane trash) as an energetic resource is almost nonexistent, except in some specific cases. In Brazil, just 40% of the harvest is mechanized (with or without burning), being the remaining 60% realized manually (usually with burning). Evaluating the energy left in the field as “*palhiço*”, or burning, it is found a value near of 135.510 MJ.ha⁻¹, considering that the “*palhiço*” energy is 13.551 MJ.t⁻¹ (RIPOLI,1996) and the average production is 10 t.ha⁻¹ (RIPOLI, 2001).

Despite bagasse be used in the ethanol production process, providing electric energy and steam, its use is inefficient, because the technology employed by the most industries is outdated and obsolete. The use of bagasse with high humidity is another aspect that influences strongly the steam and energy electric generation, because reduces the burning efficiency and the boilers performance.

According LEAL (2005), the optimization of energy consumption in the ethanol production process would allow a further generation of bagasse surplus, as well as a harvest being realized without previous burning would allow the recover of straw (leaves and tips). This type of biomass, presented as an expressive quantity of fibers and could be used to increase the ethanol production, by hydrolysis process (acid or enzymatic) or gasification process (thermochemical pathways), or even increase the electric energy generation in the ethanol plant, which excess could be sold to the market. In the current scenario, the productive process of ethanol by the fermentative pathways, only 25% of the primary energy is taken, which value could be increased to over 50%, optimizing the use of energy in the plants and recovering part of the material which was burned or left in the field.

Nowadays, the need to increase the ethanol production due to the increasing of the internal consumer, as well as in meeting international demand, raises the need to optimize the energy production per hectare of sugarcane. This is necessary because it reduces the need to occupy large areas (increase of agricultural limits). According to CERQUEIRA LEITE *et al.* (2009), to replace 5% of the worldwide gasoline consumption by the ethanol (considering a projection consumption until 2025), Brazil would need a 21 million hectares of land occupation, i.e., an increase of 5,3 times the area occupied today (4 millions hectares). However, according to the authors, if the bagasse was submitted to hydrolysis process and there was a better use of the straw, this agricultural expansion would be reduced in 33-38%, i.e., the need to the land area could be reduced of 21 millions hectares to 13-14 millions hectares.

In this context, a new concept stands out, the “energy sugarcane”, where the use of sugarcane is not only obtained through the sucrose (sugar and alcohol production), but through all their parts. An attractive option, would be the use of all components together (whole sugarcane), because it could contribute to reduce the biomass costs (or energy costs), mainly those related to the harvest and transport.

Using whole sugarcane, the fast pyrolysis would appear as an attractive process, because it presents high conversion efficiency (about 68%) and prioritizes the production of liquid fuel (bio-oil). According to LORA (2008), it would be possible to submit this fuel to BTL process (Biomass to Liquid), converting, through the catalytic synthesis, the bio-oil, in synthetic fuels (alcohol, gasoline and diesel) and chemical products.

In this concept, this work presents the results of a preliminary study, where the whole sugarcane (straw, leaves, tips and stalks) was submitted to the fast pyrolysis process working with a fluidized bed reactor.

2. MATERIAL AND METODS.

2.1 Description of Fast Pirolisis Plant.

The tests were realized in a Fast Pyrolysis Plant (PPR-200), which is installed in the Thermodynamic and Energy Laboratory, State University of Campinas, School of Agricultural Engineering (FEAGRI). This plant has the processing capacity to 200 kg.h⁻¹ of dry biomass. The main equipments/components are presented on Fig. 1.

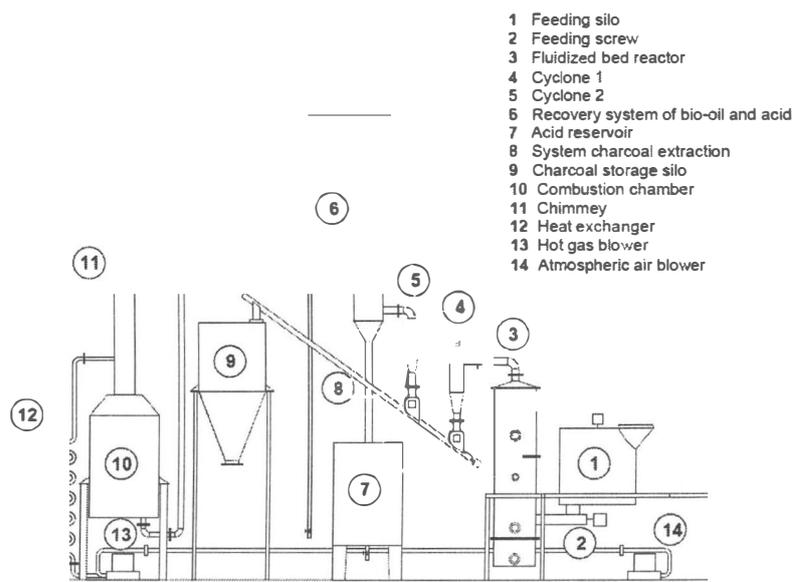


Fig. 1. Fast Pyrolysis Plant Layout (PPR-200).

In PPR-200, the operation works as describe in the following: biomass is fed into the silo (1), which has an endless screw (2) to inject biomass into the fluidized-bed fast pyrolysis reactor (3). The biomass gets in contact with the reactor bed and is volatized, becoming solid (charcoal), steam (bio-oil and acid extract) and gas. The charcoal is separated in a series-connected cyclone (4 and 5) and stored in that silo (9); acid extract and bio-oil are independently separated in the recovery system (6). In the reservoir (7) acid extract is obtained and bio-oil is removed through the upper side outlet of the separation system by using a rotating mechanical system. Other gases are burnt in the combustion chamber (10). Such gas may be used as fluidizing agents in the process by means of a heat exchanger (12) and a hot gas blower (13). The heat exchanger and hot air blower have not been installed so far; the tests are being conducted using air from the existing blower (14).

The productions yields obtained in PPR-200, for the biomasses tested (orange bagasse, tobacco residues, sawdust and elephant grass), were: 20-30% for bio-oil, 20-30% for charcoal, 10-15% for acid extract and 30-40% to the pyrolytic gases. These values were relative to mass production yield, obtained from the mass of biomass actually pyrolysed (net mass of biomass), i.e., the total fed biomass less the mass of water (humidity), the ash mass and the mass of biomass that was burned in the reactor. In PPR-200, employing a pyrolytic autothermal reactor to provide heat to the process, that operated by burning part of the fed biomass. The quantity of biomass burned is among 10-15% (mass base) of the total fed biomass.

2.2 Harvest and pretreatment of whole sugarcane.

The whole sugarcane was manually harvested, without taking the leaves, in sugarcane plantation located near to State University of Campinas and being transported until the tests location (Fig. 2).



Fig. 2. Whole sugarcane (stalks and leaf)

The sugarcane pretreatment was formed by the chopping, drying and grinding processes. The chopping process was performed in a desintegrator, chopper and grinder machine (business technology). The equipment was developed to process grains and feed, working with a fixed hammer impeller (with three-knife impeller) and mechanical separation (Fig. 3).

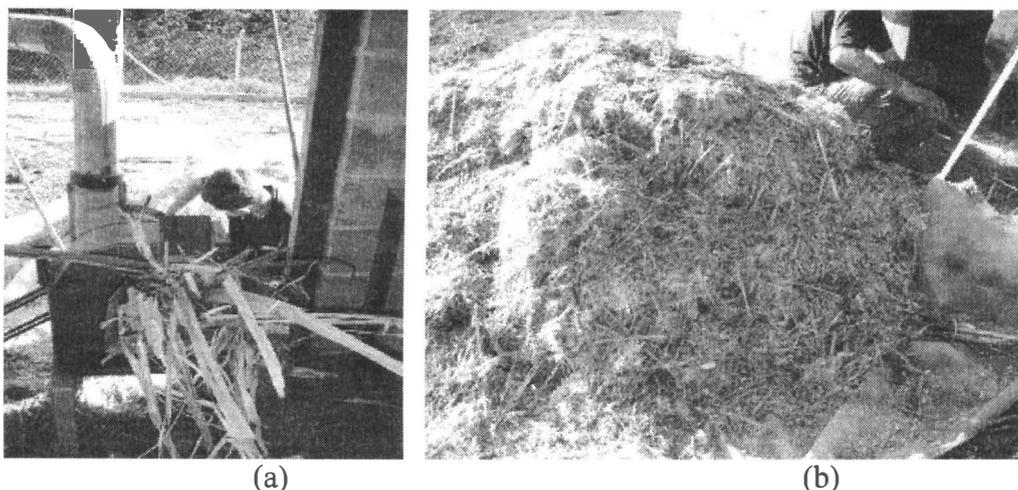


Figure 3. Chopping Process (a) Desintegrator, chopper and grinder machine, Nogueira brand, DPM-2 model (b) Whole sugarcane chopped

After chopping, all material was submitted to the drying process (drying under sun). As it was a natural process, the humidity reached was 10-15% (equilibrium humidity).

The sugarcane dried was submitted to the grinding process, that reduced the particles size to medium values nearly to 2,0 mm (diameter). It was employed the same equipment used in the chopping process, however, there was a sieve with an opening of 5 mm.

To estimate the chemical composition of the whole sugarcane, it was used some data found in the literature which referring to the sugar, bagasse and straw composition, considering the mass fraction of each component.

In sugar case, only the sucrose contribution was considered, because according to BNDES e CGEE (2008), the sucrose is responsible for 95% of sugar from sugarcane. It was used as the chemical formula of sucrose the relation $C_{12}H_{22}O_{11}$, with molecular weight of each element being equal to: $C=12 \text{ kmol.kg}^{-1}$, $H=1 \text{ kmol.kg}^{-1}$ e $O=16 \text{ kmol.kg}^{-1}$.

For the bagasse, were employed data presented by SEYE *et al.* (2003), where the chemical composition (on mass basis) of each element was equal to $C=46,73\%$, $H=5,9\%$, $N=0,87\%$ e $O=46,5\%$.

Considering the straw (sugarcane trash), the data used were provided by the *Instituto de Pesquisas Tecnológicas* (IPT) that conducted the laboratory analysis of material. The laboratory analysis were realized according to the American Society for Testing and Materials (ASTM) D 5373-02(07) and D 4239-04a.

For determining the mass of each component (sugar, bagasse and straw) in whole sugarcane, it was used data from CGEE (2004), where in each ton of stalk, there are about 140 kg of straw, 140 kg of bagasse and 150 kg of sugar (dry basis).

2.3 Pyrolysis Tests.

The experiments were conducted with the reactor operating at a temperature of 450-470 °C, medium pressure of 120 kPa and fluidized air flow of $111 \text{ m}^3.\text{h}^{-1}$.

Of all products obtained in the whole sugarcane pyrolysis, only the bio-oil was qualitatively evaluated. It were realized proximate and ultimate analysis, as well as it were determined the pH, the humidity, the higher heating value (HHV) and the lower heating value (LHV).

In previous works, the same experiments were realized with sugarcane trash (under the same conditions of the operation reactor), being the bio-oil produced, qualified according to the same methodology used in the qualification of whole sugarcane bio-oil.

The proximate analysis of whole sugarcane and sugarcane trash bio-oil were realized by the *Associação Brasileira de Cimento Portland* (ABCP), according to NBR 8289/83, NBR 8290/83 e NBR 8293/83. The ultimate analysis and the values of HHV and LHV were realized by the *Instituto de Pesquisas Tecnológicas* (IPT), according to ASTM D 5291-02(07), ASTM D4239-04a e ASTM D 240-02(07).

The determination of the humidity (by Karl Fisher Method) and the pH were realized by IPT, according to PO-GT-6029-Rev.1 and PO-GT-3062-Rev.1, respectively.

In this study, a comparison among the quality of whole sugarcane and sugarcane trash bio-oil was made.

3. RESULTS AND DISCUSSION.

In the pretreatment stage was checked a good performance of the equipment used, and visually, it was not verified the lost of water from whole sugarcane during the chopping process.

The drying under sun was simple and effective in the process of humidity reduction. However, the dependency of the climatic conditions and the long time for drying are negative aspects in this method. It is necessary to evaluate if these aspects will be maintained, in the case of handling major biomass volume.

Comparing the whole sugarcane pyrolysis to the sugarcane trash pyrolysis process, there were not difference in the conditions of plant operation, meantime, major settlements and a better control/automation system should be implanted to allow a better management and control of process.

Table 1 shows an estimative of the whole sugarcane composition (per ton of material), considering the presence of sugar, bagasse, straw and water, based on data presented in CGEE (2004).

Table 1. Composition of one ton of whole sugarcane.

COMPONENTS	MASS [kg]
Straw (dry mass)	120,2
Bagasse (dry mass)	120,2
Sugar (dry mass)	128,8
Water (by difference)	630,8

Table 2 shows a chemical composition from bagasse, straw, sucrose and whole sugarcane. The data were estimated according to the data presents on item 2.2 and on Table 1.

Table 2. Estimative of whole sugarcane chemical composition.

COMPONENTS	CHEMICAL COMPOSITION (dry mass basis)				
	C (%)	H (%)	N (%)	O (%)	S (%)
Bagasse	46,73	5,90	0,87	46,50	-
Sugarcane Trash (Straw)	41,58	5,80	0,45	52,09	0,08
Sucrose	42,10	6,43	-	51,47	-
Whole Sugarcane	43,44	6,05	0,43	50,05	0,03

The proximate and ultimate analysis of whole sugarcane bio-oil and sugarcane trash bio-oil are presented on Tables 3 and 4, respectively.

Table 3. Results of bio-oil proximate analysis.

	WHOLE SUGARCANE	SUGARCANE TRASH	PERCENTAGE DIFFERENCE
pH	6,8	6,2	8,8 %
Fixed Carbon [% mass] (dry basis)	8,03	7,92	1,4 %
Ashes [% mass] (humity basis)	0,66	0,40	39,4 %
Volatile material [% mass] (humity basis)	91,04	91,41	-0,4 %
Water (Karl Fischer Method)	15,8	8,2	48,1 %

Table 4. Results of bio-oil ultimate analysis.

	WHOLE SUGARCANE	SUGARCANE TRASH	PERCENTAGE DIFFERENCE
Carbon [% mass]	55,0	58,0	-5,5 %
Hydrogen [% mass]	7,2	6,8	5,6 %
Nitrogen [% mass]	0,2	0,4	-100 %
Sulfur [% mass]	0,08	0,05	37,5 %
HHV [MJ.kg-1]	23	24	-4,3 %
LHV [MJ.kg-1] (calculated)	21	23	-9,5 %

From Tables 3 and 4, it is possible to check percentages under 10% in 7 from 11 evaluated points, showing that there were not significant differences in bio-oil produced by whole sugarcane and by sugarcane trash.

In spite of whole sugarcane bio-oil presents 37,5% more sulfur than sugarcane trash bio-oil, both values were less than 1%, being compatible with the usually values found in the bio-oil produced by another types of vegetal biomass.

The difference of -9,5% found on bio-oils LHV are justified by the major ash volume and humidity presents on whole sugarcane bio-oil.

Table 5 shows the bio-oil and charcoal production yield, both in mass basis.

Table 5. Fast Pyrolysis Production Yield.

BIOMASSA	PRODUCTION YIELD (mass basis)		
		[$m_{\text{product}}/m_{\text{biomassa}}$]	
	Bio-oil [%]	Charcoal [%]	Total [%]
Sugarcane trash	23	33	56
Whole Sugarcane	24	32	56

From Table 5, it is possible to check that there was not difference among the results of the production, even in the generated products (bio-oil and charcoal), as in the total process.

When a pyrolysis process was evaluated in energetic terms, i.e., evaluating the conversion efficiency of whole sugarcane primary energy in bio-oil and charcoal, it was found a efficiency of 41%, i.e., 3.034 MJ of energy were produced (bio-oil and charcoal) per ton of whole sugarcane. Comparing the efficiency of pyrolysis process and the fermentative pathway (ethanol production), it was possible to check that, processing all three components together (bagasse, straw and sugar) in the pyrolysis provided a 60% increase in energy production (considering an efficiency of energy use in the fermentative pathways equal to 25,7%). However, it is important to stand out that, the bio-oil produced in pyrolysis is not ready to vehicular use, unlike ethanol.

4. CONCLUSION.

This work showed to be possible to process whole sugarcane in pyrolysis plant, i.e., straw, bagasse and sugar working together, without major operational problems.

In the whole sugarcane pretreatment, the chopping and grinding technology used, as well as drying process realized, were considered effective.

Qualitatively, significant differences were not observed between the whole sugarcane bio-oil and the sugarcane trash bio-oil produced. The same aspect also was observed in production yield.

The pyrolysis process did not distinguish between the different sugarcane components (fibers and sucrose), because the whole sugarcane and the sugarcane trash were transformed in similar products. Therefore, the use of whole sugarcane in pyrolysis process is not justified by increasing of production yield or by obtaining a bio-oil with distinct characteristics, but aiming the increasing of use the primary energy of sugarcane.

The total mass production yield presented below the desired value (60-68%), showing the necessity of improvement the process.

As future works stand out: the improvements in PPR-200 (automation and control, cooling system, biomass feeding system); another studies to the use of whole sugarcane and the better use of sugarcane trash (harvest, transport, storage, pretreatment, others)

and; major studies the bio-oil and the charcoal conversion into another fuels (gasoline, diesel and synthetic ethanol) by the thermochemical pathways (gasification and catalytic synthesis).

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