FAST PYROLYSIS TEST WITH WHOLE SUGARCANE

Luis A. B.CORTEZ[1]

Rodrigo A. JORDAN[2]

Juan M. M. PEREZ[3]

Ricardo BALDASSIN Jr[4]

Douglas Fernandes BARBIN[5]

ABSTRACT

This paper shows a preliminary study proposing the usage of whole sugarcane in the thermoconversion process. . Tests were made on fast pyrolysis of biomass as whole sugarcane (bagasse, sugar and sugarcane straw) crushed and dry. These experiments were performed in order to verify the suitability of this type of biomass for the fast pyrolysis process in a fluidized bed. The pre-treatment was assessed, during which, for the preparation of the whole sugarcane, an ordinary machine for chopping and grinding was employed. The pyrolysis process was conducted without major changes in the plant operating conditions to other biomass such as sugarcane trash. The efficiency of energy conversion of biomass to fine coal and bio-oil was 41%, resulting in a production of 3034 MJ per ton of the whole sugarcane processed, compared to 1900.6 MJ obtained in the production of ethanol via fermentation, where the conversion efficiency was around 26%. With the advances in this pyrolysis, efficiency may increase in the coming years, an interesting route for production of second generation fuels via catalytic synthesis using syngas from gasification of the mixture of bio-oil and fine charcoal.

Keywords: Bioenergy, Whole sugarcane, Bio-oil, Fast pyrolysis.

[1]Prof. Dr. of the Faculty of Agricultural Engineering, UNICAMP, Campinas-SP. E-mail: cortez@reitoria.unicamp.br
[2]Prof. Dr. of the Faculty of Agricultural Sciences of UFGD, Associate Researcher of FEAGRI/UNICAMP.
[3] Dr. in Agricultural Engineering, Technical Director of Bioware Tecnologia, Campinas-SP.
[4]MSc. Energy Planning, PhD Student in the Faculty of Agricultural Engineering , UNICAMP.
[5] School of Biosystems Engineering, University College Dublin, National University of Ireland, Agriculture and Food Science Centre, Belfield, Dublin 4, Ireland.

INTRODUCTION

Even with the good results achieved by the sugarcane industry, the energy use of sugarcane is still relatively low. The way the productive process of alcohol has been currently used leads to an efficiency use of primary energy from sugarcane of about 26%. This is due to the current production model being based on the utilization of sugarcane sugars using the bagasse as fuel for the plant, whereas the sugarcane trash is discarded. Approximately two thirds of the primary energy of sugarcane is in fibers (sugarcane trash and bagasse).

The sugarcane trash is the material remaining on the soil surface after harvest, especially mechanized harvesting, consisting of green leaves, straw, tips and/or its fractions, fractions of stalks, roots, in addition to particles of soil that are adhered to the material (Ripoli & Ripoli, 2004). According to Ripoli (2001), approximately 10 t ha^{-1} are produced. Each ton of chaff provides an average of 13.551 MJ (Ripoli, 1996).

According to Braunbeck et al (2008), the use of sugarcane trash as an energy resource is practically nonexistent today, except for some specific cases. Currently, only 40% of the harvest is mechanized in the country, with or without prior burning, while the remainder is handmade, usually with prior burning.

In the case of bagasse, despite being used in the process itself providing electrical and thermal energy, its use occurs inefficiently, since most plants use older technologies, thus presenting low yield. Likewise, the use of bagasse with high moisture content reduces the combustion efficiency and performance of the boiler.

According to Leal (2005) a significant portion of the sugarcane fibers could be made available at the plant by optimizing the energy production process (a surplus of bagasse) and harvesting of sugarcane with no prior burn, to recover part of the sugarcane trash (leaves and pointers). This biomass can be used to produce more alcohol via hydrolysis or gasification routes (thermochemical), and/or surplus electricity to be dispatched in the network. Thus, the use of primary energy of sugarcane (about 7400 MJ t^{-1}), which today is around 25%, could be increased to more than 50%.

There is a strong need to increase energy production per hectare of sugarcane, which is leading to a paradigm shift, from "sugarcane" to "sugarcane energy". Before, the targeted product was the sucrose used in sugar and alcohol production. As for the concept of "sugarcane energy", sugarcane trash and bagasse are now valued as much as sugar.

Thus, the increased use of primary energy from sugarcane, through its full use in energy conversion processes may be more interesting in the use of bagasse, sugarcane trash or sucrose independently, as it may lead to the reduction of costs, mainly those related to harvesting and transport.

Pyrolysis is an alternative for energy conversion of sugarcane harvested as a whole, and even to avoid the costs of separation of sugarcane trash. Thus, all material would be converted into fine charcoal and bio-oil. Later, within the concept of BTL (*Biomass to* *liquid*), bio-oil could be converted into synthesis gas and, through catalytic synthesis, into synthetic fuels (ethanol, gasoline, diesel) and chemical inputs (Lora, 2008).

In this context, fast pyrolysis can be framed as a pretreatment step, improving the characteristics of biomass for transport over long distances, thus reducing costs related to this step, which currently weighs significantly on its cost. The bio-oil can be considered a liquid biomass with density of 1200 kg m^{-3}, which is much higher than bulk density of polydisperse biomass which is within the 80-240 kg m^3 range.

This work shows the results of a preliminary study, in which the whole sugarcane areas (straw, leaves, pointers and stalks) were subjected to the process of fast pyrolysis in fluidized bed reactor.

MATERIAL AND METHODS

Description of the pyrolysis plant where the tests were performed

The tests were carried out in the fast pyrolysis plant installed attached to the Laboratory of Thermodynamics and Energy School of Agricultural Engineering (FEAGRI), in the University of Campinas – (UNICAMP), . Figure 1 shows a schematic diagram of the plant with the main equipment components.

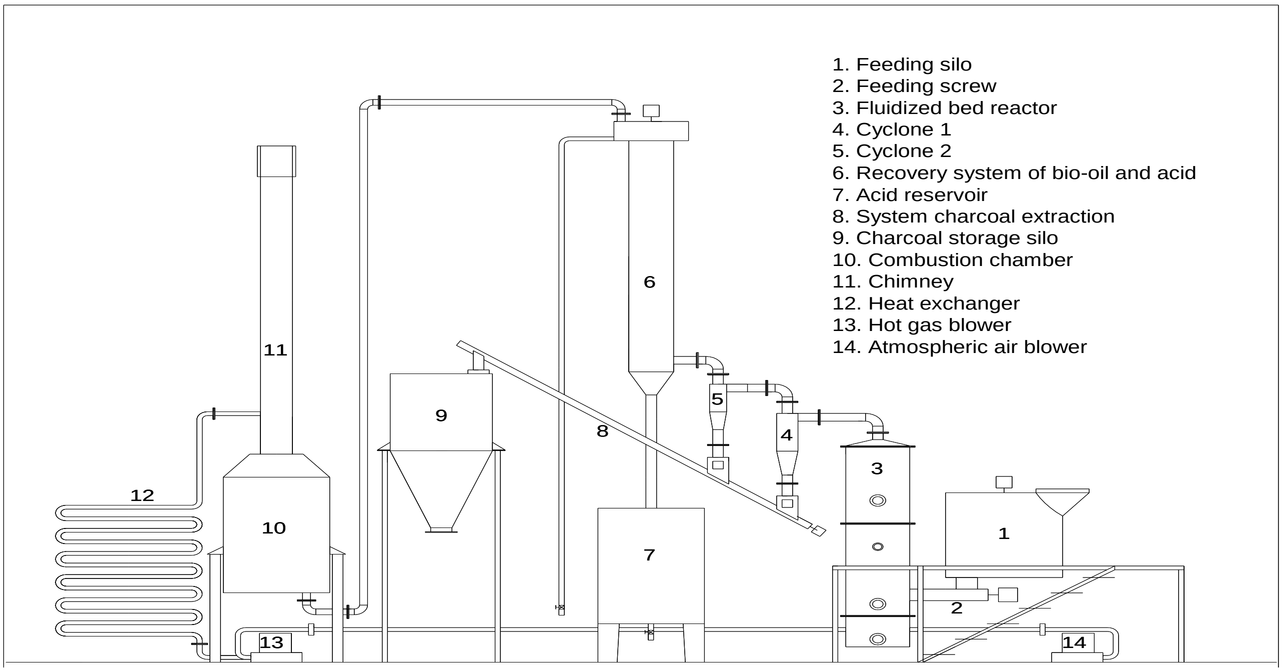

Figure 1. Schematic of fast pyrolysis plant at UNICAMP.

The operation is as follows: biomass is fed into the silo (1), which has an endless screw (2) that injects the biomass into the fast pyrolysis reactor of fluidized bed (3). Biomass, when in contact with the bed of the reactor, is volatilized, thus becoming solid (charcoal), steam (bio-oil and pyroligneous acid) and gases. The charcoal is separated in the battery of cyclones (4 and 5) and stored in the silo (9), the pyroligneous acid and bio-oil are separated in the recovery column (6), independently. In the reservoir (7) the acid extract is obtained and the bio-oil is removed from the top side exit of the recovery column through a rotating mechanical system. The remaining gases are burned in the combustion chamber (10). These gases can be used as bed fluidizing agent using a heat exchanger (12) and a hot gas blower (13). However, so far the tests use atmospheric air from the blower (14).

The average yields in products obtained from this fast pyrolysis plant for some tested biomasses is shown in the following range: bio-oil (20-30%), fine charcoal (20-30%), pyroligneous acid (10-15%) and pyrolytic gases (30-40%). These yields consider the organic mass (net mass of biomass), which is calculated by subtracting the present amount of water and ash in biomass and deducting the percentage of biomass that is combusted by the oxygen contained in the fluidization air to provide heat to the process. Regarding the current system, between 10 and 15% of biomass is used to provide heat to the process, as the reactor is auto-thermal.

In addition to the characteristics of biomass, performance also vary depending on operating conditions: height and temperature of the inert bed reactor, reactor pressure and fluidization air flow rate.

Collection and pretreatment of whole sugarcane

The sugarcane was harvested manually, with no separation between the leaves and stalks (whole sugarcane) in a sugarcane field near UNICAMP in Campinas. Subsequently, it was transported to the testing site (Figure 2), where it was first referred to pre-treatment steps.

Figure 2. Whole sugarcane (stalks and leaves)

In the next stage, whole sugarcane was pre-treated, in a step which included chopping, drying and grinding. The chopping process of whole sugarcane was carried out in a machine for disintegrating, chopping and grinding grains and fodder. The equipment used operated with a knife and hammer mill with mechanical separation, brand Nogueira DPM-2 (Figure 3).

(a) (b)

Figure 3. Chopping process (a) Processing in Nogueira DPM-2 hammer mill, (b) chopped sugarcane

After properly chopped, all material was submitted to the drying process, which took place in the sun. Because it is a natural process, the moisture content was reached in the order of 10-15% (equilibrium moisture).

Later, the dry and chopped whole sugarcane was subjected to the process of grinding/milling in order to reduce the particle size to an average diameter of approximately 2.0 mm. In this step, it was employed the same equipment used in the chopping process; though using a sieve with a 5 mm opening instead.

Determination of elemental composition of full sugarcane

The estimation of the elemental composition of whole sugarcane was conducted using data from the literature related to the constitution of its components, individually (sugar, bagasse and sugarcane trash), taking into account the mass fraction of each component.

In the case of sugars, it was only considered the contribution of sucrose, as according to BNDES and CGEE (2008), it is responsible for95% of the sugars present in sugarcane. In this sense it was employed, as the chemical formula of sucrose, the $C_{12}H_{22}O_{11}$ ratio with molecular weight of each element being equal to: C=12 kmol/kg, H=1 kmol/kg e O=16 kmol/kg. For the bagasse, it was employed data reported by Seye et al (2003), with an elementary mass base composition of each element being equal to: C=46.73%, H=5.9%. N=0.87% e O= 46.5%. In the case of sugarcane trash, the data used was provided by the Institute for Technological Research (IPT). These data were obtained in laboratory tests of sugarcane trash samples used in the pyrolysis tests in plant PPR-200. Laboratory tests were performed according to the Standards of the American Society for Testing and Materials (ASTM) D 5373-02 (07) and D 4239-04a.

The determination of the mass amount of each component (sugar, bagasse and sugarcane trash) in the whole sugarcane was carried out using data provided by CGEE (2004), where in each ton of clean sugarcane (stalks) there is about 140 kg of sugarcane trash, 140 kg of bagasse and 150 kg of sugars, all in a dry basis.

Pyrolysis tests

The experiments were conducted with the reactor operating at 450-470°C, mean pressure of 120 kPa and fluidization air flow rate of about 111 $m^3 h^{-1}$.

From products generated in the whole sugarcane pyrolysis, only the bio-oil was evaluated qualitatively through ultimate and proximate analysis. In addition, the acidity index, water content, higher calorific value (HCV) and lower calorific value (LCV) were determined.

In previous works, the same experiments were performed with dry and ground sugarcane trash (under the same conditions of reactor operation). The bio-oil was produced from sugarcane trash and qualified according to the same methodology used in the qualification of bio-oil from whole sugarcane.

The proximate analysis of samples of bio-oil of whole sugarcane and sugarcane trash were conducted by Associação Brasileira de Cimento Portland (ABCP), according to NBR 8289/83, NBR 8290/83 and NBR 8293/83. The ultimate analysis and HCV and LCV determinations were performed by the Institute for Technological Research (IPT), according to Standards ASTM D 5291-02 (07), ASTM D4239-04a and ASTM D 240-02 (07). Determination of water content and pH were carried out by ABCP, according to Standards EN-6029-Rev.1-GT and GT-PO-3062-Rev.1, respectively. The quality of whole sugarcane bio-oil was compared with sugarcane trash bio-oil.

RESULTS AND DISCUSSION

The absence of sugarcane juice loss was observed by visual assessment during the chopping process, indicating an adequate performance of the equipment used (grinder).

The process of sun drying proved to be easy to perform and efficient in the process of biomass moisture reduction. However, reliance on weather conditions and the long drying time are negative aspects of this process, which require the use of industrial dryers.

The whole sugarcane pyrolysis, compared to the process of sugarcane trash pyrolysis, was held without major changes in plant operating conditions, but major adjustments and greater control/automation should be applied in order to provide better management and control.

Table 1 shows an estimate of the composition of whole sugarcane (per ton of matter) regarding the presence of sugar, bagasse, sugarcane trash and water, based on data presented in CGEE (2004).

Table 1. Estimated composition of of whole sugarcane (1 ton).

Components	Mass (kg)
Sugarcane trash (dry matter)	120.2
Bagasse (dry matter)	120.2
Sugar (dry matter)	128.8
Water	630.8

Table 2 shows the elemental composition of sugarcane trash, bagasse and sucrose in addition to the whole sugarcane, which were estimated according to data presented in item 2.3. As for the whole sugarcane composition, the components fractions were summed, according to the composition presented in Table 1.

Table 2. Elemental constitution of sugarcane components and whole sugarcane.

	Elemental composition (dry basis)				
	C (%)	**H (%)**	**N (%)**	**O (%)**	**S (%)**
Sugarcane bagasse	46.73	5.90	0.87	46.50	-
Sugarcane trash	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**

Table 3 shows the results of the proximate analysis of samples of bio-oil from whole sugarcane and sugarcane trash. Table 4 shows the results of the ultimate analysis of bio-oil samples.

Table 3. Proximate analysis of bio-oil from whole sugarcane and sugarcane trash.

Test	Whole sugarcane	Sugarcane trash
pH	6.8	6.2
Fixed carbon (dry basis) [% mass]	8.03	7.92
Ashes (Wet basis) [% mass]	0.66	0.40
Volatile material (wet basis) [% mass]	91.04	91.41
Water content by Karl Fischer	15.8	8.2

Table 4. Ultimate analysis of bio-oil from whole sugarcane and sugarcane trash.

Test	Whole sugarcane	Sugarcane trash
Carbon [% mass]	55	58
Hydrogen [% mass]	7.2	6.8
Nitrogen [% mass]	0.2	0.4
Sulfur [%mass]	0.08	0.05
HHV [MJ kg^{-1}]	23	24
LHV [MJ kg^{-1}]	21	23

As it can be observed, several properties are similar for whole sugarcane bio-oil and sugarcane trash, such as pH, fixed carbon content and volatile content. The hydrogen content is slightly higher for the whole sugarcane bio-oil. On the other hand, the nitrogen content in sugarcane trash bio-oil is two times higher than the amount encountered for the whole sugarcane bio-oil.

The water content was higher for the whole sugarcane bio-oil, nearly two times the amount reported by sugarcane straw bio-oil. The sulfur content of the two bio-oils was less than 1%, and consistent with the values normally found for bio-oils obtained from other biomasses, mainly because its plant biomass has low composition of this element, as shown in Table 2.

The lower heating value (LHV) and higher heating value (HHV) were higher for the sugarcane straw bio-oil. The ash content, which was higher for the whole sugarcane bio-oil, contributed for presenting lower HHV, as well as higher humidity affected the LHV.

As shown, the characteristics are similar for both bio-oil samples. The same was observed for the elemental composition of biomasses (sugarcane trash and whole sugarcane). The yields of pyrolysis products of whole sugarcane and pyrolysis of sugarcane trash were also similar (Table 5).

Table 5. Yield in bio-oil and charcoal pyrolysis.

Biomass	**Yield (mass/mass)**	
	Bio-oil (%)	**Fine charcoal (%)**
Sugarcane trash	23	33
Whole sugarcane	24	32

Thus, the whole sugarcane pyrolysis is not based on the increased yield in the pyrolysis process or in the expectation to obtain bio-oil with different characteristics. Actually, it is based on the overall yield of primary energy from sugarcane. The reason is that the pyrolysis process does not distinguish the sugarcane components (sugars and fibers).

As for alcoholic fermentation, only sugars are converted into energy, thus leading to the low usage of primary sugarcane energy. According to Leal (2007), the primary energy of one ton of sugarcane is distributed as follows: straw (2500 MJ), bagasse (2500 MJ) and sugars (2400 MJ). Since the production of ethanol is quantified per ton of clean sugarcane (stalks) for 85 liters (CGEE and BNDES, 2008), with a lower heating value of 22.86 MJ L^{-1}, there is an energy production of 1900.6 MJ in the form of ethanol. Thus, the overall conversion efficiency considering the primary energy from whole sugarcane is approximately 26%. Figure 4 illustrates the current production model, which does not include the use of sugarcane trash.

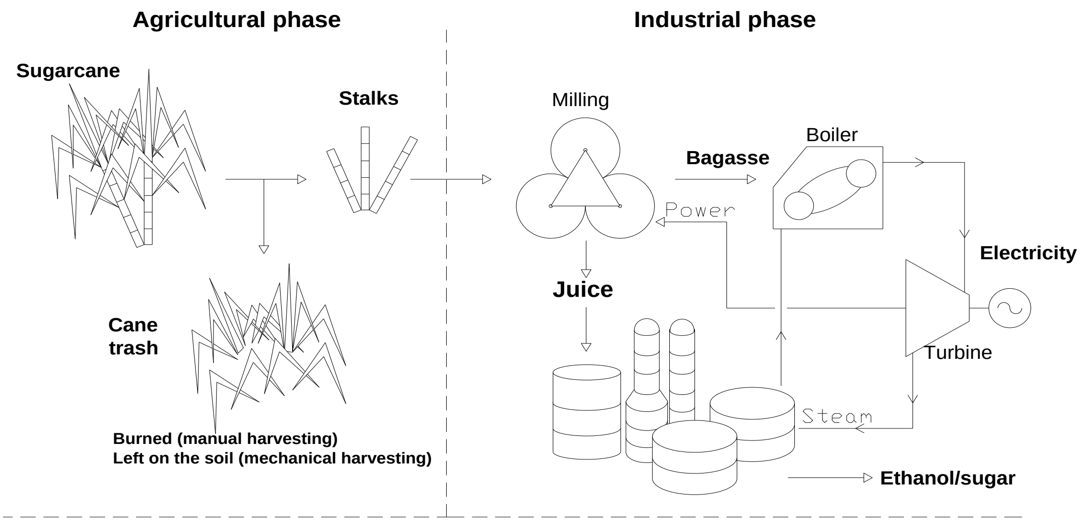

Figure 4. Current production model: disposal of straw in the field.

Even considering the current performance of the fast pyrolysis plant in UNICAMP, which are still relatively low, there is the conversion yield of the biomass energy in fine charcoal and bio-oil of about 41%. When this value is applied for the whole sugarcane, it results in a production of 3034 MJ per ton of processed biomass. This result is higher than the 1900.6 MJ obtained through the process of ethanol production by fermentation. However, unlike ethanol, bio-oil is not a ready fuel for vehicular use, and needs to be subsequently subjected to transformation process.

Given the progressing researches aimed at increasing the pyrolysis performance, it is estimated a 20-year period so that the conversion yield of the process reaches 70%. Thus, regarding the production of bio-fuels by thermochemical route, the bio-oil mixed with fine charcoal would be gasified, transformed into synthesis gas and converted into bio-fuels (gasoline, diesel and synthetic ethanol) and chemicals through catalytic synthesis.

Figure 5 illustrates the proposed model for the energy conversion of whole sugarcane through fast pyrolysis, the primary products obtained and some options for their application. Some of them require posterior transformation processes, such as the manufacture of briquettes and gasification followed by catalytic synthesis for the production of liquid bio-fuels for vehicles.

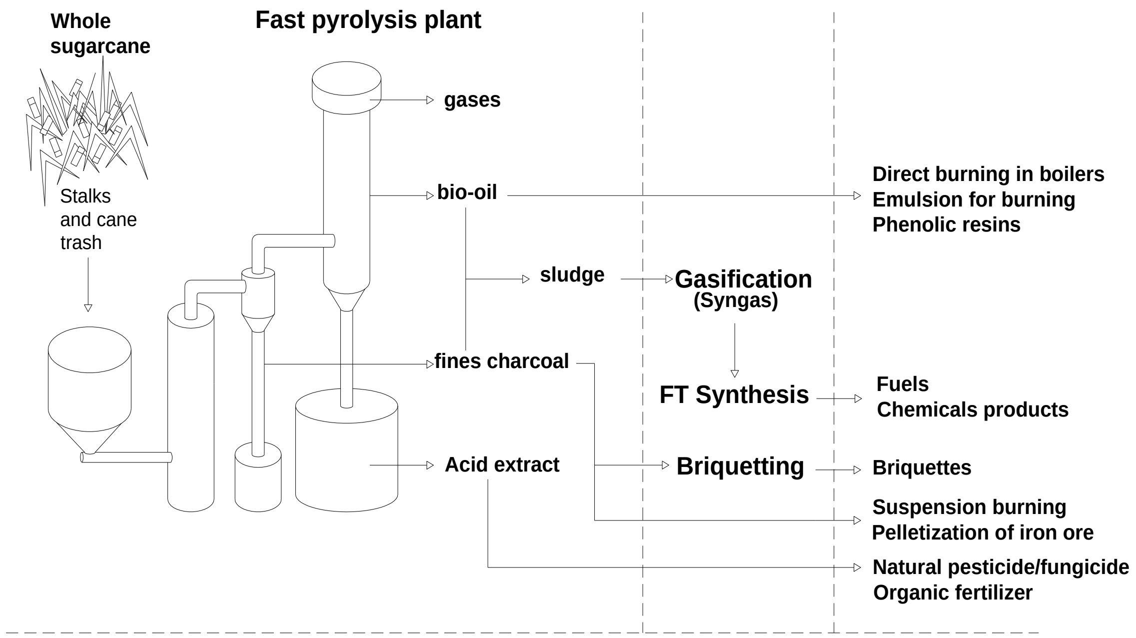

Figure 5. Proposed model for energy conversion of whole sugarcane

For this future scenario also considering the increased efficiency of the gasification and catalytic synthesis processes, it is estimated that the overall efficiency of primary energy conversion of sugarcane in liquid fuels may reach 42%. This is equivalent to a production of 136 liters of ethanol per ton of sugarcane. On the other hand, according to Lora (2008) cited by Cortez (2010), it is necessary volumes of production around 5 million tons of biomass or 1700 MW per year, to enable the catalytic synthesis to be reached.

The amount of sugarcane trash to be removed from the field is still a subject that needs to be further discussed, considering microbiological soil aspects. However, as noted by Braunbeck et al (2008), within the “energy sugarcane” concept, the most economic way for the recovery of sugarcane trash is the whole sugarcane harvesting.

CONCLUSIONS

It has been shown the possibility to pyrolize the whole sugarcane, using sugarcane trash, bagasse and sugar, without significant changes in the process under normal operation conditions of the pyrolysis plant.

In the pretreatment of whole sugarcane, for the scale of pyrolysis plant tested (processing of 200 kg h^{-1}), the technology employed in the chopping and grinding processes, as well as the biomass drying process, were efficient. Qualitatively, there were no significant differences between the sugarcane trash bio-oil and whole sugarcane bio-oil, the same occurring in the mass production yields.

Thus, it was found that the pyrolysis process does not distinguish the different components of sugarcane (fibers and sucrose), since it converted the whole sugarcane and the sugarcane trash into similar products. Thus, the use of whole sugarcane in the pyrolysis process is justified by the increased yield of sugarcane primary energy.

The mass yield (fine charcoal plus bio-oil) was below the intended value (60-71%), thus pointing out the need for improvements in the process. The same occurred for the conversion yield of primary energy of whole sugarcane through pyrolysis, which although providing a higher efficiency of fermentative route conversion, needs to reach higher values.

The production route of bio-fuels, going through the pyrolosis of whole sugarcane, followed by the gasification and catalytic synthesis, could significantly increase the production capacity per area of planted sugarcane, and would produce not only ethanol, but also diesel and synthetic gasoline, in addition to other energy and chemical inputs.

REFERENCES

Braunbeck, O.A.; Magalhães, P.S.G.; Garcia, M. O. Colheita e Recuperação de Biomassa. Capítulo III, 63-91 pag. In: Biomassa para Energia. Editora Unicamp, Campinas/SP, 2008, 732p.

BNDES - Banco Nacional de Desenvolvimento Econômico e Social; CGEE - Centro de Gestão e Estudos Estratégicos. Sugarcane-based bioethanol: energy for sustainable development. Rio de Janeiro: BNDES. 304 p. 2008.

Cortez, L. A. B.; Jordan, R. A.; Mesa Perez, J. M.; Rocha, J. D. Roadmap tecnológico para o etanol: Componente termoconversão de biomassa. Parte 5, cap. 6, pag. 937-948. In: Bioetanol de cana-de-açúcar - P&D para a produtividade e sustentabilidade. 2010, 1° edição, editora Blucher, parte.5, cap.6, pag.937-948.

CGEE - Centro de Gestão e Estudos Estratégicos. Avaliação da Expansão da Produção de Etanol no Brasil. Brasília: CGEE. 73 p. 2004.

Leal, M.R.L.V. Energia da biomassa: álcool, biodiesel e eletricidade. In: 3ª Conferência Nacional de C, T&I, 2005, Brasília. Available from http://74.125.47.132/search?q=cache:4xfctrQPobwJ:www.cgee.org.br/atividades/redirect.php%3FidProduto%3D2072+Energia+da+biomassa:+%C3%A1lcool,+biodiesel+e+eletricidade&cd=1&hl=pt-BR&ct=clnk&gl=br. Acesso em: 17 ago. 2009.

Leal, M.RL.V. Cana de açúcar como fonte de energia. Energia na indústria de açúcar e álcool, 2007, Pirassununga. Available from: http://www.fzea.usp.br/green/GERA/7%20-%20Regis%20Lima%20Verde%20Leal.ppt . Acesso em: 3 ago. 2009.

Lora, E.E.S.; Venturnini, O.J. Termoquímica para combustíveis. XIII Encontro Nacional de Metodologias de Laboratório (XIII MET). 2008.

Available from http://xiiimet.cpatu.embrapa.br/arquivos/Termoquimica%20para%20Biocombustiveis%20-%20P1.pdf. Acessado em: 09 jun. 2009.

Ripoli, M.L.C.; Ripoli, T.C.C. Caracterização dos principais constituintes da biomassa de três variedades de cana-de-açúcar. In: Simpósio de Iniciação Científica da Universidade de São Paulo, 4., 1996, Piracicaba. Resumos...Piracicaba: EDUSP, 1996. v.1, p. 463.

Ripoli, M.L.C.; Ripoli, T.C.C. Effects of pre-harvest burning in sugar sugarcane (Saccharum spp.) in Brazil. Rivista di Ingegneria, Bologna, v. 32, n. 4, p. 202-10, nov. 2001.

Ripoli, M.L.C.; Ripoli, T.C.C. Biomassa de cana-de-açúcar: colheita, energia e ambiente. Piracicaba, edição dos autores. 2004. 302 p.

Seye, O.; Cortez, L.A.B.; Olivares Gómez, E. Estudo cinético da biomassa a partir de resultados termogravimétricos. In: 3º Encontro de Energia no Meio Rural, Campinas-SP, 2003.