THE HISTORY OF RESEARCH AND DEVELOPMENT OF FAST PYROLYSIS PLANT FOR BIO-OIL PRODUCTION AT THE FACULTY OF AGRICULTURAL ENGINEERING OF UNICAMP

HISTÓRICO DA PESQUISA E DESENVOLVIMENTO DA PLANTA DE PIRÓLISE RÁPIDA PARA PRODUÇAO DE BIO-ÓLEO DA FACULDADE DE ENGENHARIA AGRÍCOLA DA UNICAMP

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ABSTRACT

This article is dedicated to describe the fast pyrolysis plant of biomass PPR-200 settled at UNICAMP School of Agricultural Engineering (FEAGRI). This fast pyrolysis plant, the first in Brazil to produce oil with fluidized bed reactor , began operating in 1998 with studies in a reactor for gasification, adapted to obtain bio-oil. Currently, PPR-200 operates with a 200 kg h-1 biomass capacity, and is used to conduct exploratory testing with various vegetable raw materials, such as sugar cane trash and bagasse, elephant grass, sawdust from wood, rice straw, coffee straw, orange bagasse, etc.. Around 15% of biomass is burnt to provide heat to the process. The remainder turns into the following products: bio-oil (20-40%), fine charcoal (20-30%), extract acid (10-15%) and pyrolysis gas (15-35%). The pyrolysis gas is composed mainly by CH_4, the H_2, CO and CO_2.

Keywords: Biomass, bioenergy, reactor, fluidized bed.

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RESUMO

Este artigo é dedicado a descrição da planta de pirólise rápida de biomassa PPR-200 instalada na Faculdade de Engenharia Agrícola (FEAGRI) da Universidade Estadual de Campinas (UNICAMP). O desenvolvimento desta planta de pirólise rápida, a primeira no Brasil a produzir bio-óleo com reator de leito fluidizado, teve seu início em 1998 com estudos em um reator de gaseificação, adaptado para possibilitar a obtenção de bio-óleo. Atualmente, a planta opera com uma capacidade 200 kg h^{-1} de biomassa, sendo utilizada para testes exploratórios com diversas matérias-primas vegetais, tais como: palha e bagaço de cana-de-açúcar, capim elefante, serragem de madeira, palha de arroz, palha de café, bagaço de laranja entre outros. Cerca de 15% da biomassa é queimada para fornecer calor ao processo, o restante, se transforma nos seguintes produtos: bio-óleo (20-40%), finos de carvão (20-30%), extrato ácido (10-15%) e gases de pirólise (15-35%). O gás de pirólise é composto, principalmente, por CH_4, H_2, CO e o CO_2.

Palavras Chave: Biomassa, Bioenergia, Reator, Leito Fluidizado.

INTRODUCTION

Brazil is a predominantly agricultural country, which produces approximately 300 million tones of agricultural and agro-industrial residues every year. Nevertheless, only a small part of them is used as energy sources, as they have poor energy characteristics (low density, low calorific value and high humidity), leading to high transportation, handling and storage costs (SUAREZ ET AL., 2003).

Thus, the integral use of such naturally occurring residues would not be cost-effective. Any approach to use biomass waste as energy source must necessarily consider the pre-treatment to streamline the logistics (handling and transportation) and cut costs, and the application of thermal conversion technologies to obtain primary products and/or fuels.

Pyrolysis is characterized by thermal degradation of solid fuel, which can be performed in the complete absence of an oxidizing agent or in such a quantity that gasification does not occur extensively.

Biomass fast pyrolysis to produce an optimum fraction of aqueous organic liquid (bio-oil) is a thermochemical conversion process, i.e., i

it occurs at high temperatures and involves chemical reactions. The fluidized-bed technology is a very interesting alternative because it is a versatile and relatively simple technique and offers attractive deployment costs when compared with other options, such as vacuum pyrolysis, the rotating cone and the vortex ablative. (BRIDGEWATER, 2001). Bio-oil obtained from biomass pyrolysis can be used as a renewable fuel, replacing diesel and fuel oil for stationary power generation in thermal systems.

Currently, in Brazil, among the technologies proposed for using agricultural waste to produce energy, fast pyrolysis for bio-oil production is in a more advanced stage to be implemented in the short and medium terms.

The pilot plant of biomass fast pyrolysis with a fluidized reactor developed by Unicamp researchers, which is the first pilot plant for bio-oil production in Brazil, was originally installed at the premises of the former Copersucar Technology Center, currently the Cane Technology Center (CTC), in Piracicaba - São Paulo. The pilot plant is called PPR-200, which is an acronym for Fast Pyrolysis Plant and a reference to its capacity (200 kg/h of dry biomass). In 2007, during a research project in partnership with Bioware[1], the plant was

transferred to the Faculty of Agricultural Engineering of Unicamp.
This paper provides data on the development of the PPR-200, technical and operational (plant start-up) details, characteristics of raw materials and products obtained.

(Footnotes)
[1] Spinoff of UNICAMP.

FAST PYROLYSIS PLANT PPR-200

History of the pilot plant of biomass fast pyrolysis.

In 1998, the reactor started to be assembled at the CTC premises in order to generate gases through the biomass gasification process. Three years later, an experimental study was conducted to verify the reactor operation under pyrolysis conditions by assessing the fine charcoal product obtained in the process (OLIVAREZ-GÓMEZ, 2002).

In 2002, the creation of Bioware by members of the Unicamp research group added a new burst of energy in the PPR-200 activities. In 2003, the main development goal was to prepare the plant to produce bio-oil as the main product and fine charcoal as a secondary product, but it was not possible to measure the performance of the bio-oil recovery system due to the low bio-oil yields in the gas phase (MESA-PÉREZ, 2003).

In 2004, the pilot plant was modified as an attempt to reduce the residence time of pyrolysis vapor and increase the yield of liquid products. From 2005 to 2007, significant bio-oil samples were obtained by using a centrifugal separator (patent has been applied for), which was adjusted to produce higher yield and high quality bio-oil. In 2007, then in a more advanced stage, PPR-200 was transferred to the Faculty of Agricultural Engineering of Unicamp as part of the research project in partnership with Bioware. Figure 1 shows the evolution of PPR-200.

1998: The beginning: the reactor designed to gasify biomass.

2001: Production of fine charcoal.

2004: Modification to increase the yield of liquid products

2007: Pyrolysis tests with whole sugarcane

FIGURE 1: A brief history of PPR-200 evolution

The PPR-200 was developed with the financial support from the Foundation for Research Support of the State of São Paulo (FAPESP), the Brazilian National Council for Scientific and Technological Development (CNPq), the Brazilian Ministry of Mining and Energy (MME), the Brazilian Funding Authority for Studies and Projects (FINEP) and Bioware.

PPR-200 process description

Figure 2 shows the current design configuration and main equipment components of PPR-200. The plant operation is comprised of the following steps: biomass is fed into the silo (1), which has an endless screw (2) for injecting the biomass into the fluidized-bed fast pyrolysis reactor (3). The biomass comes in contact with the reactor bed at a temperature of approximately 500ºC and is volatized, becoming solid (fine charcoal), steam (bio-oil and acid extract) and gas. The fine charcoal is separated in a series-connected cyclone (4 and 5) and stored in the silo (9); the acid extract and the bio-oil are independently separated in the recovery system (6). In the reservoir (7), the acid extract is obtained and the bio-oil is removed through the upper side outlet of the separation system by using a rotating mechanical system developed by the researchers involved in the project. Other gases are burnt in the combustion chamber (10). Such gases 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 yet; the tests are being conducted using air from the existing blower (14).

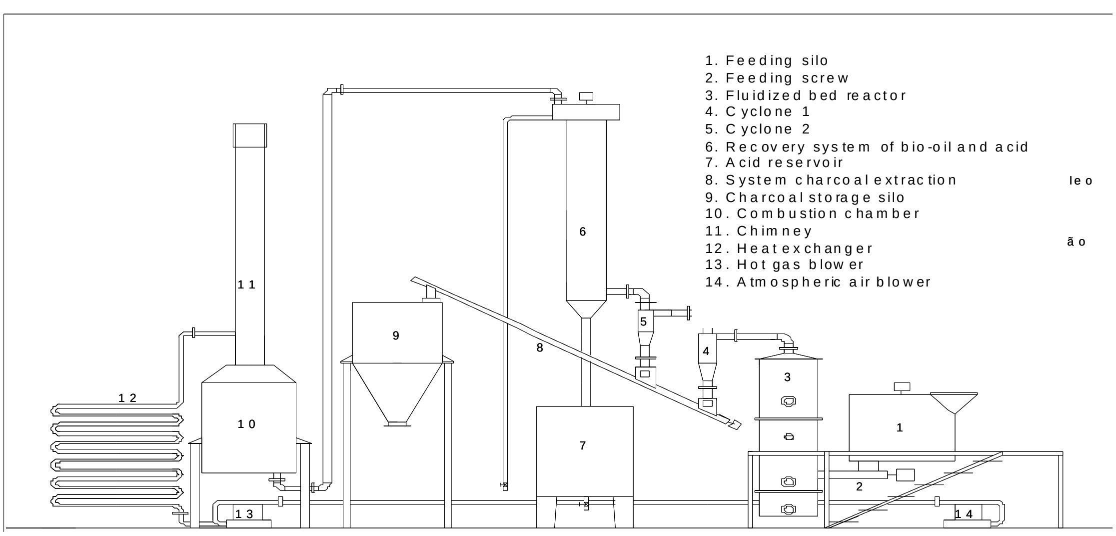

FIGURE 2: Fast pyrolysis plant design.

The reactor is cylindrical carbon steel containment vessel of 417 mm in diameter and internally coated with refractory insulation. Its rated feed capacity is of 200 kg.h^{-1} polydisperse dry biomass and an inert material bed is used during its operation. A data acquisition system is used to log and store temperature and pressure parameters along the height of the reactor and at the recovery system outlets. Table 1 provides the main reactor features.

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TABLE 1: Reactor technical specifications

Type	Fluidized-bed
Build material	Carbon steel
Internal diameter	417 mm
Height	2600 mm
Bed height	400 mm
Insulation	Refractory
Insulation material thickness	80 mm
Distribution plate material	Carbon steel
Minimum fluidization speed at 25 ºC	0.025 m/s
Particles retention time	2 to 3 s
Operating temperature	500ºC
Pressure	300 mm$H_2$0

Silica sand (silicon dioxide – SiO2) with particles of 0.164 mm average diameter and 0.6 mm average sphericity is used as inert material in the bed.

The reactor is operated by burning part of the biomass (10-15%) to heat the inert material bed, where the air is injected to ensure fluidization and promote the heat exchange in a short period of time. The air is blown through a blower located at the base of the reactor and flows through holes on the distribution plate, over which the inert material bed lies.

Fine charcoal from eucalyptus wood carbonization is fed into the reactor for the startup, which lasts until the silica sand bed reaches an average temperature between 550ºC and 600ºC. Under such temperatures and specific flow rate, biomass is fed into the reactor, no charcoal is added, and as mentioned above, part of the biomass is used to generate heat.

Currently, the fast pyrolysis plant produces samples of fine coal and bio-oil as part of a project supported by CNPq, a Brazilian research promotion agency. The pyrolysis products, such as charcoal, bio-oil and acid extract, are continuously withdrawn and stored in suitable tanks.

Biomass pre-treatment

Before being processed in PPR-200, the biomass undergoes a pre-treatment that consists in drying and grinding it in order to achieve a moisture content and the appropriate size of particles. For the proper reactor operation, it is required that biomass and inert material be a homogeneous mixture. To achieve this, a given diameter and density rate must be consistently used for the particles of the inert material and the biomass in the bed (Rasul, 1999). If this rate exceeds a given threshold, biomass segregation may occur at the bottom or top of the bed, leading to ash sintering.

Figure 3 shows the biomass reception, handling and pre-treatment steps prior to being processed in PPR-200. The pictures show samples of sugar cane straw, which is cultivated in the State of São Paulo. Biomass is dried up to a 12% humidity content in a dry-weight basis.

In addition to straw and sugar-cane bagasse, other types of biomass are processed in PPR-200, such as elephant grass, sawdust and crop residues, such as rice and coffee husks. All biomass residues are pre-treated prior to being processed in PPR-200. Depending on the conditions and characteristics of biomass, more grinding and drying are required. For processing, the ideal average diameter of the particles is approximately 5 mm.


Reception


Milling


Drying


Biomass ready for pyrolysis

FIGURE 3: Biomass reception and pre-treatment

Characteristics of some biomass sources and products obtained in the PPR-200

Lignocellosic biomass is a complex mixture of natural carbohydrate polymers known as cellulose, hemicellulose, lignin and small amounts of other substances, such as extractives substances and ashes.

The biomass composition plays a significant role in the distribution of products during their thermoconversion. Each material shows a distinctive characteristic when thermally degraded due to the proportion of its components (OLIVAREZ-GÓMEZ, 2002). Studies related to the effects of biomass components on the pyrolysis process show that ashes and extractive substances inhibit the formation of certain compounds during thermal decomposition.

The devolatization process includes the formation of volatile components by thermal destruction of the biomass components, mainly cellulose and hemicellulose, which are removed from the lignocellulosic structure. Lignin is the most thermally stable component in biomass, which basically are the main source of carbon in charcoal.

Table 2 shows ultimate and proximate analysis data for some types of biomass processed in PPR-200. Table 3 shows the results of the chemical composition analysis (percentage of cellulose, hemicellulose and lignin).

TABLE 2: Ultimate and proximate chemical composition results for some types of biomass processed in PPR-200

Analysis	Description	Sugarcane trash	Orange bagasse	Tobacco residues	Elephant grass
Ultimate (%)	Carbon (C)	41.58	44.7	37.24	41.16
	Hydrogen (H)	5.80	5.96	5.37	5.55
	Nitrogen (N)	0.45	1.18	2.58	1.78
	Sulfur (S)	0.08	0.07	0.22	-
Proximate (%)	Ashes	11.70	4.79	19.19	4.92
	Volatile Material	81.55	79.87	71.28	67.34
	Moisture	9.92	8.10	3.72	12.20
	Fixed Carbon	6.90	15.34	9.28	15.54
HHV	Higher Heating Value (MJ/kg)	17.74	16.75	14.56	14.70
LHV	Lower Heating Value (MJ/kg)	16.51	15.49	13.42	-

TABLE 3: Cellulose, hemicellulose and lignin percentages for some samples of biomass processed in PPR-200.

Material	Lignin (%)	Cellulose (%)	Hemicellulose (%)	TOTAL (%)
Sugarcane trash	22.82	41.42	32.65	96.88
Orange bagasse	8.17	52.75	16.30	77.22
Tobacco residues	3.54	NA	NA	NA
Elephant grass	27.50	NA	NA	NA

There is a variation in the level of some components according to the type of biomass used, as well as in the calorific value and lignin, cellulose and hemicellulose contents, causing both the amount and composition values of the resulting products to vary.

INDICATORS PERFORMANCE OF PLANT PPR-200

Table 4 presents the approximate yield values for the products of biomass fast pyrolysis in PPR-200.

TABLE 4: Pyrolysis resulting product yields for some types of biomass processed in PPR-200

Product	Yield (%)		
	Sugarcane trash	Orange bagasse	Tobacco residues
Fine charcoal	25	20	40
Total liquid	35	40	31
Acid extract	10	10	-
Gases (by difference)	30	30	29

The production has not been optimized, resulting in a consumption of 10 to 15% of the biomass in the process. The use of resulting gases for pre-heating the air fluidization should contribute to increase the amount of resulting products. As for the quality of the fraction products, it is necessary to install a separator to fractionate the bio-oil into light and heavy fractions.

The biomass fast pyrolysis resulting bio-oil is not a bio-fuel, but can be used to partially or totally replace fossil fuel oil and diesel in electricity and heat generation. It is composed of cellulose and lignin fragments, natural polymers that form the plant tissue. Therefore, such applications are innovative and eligible for carbon credits.

Table 5 presents the results of ultimate analysis, water content obtained by the “Karl-Fischer” method and the higher and lower heating values of bio-oil produced in PPR-200 from sugar cane trash, orange bagasse, tobacco residues and elephant grass. Pyrolysis liquid products are acid (pH H” 2.5), therefore, it is important to choose suitable storage vessels (stainless steel or carbon steel and polymer resin coated.).

TABLE 5: Chemical composition, higher/lower heating value and pH values for bio-oil from biomass processed in PPR-200.

Analysis	Description	Sugarcane trash	Orange bagasse	Tobacco residues	Elephant grass
Ultimate (%)	Sulfur (S)	0.06	0.05	0.51	-
	Carbon (C)	56.26	58.53	36.88	61.10
	Hydrogen (H)	7.42	8.37	8.95	7.63
	Nitrogen (N)	0.77	1.84	3.32	1.20
HHV	Higher Heating Value (MJ/kg)	23.50	24.09	17.70	24.68
LHV	Lower Heating Value (MJ/kg)	21.93	22.31	15.80	-
pH	-	3.20	3.68	9.36	3.21
Water	Karl-Fischer method (%)	16.00	19.81	49.30	13.20

Note: Detection thresholds: HCV = 0.24 cal/g; C = 10 ppm; H = 100 ppm; N = 600 ppm; S = 10 ppm, Dry-weight basis analysis (samples of naturally occurring residues).

Table 6 presents the results of analysis of resulting fine charcoal samples produced in PPR-200 from sugar cane trash, orange bagasse, tobacco residues and elephant grass.

Low granulometry is a characteristic of charcoal resulting from fast pyrolosis and represents an advantage in applications such as iron ore pelotization and furnace suspension burning.

Where the use of larger particle size charcoal (pellets or briquettes) is required, compression can be performed by using corn starch or bio-oil pitch as binders.

TABLE 6: Chemical composition and higher/lower heating value of fine charcoal samples resulting from the processing of some types of biomass in PPR-200.

Analysis	Description	Sugarcane trash	Orange bagasse	Tobacco residues	Elephant grass
Ultimate (%)	Sulfur (S)	0.12	0.07	0.36	0.32
	Carbon (C)	50.90	56.65	37.04	50.92
	Hidrogen (H)	2.69	3.15	0.44	3.09
	Nitrogen (N)	0.69	1.55	2.16	1.10
Proximate (%)	Moisture	1.20	1.20	0.80	0.94
	Ashes	42.86	24.07	19.84	18.45
	Volatile materials	21.92	30.92	45.95	39.00
	Fixed carbon	35.10	44.85	33.61	42.55
HHV	Higher Heating Value (MJ/kg)	16.42	24.09	13.07	18.36
LHV	Lower Heating Value (MJ/kg)	15.85	22.31	12.98	-

Another byproduct of the pyrolysis process is the acid extract: a solution that can be diluted in water and used in agricultural applications. The solution acts as a biostimulant for crops, such as soybeans and coffee, and fruits (orange, persimmon and passion fruit, for example). The acid extract is an effective tool to improve crop health and productivity, eliminating the application of pesticides. In the irrigated cultivation of beans, for example, it eliminates “fusarium” fungus, and in coffee growing, it controls the leaf miner larvae, having the advantage of being 40% cheaper than conventional methods. The use of acid extract in agriculture offers a 50% reduction of pesticides and chemical fertilizers, with no efficiency losses.

Pyrolytic gases have a composition similar to that of the synthesis gas, consisting of carbon monoxide and hydrogen gas (CO and H2), and can be used in conversion systems for a variety of products, such as hydrocarbons, by using Fischer-Tropsch synthesis. Other gases are also found, such as CO2 (carbon dioxide), NOx (nitrogen oxides), CH4 (methane) and other hydrocarbons. Nevertheless, the best application for such gas is the burning in a combustion chamber adjacent to the fluidized bed and the use of combustion gas and the energy contained in them (gas temperature of approximately 700ºC), as an additional heat source to the fast pyrolysis process and its use as an a fluidizing bed agent.

CONCLUSIONS

1. After a long process, we were able to obtain a significant amount of bio-oil as the main product of the PPR-200 fast pyrolysis plant, what was possible with the development of the sorter.

2. It is possible to process different types of biomass in PPR-200, provided that appropriate pre-treatment conditions (humidity and particle size) are ensured for the pyrolysis process in the fluidized bed reactor, which has been effective. Some specific adjustments allow improving the quality and quantity of products.

3. The yields of pyrolysis products (coal and bio-oil) and their composition vary according to the type of biomass

4. Leftovers of agroindustry processes, such as orange bagasse, can be pyrolyzed and converted into significant energy inputs, such as charcoal and bio-oil.

5. The plant needs to be optimized to use the gases generated in the process, thus, reducing the consumption of biomass and increasing the yield. In addition to that, a separation system for fractioning the resulting bio-oil needs to be deployed in order to generate steam in the pyrolysis reactor.

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