PRODUCTS FROM CANE BAGASSE AND TRASH FAST PYROLYSIS
FLUIDISED BED SYSTEM: THE BRAZILIAN EXPERIENCE

By

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Abstract

The fast pyrolysis process has been developed in a fluidised bed pilot plant scale in Brazil since 1995. The country has raw material such as cane bagasse and trash to feed the process and all appropriate conditions in terms of human and natural resources. The experiments were carried out in the pilot plant located at Centro de Tecnologia Copersucar in Piracicaba by students and staff from Universidade Estadual de Campinas in Campinas. The progress of this technology will put Brazil ahead of the all Latin American countries in this important area. Bio-oil, fine charcoal, and low calorific value gas are the products of biomass pyrolysis. Samples and operational parameters are obtained in the demonstration facility. Fast pyrolysis temperature is in the range of 450–500°C, and the pressure is atmospheric. The pilot plant feed capacity is 200 kg/h of dry (approximately 15% wt of moisture) biomass and particle size smaller than 1 mm. Fluidised bed reactor has 0.5 m as external diameter and 5 m long. The cleaning gas system has two cyclones to retain the charcoal fine particles, a wet scrubber to recover the bio-oil, and pyrolysis gas is burned in a combustion chamber to recycle the heat in the process. The technology is fully instrumented, being able to be operated continuously by 2 workers per shift. The aim in this technological development is an innovative technology to process residual biomass to produce new biofuel and material as a contribution to cane industry diversification and to create new jobs and income mainly in the rural areas of the country. The applications for the main product, bio-oil, is its use as fuel to replace fuel oil and diesel in electricity generation, to be an additive to emulsify heavy petroleum fraction, an additive to food industry, and a substitute to petrochemical phenol in phenolic (PF) resins, etc. Charcoal has also attractive applications for iron ore pelletisation, briquetting, and activated carbon.

Introduction

There is an increasing demand for renewable energy in the world due to its environmentally friendly characteristic. Brazil is a country with a very clean energy profile. According to the official publication, the Energy Brazilian Balance 2003 (data based on year 2002), 41% of the domestic energy supply is from renewables.

Hydraulic and electricity, firewood and charcoal, and sugarcane products have 14, 11.9, and 12.6% respectively (the other 2.5% includes wind, black liquor, PV, solar thermal, etc.).

The country has excellent weather conditions to increase the use of biomass for energy. Although, for some agro-industrial and forest residues such as cane trash, rice hulls, sawmill residues, tree branches, etc., there exists a broad technological gap to be filled.

In this sense, an enormous effort has been made in the national research centers, universities, public and private companies countrywide to develop and update appropriate technology to transform raw biomass into renewable energy and materials (Coelho and Rocha, 2002; Rosillo-Calle et al., 2000).
Bioware Tecnologia is a spin-off company at the University of Campinas dedicated to the area of thermochemical processes to convert forest and agro-industrial residues into high aggregated-value products using innovative and environmentally friendly technologies.

Its main focus is to develop biomass fast pyrolysis technology in a continuous atmospheric bubbling fluidised bed reactor to bio-oil and fine charcoal production. The company has also in its portfolio some courses and training and consulting in biomass thermal conversion, energy generation and cogeneration, thermodynamic analysis, etc.

**The Bioware fast pyrolysis process**

The Bioware fast pyrolysis process is a non-catalytic thermal degradation for lignous-celullosic materials. It happens under atmospheric pressure in a bubbling fluidised bed, moderate temperatures, high heat transfer rate from hot inert sand bed to biomass particles, and a short hot vapour residence time. The company has already claimed an application patent and a process patent.

Elephant grass, cane trash and bagasse are the main feedstocks processed successfully in the pilot plant. In the Bioware fast pyrolysis process, the bed temperature during continuous operation is in the range of 480-500°C, and the fluidisation gas/feedstock mass ratio is 0.4 (dry basis).

With the reactor operating in these conditions, the wet scrubber is able to recover about 50% wt (db) of bio-oil. Some liquids to mass transfer have been tested to improve the yield in a wet scrubber (Mesa et al., 2002; Rocha et al., 2002a,b)

**The pilot plant project and operation**

The demonstration pilot plant facility has a nominal capacity of up to 300 kg/h (db). It is the result of almost one decade of research carried out by the Biofuel Group at UNICAMP in Campinas, Brazil (Figure 1).

![Fig. 1—Flowsheet of Bioware process technology.](image)

The pilot plant is located in the town of Piracicaba outside the campus about 80 km from Campinas. It is fully automated and operated to produce bio-oil samples to be tested in lab. and industrial applications. The facility is also used to generate and validate process variables and for R&D (Figure 2). Our group carries out a scale-up project and a 500 to 1000 kg/h plant is planned to be built next year.
Biomass fast pyrolysis product characteristics

Bio-oil and charcoal properties

Bio-oil and fine charcoal are produced during the pilot plant operation as co-products. Some of their main physico-chemical properties are reported in Tables 1 and 2 respectively.

Table 1—Properties of Bioware bio-oil.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Bio-oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity, 20/20°C</td>
<td></td>
<td>1.1493</td>
</tr>
<tr>
<td>Cinematic viscosity @ 37°C</td>
<td>cSt</td>
<td>9,500</td>
</tr>
<tr>
<td>Cinematic viscosity@ 65°C</td>
<td>cSt</td>
<td>1,100</td>
</tr>
<tr>
<td>Higher heating value</td>
<td>MJ/kg</td>
<td>31.41</td>
</tr>
<tr>
<td>Copper corrosion, 3h @ 100°C</td>
<td></td>
<td>1b</td>
</tr>
<tr>
<td>Pour point</td>
<td>°C</td>
<td>9.0</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>2.2</td>
</tr>
<tr>
<td>Total number of acids</td>
<td>MgKOH/g</td>
<td>30.4</td>
</tr>
<tr>
<td>Ash</td>
<td>% (wt)</td>
<td>0.55</td>
</tr>
<tr>
<td>Moisture content (Karl Fischer method)</td>
<td>% (wt)</td>
<td>2.21</td>
</tr>
<tr>
<td>Carbon</td>
<td></td>
<td>70</td>
</tr>
<tr>
<td>Hydrogen</td>
<td></td>
<td>7.1</td>
</tr>
<tr>
<td>Elemental Analysis (%)</td>
<td>Oxygen (by difference)</td>
<td>21.05</td>
</tr>
<tr>
<td></td>
<td>Nitrogen</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>Sulfur (total)</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 2—Properties of Bioware charcoal, cane trash, and elephant grass raw material.

<table>
<thead>
<tr>
<th>Property</th>
<th>Cane trash</th>
<th>Elephant grass</th>
<th>Charcoal fines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk Density, Kg/m³</td>
<td>75</td>
<td>76</td>
<td>140</td>
</tr>
<tr>
<td>Volatile, % (d.b.)</td>
<td>73.9</td>
<td>73.5</td>
<td>7.4</td>
</tr>
<tr>
<td>Fixed carbon, % (d.b.)</td>
<td>19.0</td>
<td>20.2</td>
<td>61.9</td>
</tr>
<tr>
<td>Ash, % (d.b.)</td>
<td>7.1</td>
<td>6.3</td>
<td>30.7</td>
</tr>
<tr>
<td>Moisture content, %</td>
<td>13.6</td>
<td>10.1</td>
<td>2.7</td>
</tr>
<tr>
<td>Higher heating value, MJ/kg (d.b.)</td>
<td>17.56</td>
<td>17.03</td>
<td>22</td>
</tr>
<tr>
<td>Particle average diameter, μm</td>
<td>3.30</td>
<td>2.24</td>
<td>75</td>
</tr>
</tbody>
</table>
Figure 3 shows a bio-oil sample. Analyses were carried out in co-operation with R&D centers such as Centro de Tecnologia Copersucar, Institute of Chemistry at Unicamp and USP (University of São Paulo), and IPT (Technology Research Institute in São Paulo).

The results presented in this report are related to the elephant grass as raw material. Tests using cane products have been done, but the results were not available yet when this report was prepared. They will be presented during the Silver Jubilee Congress. The elephant grass (*Pennisetum purpureum*) used as raw material in this research was produced in an experimental project and it has a composition very similar to cane trash.

**Applications for biomass fast pyrolysis products**

The main applications for bio-oil are:

- Emulsifier agent for heavy petroleum and its fractions;
- Additive for cellular concrete;
- Phenol partial substitute in PF resin formulations;
- Biofuel to replace fuel oil and diesel for energy generation;
- BiopLime to SO$_2$ emission reduction in flue gas during fossil fuel burning;
- Slow-release fertiliser to replace mineral fertilisers;
- Wood preservative to act as insecticides and fungicides, also for veterinary uses;
- Smoke flavours and browning agent to be used as food additive;
- Road de-icers to replace calcium chlorine;
- Fine chemical such as glycoaldehyde, levoglucosan, etc.

Bio-oil is the basis for an additive production able to emulsify heavy petroleum and heavy petroleum fractions. This application is particularly important due to the higher quantity of heavy oil fields discovered in the world. Approximately 60% of all oil is heavy worldwide. In Brazil half of its oil production is heavy. The bio-emulsifier made from bio-oil acts as a surfactant to form emulsions water/heavy hydrocarbons allowing pumping, transport, refine, and combustion.

Cellular concrete is a kind of non-structural, acoustic, and insulator cement that uses an additive based on bio-oil to trap air bubbles and form a light filling in buildings. It can be applied directly in the site construction and this is the main difference from other similar additives that have to be autoclaved.
It is well-known that the bio-oil composition is basically phenol derivatives because of the phenolics presented in lignin. Our research proved that 50% wt of pure phenol may be replaced by bio-oil in resoles. Brazil has a PF resin production of 60 thousand tonnes annually (PYNF, 2004).

Bio-oil from biomass fast pyrolysis is a biofuel to burners, furnaces, boilers, diesel engines, gas turbines, and Stirling engines. It can be easily transported and stored using the same logistic as petroleum derivatives and fuel ethanol. Bio-oil combustion is essentially CO\textsubscript{2} neutral and very low in SO\textsubscript{2} and NO\textsubscript{x} emissions. The use of bio-oil as fuel is the least attractive option we are considering, but it is very strategic for isolated communities such as villages in the Amazon. In that region it is very common to burn four litres of diesel to deliver one litre. The economic and the environmental costs are very high for the country in places where biomass is largely available. Some blended fuels are also studied such as bio-oil plus ethanol, bio-oil plus diesel, and bio-oil plus biodiesel. It is 100% soluble in ethanol (Czernik and Bridgewater, 2004).

The applications we are looking for from the fine charcoal produced during biomass fast pyrolysis are:

- Pelletisation for use as domestic fuel in barbecue or industrial in boilers, and ovens;
- As a pre-reducer for iron ore pellets. Brazil is the largest exporter of iron ore pellets in the world. This application was successfully tested;
- Activated carbon;
- Catalytic substrate.

Pyrolysis producer gas is burned on site to additionally heat the process. It presents an average composition that includes CO, H\textsubscript{2}, CH\textsubscript{4}, CO\textsubscript{2}, NO\textsubscript{x}, and some high hydrocarbons. Carbon monoxide and hydrogen are the synthesis gases that have many applications to form complex molecules. They can also be burned together with all hydrocarbons for heat. Gases with nitrogen are produced due to the use of air as a fluidised gas. When only combustion gas, that is rich in carbon dioxide, is the fluidised agent, nitrogen gas levels are very low.

The good in biomass is that no sulfur gases are produced. The acid water phase separated from bio-oil has application in organic agriculture as a pesticide. Water in bio-oil comes from original water in bio-oil and from dehydration reactions during the process. Differently to fossil fuels, bio-oil always presents some emulsifier water in it. In the case of industrial use of biomass, a CO\textsubscript{2} emission is zero or negative when all biomass life cycle is considered.

**Conclusions**

This technological development has found strong support from both public and private sectors in Brazil due to its characteristics to recycle residues to produce high aggregated value fuels and materials in a social and environmentally friendly way. The country has a large number of cheap raw materials suitable to feed the Bioware process. Specifically, the Brazilian sugarcane industry is very supportive and interested in this technology. Also, pulp and paper, sawmill, and rice industries are interested in partnership. The Biofuel Group at Unicamp has cooperation with many national groups and companies, including some international cooperation in Cuba and Spain.

**Acknowledgements**

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**REFERENCES**


LES PRODUITS D'UN SYSTÈME DE PYROLYSE RAPIDE DE BAGASSE ET DE PAILLE DE CANNE SUR UN LIT FLUISE: L'EXPERIENCE BRESILIENNE

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Résumé

Le procédé de pyrolyse rapide sur un lit fluidisé a été développé dès 1995 au Brésil, à l'échelle d'une installation pilote. Le Brésil dispose de matière première telle que la bagasse et la paille de canne pour alimenter le procédé et possède toutes les ressources humaines et naturelles appropriées. Les expériences ont été effectuées par des étudiants et le personnel de l'Universidade Estadual de Campinas dans l'installation pilote située à Centro de Tecnologia Coopersucar à Piracicaba. Les progrès réalisés dans cette technologie placeront le Brésil en tête de tous les autres pays latino-américains dans ce domaine important. Les produits de la pyrolyse de biomasse sont la bio-huile, le charbon fin et le gaz à basse valeur calorifique. Des échantillons de ces produits ainsi que des paramètres opérationnels sont obtenus de cette installation de démonstration. La température de la pyrolyse rapide se situe entre 450°C et 500°C, à la pression atmosphérique. La capacité d'alimentation de l'installation pilote est de 200 kg de biomasse sèche par heure (à 15% d'humidité) et la dimension des particules est inférieure à un millimètre. Le réacteur à lit fluidisé a un diamètre externe de 0.5m et une longueur de 5m. Le système de nettoyage à gaz est équipé de deux cyclones pour retenir les fines particules de charbon et d'un dépoussiéreur humide pour récupérer la bio-huile. Le gaz de pyrolyse est brûlé dans une chambre de combustion afin de réutiliser la chaleur dans le procédé. La technologie est entièrement instrumentée et peut être opérée en continu par des équipes de deux opérateurs selon un système de relais. Le but du développement de cette technologie innovatrice est de traiter la biomasse résiduelle afin de produire du nouveau biocarburant et autre matériel qui contribueront à la diversification de l'industrie de la canne et à la création de nouveaux emplois et d'autres sources de revenus, principalement dans les régions rurales du pays. Le produit principal - la bio-huile - sera utilisé comme carburant pour remplacer l'huile lourde et le diesel dans la production d'électricité, comme additif pour l'émulsion de la fraction du pétrole lourd et dans l'industrie alimentaire ; il servira de substitut au phénol pétrochimique dans des résines, entre autres. Le charbon possède également des propriétés intéressantes pour la pelletisation des minéraux de fer, le briquetage et le charbon actif.
PRODUCTOS DEL BAGAZO DE CAÑA Y RESIDUOS MEDIANTE EL SISTEMA DE PIROLISIS RÁPIDA EN CAMA FLUIDA: LA EXPERIENCIA BRASILEÑA

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Resumen
El proceso de pirólisis rápida ha sido desarrollado en una planta lechofluidizado a escala piloto en Brasil desde 1995. El país posee materias primas como el bagazo de caña y residuos agrícolas para alimentar el proceso, así como todas las condiciones apropiadas en términos de recursos materiales y humanos. Los experimentos se realizaron en la Planta Piloto ubicada en el Centro de tecnología Copersucar en Piracicaba por estudiantes y personal de la Universidad estatal de Campinas, en campinas. El progreso de esta tecnología colocará a Brasil al frente de todos los países de América Latina en esta importante área. Bioaceite, carbón fino y ‘gas pobre’ son los productos de la pirólisis de la biomasa. Se obtuvieron muestras y los parámetros operacionales en las instalaciones demostrativas. La temperatura de la pirólisis rápida se encuentra en el rango de 450–500 grados Celsius, y la presión es la atmosférica. La capacidad de alimentación de la planta piloto es 200 Kg/h de biomasa seca (aproximadamente 15% de humedad en peso), el tamaño de partícula inferior a 1mm. El reactor de lecho fluidizado tiene 0,5m de diámetro externo y 5 m de longitud. El sistema de limpieza del gas posee dos ciclones para retener las partículas de carbón fino, un depurador húmedo para recuperar el bioaceite y el gas de la pirólisis se quema en una cámara de combustión para recircular el calor en el proceso. La tecnología está totalmente instrumentada posibilitando que pueda operar con dos trabajadores por turno. El objetivo de este desarrollo tecnológico es el de una tecnología innovativa para procesar biomasa residual y producir un nuevo biocombustible y materiales como una contribución a la diversificación industrial y crear nuevos empleos e ingresos, básicamente en las áreas rurales del país. Las aplicaciones del producto principal, el bioaceite, es su empleo como combustible en sustitución del fuel oil y el diesel en la generación eléctrica, como aditivo para emulsionar la fracción pesada del petróleo, un aditivo para la industria alimenticia y un sustituto del del fenol de origen petroquímico en las resinas fenólicas (PF), etc. El carbón tiene también atractivas aplicaciones para la peletización del mineral de hierro, briqueteado y carbón activado.