Thermochemical and Biochemical routes to produce energy from residues: The case of Pinus patula as raw material for direct bioenergy and ethanol production

Estefanny Carmona Garcia, Jhonny Alejandro Poveda Giraldo, Carlos Ariel Cardona Alzate.

Universidad Nacional de Colombia sede Manizales, Instituto de Biotecnología y Agroindustria. Manizales, Colombia
Outline

- Introduction
- Research objective
- Methodology
- Results and discussions
- Conclusions
Global problem

Population growth

Food and water shortages

GHG emissions and fossil fuel consumption

Social and environmental problems

The implementation of new technologies is urgent as they help to ensure long-term economic growth and sustainability

An option is produce renewable and sustainable energy from biomass such as biofuels
**Pinus patula**

*Pinus patula* is a lignocellulosic rich source which is widely distributed in Colombia and is classified as softwood.

Cultivation yield: 12-22 m$^3$Ha$^{-1}$year$^{-1}$. The generation of waste during the wood processing of *Pinus patula* is a commercial interest for obtaining value-added products.

The use of organic waste for biofuel production plays an important role in reducing CO$_2$ emissions. Different products such as biogas, syngas, biobutanol, biodiesel, bioethanol can be obtained [2].
Biomass valorization – *Pinus patula*

**Ethanol production**

The high polysaccharide content in *Pinus patula* can be hydrolyzed by different physicochemical pre-treatments (acid or base), followed by enzymatic hydrolysis (saccharification) [3]–[5].

**Gasification**

Allows the transformation of biomass at high temperatures into a gas (syngas) with high energy content. Mainly composed of CO, H₂, CH₄, CO₂ and N₂, where hydrogen is the main product with the highest added value [6].
Research objective

To evaluate the potential of *Pinus patula* for the production of ethanol an experimental and simulation component was carried out.

**Experimental**

Pine was pretreated by dilute acid and enzymatic saccharification, the sugars obtained were fermented by *Saccharomyces cerevisiae* to obtain ethanol.

**Simulation**

1. Production of ethanol was simulated, including the separation stage and then an economic analysis.

2. A comparison was made between the biochemical route (fermentation) and the thermochemical (gasification). in order to determine the efficiency of each process.
Methodology: Experimental procedure

- **Particle size reduction**

- **Dilute acid hydrolysis:** H2SO4 2% v/v, 121 °C, 90 minutes, 15 psi

- **Enzymatic saccharification:** Celluclast 1.5L and Viscozymes (1%-3%), 50°C, 15 g/l of biomass [7]

- **Fermentation:** *Saccharomyces cerevisiae*, 32°C, 150 rpm, pH 4.

- **Biomass concentration**
  - Dry weight method

- **Sugar concentration**
  - Dinitrosalicylic acid (DNS) method

- **Ethanol concentration**
  - Gas Chromatography (GC) using a GC-2014 (Shimadzu) gas chromatograph
Methodology: Simulation procedure

The simulation of bioethanol production consists in four stages: pretreatment, enzymatic hydrolysis, fermentation and separation.

The beer column is either a stripper with a bottoms reboiler or a direct steam injection column that takes the product from the fermenters and strips out the ethanol overhead.

**Fig. 1** Scheme of bioethanol production from *Pinus patula*
Methodology: Economic analysis

<table>
<thead>
<tr>
<th>RAW MATERIALS</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus patula</td>
<td>40 USD/ton</td>
</tr>
<tr>
<td>Cooling water</td>
<td>0.33 USD/ m³</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>94 USD/ton</td>
</tr>
<tr>
<td>Enzyme</td>
<td>700 USD/ton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>UTILITIES</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>0.1 USD/kWh</td>
</tr>
<tr>
<td>Low pressure steam (LPS)</td>
<td>7.56 USD/ton</td>
</tr>
<tr>
<td>Medium pressure steam (MPS)</td>
<td>8.18 USD/ton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethanol</td>
<td>0.9 USD/kg</td>
</tr>
</tbody>
</table>

Table 1. Prices used in the economic evaluation

Economic analysis

It is estimated based on the information obtained in the simulation process. It is developed taking into account the methodology reported by Peters et al., [7] and using the equipment cost estimated in Aspen Economic Analyzer.

The production cost of ethanol was determined and the influence of the process scale.
Methodology: Gasification

Table 2. Typical composition of gas during gasification biomass [9].

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>12-20</td>
</tr>
<tr>
<td>CO₂</td>
<td>9-15</td>
</tr>
<tr>
<td>CH₄</td>
<td>2-3</td>
</tr>
<tr>
<td>CO</td>
<td>17-22</td>
</tr>
<tr>
<td>N₂</td>
<td>50-54</td>
</tr>
</tbody>
</table>

**Stages in gasification**

**Dried. Pyrolysis:** 700 °C. **Combustion:** 1000 °C. **Gasification 800 °C**
## RESULTS

<table>
<thead>
<tr>
<th>Pretreatment stage</th>
<th>Enzymatic hydrolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration of reducing sugars of 31 g/L was obtained.</td>
<td>13.5 g/L, due to the high amount of water used in the enzymatic hydrolysis.</td>
</tr>
</tbody>
</table>

A substrate consumption of 6.29 g/L was obtained. The final concentration of sugars was 50% of the initial concentration, which suggests that it should be inoculated with a higher concentration of biomass. For the other hand the concentration of **biomass in the concentrated hydrolysate** was 3.7 g/L.
RESULTS

The final ethanol concentration was 4.79 g/L, which corresponds to a yield of 0.035 g ethanol / g sugar (69% of the theoretical).

If a higher ethanol concentration is required, the hydrolysate must be concentrated through evaporation until reaching a higher concentration of sugars.
RESULTS

From the raw material cost, 55% corresponds to cost of *Pinus patula* (87 mUSD/year), 21% represents the enzymes added for the enzymatic hydrolysis (33 mUSD/year), 19% corresponds to the sulfuric acid used in dilute acid hydrolysis (29 mUSD/year) and 4% for process water (7 mUSD/year).

Fig. 4 Cost contribution for the base case (6000 ton/day). *Others corresponds to: maintenance (1.67%), labor (0.12%), fixed and general (1.04%) and plant overhead (0.94)
RESULTS

**Fig. 5** Influence of process scale in NVP
RESULTS

---

**Pinus patula** 83.2%

Gasification – Synthesis Gas

Losses 56.94%

Syngas 43.06%

Electricity 16.8%

**Fig. 6** Sankey diagram for gasification process

---

**Pinus patula** 73.4%

Fermentation

MP Steam 15.6%

Energy Losses 76.7%

Energy

Ethanol 23.3%

**Fig. 7** Sankey diagram for fermentation process

---

Then according to the results from the energy balance of both process, the energy yield of the ethanolic fermentation is lower than the gasification of *Pinus patula*, with values of **4.11 MJ/kg** and **7.16 MJ/kg**, respectively. As a result, the net energy efficiency of both processes is **23% for ethanol** and **43% for syngas production**.
CONCLUSIONS

- It is possible to produce ethanol from *Pinus patula* with average experimental yield 0.35 g ethanol/g glucose. From the simulation procedure, the fermentative process of *Pinus patula* has proven for higher capacities (> 6000 ton per day) generating lower production costs, even lower than the market price. Consequently, the process can provide positive NPV values.

- The energy analysis was focused in the comparison of the fermentation and gasification pathways for energy production. As a result, the net energy efficiency of both processes was 18% and 35%, respectively. Therefore, electricity from gasification cannot be considered an added-value product due to the low market price and the diversity of methods to produce it, especially in Colombia.
REFERENCES


REFERENCES
