Intermediate Pyrolysis as an Alternative to Fast Pyrolysis

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Intermediate Pyrolysis as an Alternative to Fast Pyrolysis

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Introduction

Conventional power supply
Introduction

Future power supply

Controllable

Supply

Generation

Load transfer

Demand

Consumption

Efficiency

Haushaltsgeld.net, Andreas Carjell, Viktor Mildenberger, Petra Bork, Dieter Schütz, Andreas Morlok / alle pixelio.de
Introduction

*Grids & storage*

- Supply
- Generation
- Storage
- Grids

- Controllable
- Load transfer
- Consumption
- Efficiency

Regional decoupling
Temporal decoupling

Haushaltsgeld.net, Andreas Carjell, Viktor Mildenberger, Petra Bork, Dieter Schütz, Andreas Morlok / alle pixelio.de
Introduction

Analysis of 146 regions

Base facts

- Basis BMU leadscenarios 2010
- 146 regions
- Allocation according to number inhabitants and structure
- Ideal distribution network within each region, no exchange between regions
Introduction

**Compensation demand, sorted**

- **2030**
  - ca. 27.7 TWh
- **2050**
  - ca. 80 TWh

- ca. 1 TWh
- ca. 3.3 TWh
Pyrolysis

Various reactors and three main pyrolysis procedures in practice

Fast pyrolysis
Intermediate pyrolysis
Slow pyrolysis

Most significant difference is the residence time of the solid phase within the reactor – seconds, minutes, up to hours and correlated energy transfer and temperature distribution

Gas phase residence times for fast and intermediate pyrolysis are usually below 2s
Fast Pyrolysis Reactors

Fluidised bed

Rotating cone

Ablative reactor

Circulated fluidised bed

Twin screw
<table>
<thead>
<tr>
<th></th>
<th>Fast pyrolysis 500°C</th>
<th>Slow pyrolysis 420°C</th>
<th>Slow pyrolysis 500°C</th>
<th>Slow pyrolysis 600°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total liquid, wt% on dry feed</td>
<td>75.0</td>
<td>51.9</td>
<td>52.8</td>
<td>51.9</td>
</tr>
<tr>
<td>Char yield, wt% on dry feed</td>
<td>8.5</td>
<td>33.6</td>
<td>31.9</td>
<td>32.0</td>
</tr>
<tr>
<td>Gas yield, wt% on dry feed</td>
<td>10.9</td>
<td>13.4</td>
<td>11.3</td>
<td>11.4</td>
</tr>
<tr>
<td>Closure, wt% on dry feed</td>
<td>94.4</td>
<td>98.9</td>
<td>96.0</td>
<td>95.3</td>
</tr>
<tr>
<td>Heating rate, °C/min</td>
<td>–</td>
<td>14.5</td>
<td>13.7</td>
<td>12.6</td>
</tr>
</tbody>
</table>

(Slow pyrolysis liquid from dry ice and acetone condenser – water and light ends)

|                         | 20.8         | 45.9         | 48.2         | 43.8         |
| Water content (%)                  | 0.04         | 0.02         | 0.03         | 0.03         |
| Char content (%)                    | 53.8         | 1.4          | 1.1          | 1.8          |
| Viscosity, cP                        | 2.4          | 2.3          | 2.5          | 2.4          |

Elemental analysis (%)

|                         | 43.9         | 28.13        | 28.00        | 27.39        |
| C                        | 7.4          | 9.38         | 9.38         | 9.55         |
| H                        | 0.07         | 0.03         | –            | –            |
| N                        | 48.6         | 62.5         | 62.7         | 63.1         |

(Slow pyrolysis liquid from EP – heavy organic fraction)

|                         | –            | 8.6          | 11.3         | 7.8          |
| Water content (%)                  | –            | 2.8          | 2.6          | 2.6          |
| PH                                    | –            | 6.8          | 6.4          | 7.1          |

Elemental analysis (%)

|                         | –            | 54.8         | 53.75        | 55.30        |
| C                        | –            | 7.14         | 7.41         | 7.23         |
| H                        | –            | 0.10         | 0.13         | 0.16         |
| N                        | –            | 38.0         | 38.72        | 37.32        |
| O by difference          | –            | 21.3         | 20.4         | 21.8         |
| HHV (wet), MJ/kg         |              |              |              |              |

A.V. Bridgwater*, P. Carson and M. Coulson
A comparison of fast and slow pyrolysis liquids from mallee
liquid yield from fast pyrolysis of eucalyptus at 500°C is typically high at 75 wt%. Pyrolysis conditions for woody biomass have been shown to be between 480°C and 530°C for maximum liquid yield, giving yields between 70–80 wt% on dry feedstock basis (see for example Piskorz et al., 1998).

The product yields for the slow pyrolysis of mallee do not show much variation with reaction end temperature. This is not too different from Williams and Besler (1996), who found for pine that increasing the reaction end temperature from 420°C to 600°C had almost no effect on the liquid yield, but at 600°C the char yield decreased by 4.8 wt% and

A.V. Bridgwater*, P. Carson and M. Coulson

A comparison of fast and slow pyrolysis liquids from mallee


to be agreed upon, but only for woody biomass
A comparison of fast and slow pyrolysis liquids from mallee


Typical liquid, char and gas yields for fast pyrolysis vs. temperature

- **Mallee, fast pyrolysis at 500 °C**
  - 75% Liquid, 9% Char, 11% Gas

**Intermediate**

- **Beach wood**
  - 450 °C

- **Wheat straw**
  - 450 °C

**Fast**

- **Wheat straw**
  - 500 °C

- **Mallee, slow**
  - 500 °C

**Reaction temperature, °C**

- Water of pyrolysis
Simulation of tar formation

Different reaction mechanism and different reactants

Chemical Structure
Molecular Weight Distribution

Cellulose Glucan Xylan Lignin

Oligomers
Modified Chains
Side Groups

Chain Fragments
Tar Char Gas

May cause sensible variation on the overall kinetic rate parameters as change the operative conditions

Each biomass component is considered as structural reactant with an average chemical composition

Each polymer type has its own thermo-chemical characteristics and must be considered separately
Heating rate: 25°C/min

Water (m/z 18)
CO (m/z 28)
Methane (m/z 15)

Heating rate: 25°C/min

CO₂ (m/z 44)

CO (m/z 28)

H₂O (m/z 18)

H₂ (m/z 2)

CO₂ (Oxy-allyl)guaiacol

155

-Syringol

4-(Hydroxy-prop-2-enyl)guaiacol

-0.6

0

0.2

0.4

0.6

Arbitrary units

°C/min

Abundance

Temperature °C

0 100 200 300 400 500 600 700 800

0 5 10 15 20 25 30

°C/min

Arbitrary units

0 100 200 300 400 500 600 700 800

Arbitrary units

0 5 10 15 20 25 30

°C/min

0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045

°C/min

0 0.002 0.004 0.006 0.008 0.01 0.012 0.014 0.016 0.018 0.02

°C/min

0 0.05 0.1 0.15 0.2 0.25 0.3

°C/min
Intermediate Pyrolysis
Pyrolysis of 19 t of straw in 2005, production of 6 t of biochar – slurries to be gasified for syngas production!
# Investigated materials

<table>
<thead>
<tr>
<th>Feed</th>
<th>Yield</th>
<th>Energy (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount</td>
<td>Temperature</td>
</tr>
<tr>
<td>Olive stones</td>
<td>169,3 kg</td>
<td>450°C</td>
</tr>
<tr>
<td>Rice husk</td>
<td>86,3 kg</td>
<td>450°C</td>
</tr>
<tr>
<td>Rape seeds</td>
<td>611,15 kg</td>
<td>450°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500°C</td>
</tr>
<tr>
<td>Rape residues</td>
<td>1292 kg</td>
<td>450°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>550°C</td>
</tr>
<tr>
<td>Beechwood</td>
<td>148,7 kg</td>
<td>450°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>500°C</td>
</tr>
<tr>
<td>Coco nut</td>
<td>13 kg</td>
<td>450°C</td>
</tr>
<tr>
<td>Rice bran</td>
<td>3 kg</td>
<td>500°C</td>
</tr>
<tr>
<td>Brewers grain</td>
<td>2 kg</td>
<td>450°C</td>
</tr>
</tbody>
</table>
### Products from pyrolysis of straw

(Feed approx. 1.4 kg/h, residence time 4 min (solid), 2s (gas))

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Coke wt%</th>
<th>Oil wt%</th>
<th>Gas wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>325</td>
<td>73</td>
<td>18</td>
<td>9</td>
</tr>
<tr>
<td>350</td>
<td>48</td>
<td>34</td>
<td>18</td>
</tr>
<tr>
<td>375</td>
<td>38,2</td>
<td>37,7</td>
<td>24,1</td>
</tr>
<tr>
<td>385</td>
<td>36,2</td>
<td>41,6</td>
<td>22,2</td>
</tr>
<tr>
<td>400</td>
<td>33,5</td>
<td>34,6</td>
<td>31,9</td>
</tr>
</tbody>
</table>
Intermediate pyrolysis and hot gas filtration

Filtration take place at 420°C, filter cake is dry due to low dust & tar content of the pyrolysis vapour
CAROLA® - Corona demisting unit

Rape seed, 550 °C, 15kg/h

HV injection nozzle (18 KV)

Pyrolysis oil collector

Outlet

Inlet

CAROLA

Deposition rate >99,9 %

Percent of collected liquid, %

cooling stages 1-5

CAROLA

Pyrolysis coke

Haloclean Pyrolysis

Haloclean plant

Cooling System

Outlet

Outlet

Outlet

Outlet

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Outlet

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Downstream LT Reforming subsequent to intermediate pyrolysis

Dr. Ursel Hornung/
Prof. Dr. Andreas Hornung
Yields with and without catalyst

- **gas (wt %):**
  - Without catalysis: 22.5%
  - With catalysis: 39.4%

- **condensate (wt %):**
  - Without catalysis: 13.9%
  - With catalysis: 35.6%
  - Without catalysis: 9.6%
  - With catalysis: 23%

- **char (wt %):**
  - Without catalysis: 28%
  - With catalysis: 28%
Pyroformer – Intermediate Pyrolysis and combined Reforming

Drying - Torrefaction - Pyrolysis Reforming - Char Conditioning
Experimental set-up

Biochar
## Biochar Characterisation

<table>
<thead>
<tr>
<th>Biochar</th>
<th>C %</th>
<th>H %</th>
<th>N %</th>
<th>S %</th>
<th>Ash %</th>
<th>O % *</th>
<th>HHV (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapeseed</td>
<td>60.25</td>
<td>4.03</td>
<td>4.19</td>
<td>0.1</td>
<td>4.2</td>
<td></td>
<td>27.61</td>
</tr>
<tr>
<td>Sewage Sludge</td>
<td>30.03</td>
<td>4.19</td>
<td>1.83</td>
<td>0.88</td>
<td>35.46</td>
<td></td>
<td>27.23</td>
</tr>
<tr>
<td>Wood Pellets</td>
<td>71.58</td>
<td>4.62</td>
<td>0.54</td>
<td>0.22</td>
<td>2.64</td>
<td></td>
<td>20.4</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>62.2</td>
<td>4.37</td>
<td>0.8</td>
<td>0.28</td>
<td>10.31</td>
<td></td>
<td>22.04</td>
</tr>
</tbody>
</table>

* By difference
New applications of pyrolysis water from intermediate pyrolysis

Biogas production from pyrolysis water fraction

Fa. Schnell – Methane content 50 %
Similar amounts of gas per organic matter - compared to straw
Enhanced biogas production

Volume CH4

Days

5 6 7 8 9 10 11 12 13

2.00 2.50 3.00 3.50 4.00 4.50

CH4 (L)

Vessel 1
Vessel 2
Vessel 3
Vessel 4
Fluidised bed Gasifier
- The Pyroformer™ can be directly coupled with a fluidized bed Gasifier to produce consistent and high quality gases that increase the efficiency of combined heat and power production.

Dry Anaerobic Digester
- The residue from anaerobic digestion can be used as a feedstock for the Pyroformer™.
- This means that even more energy can be obtained from the original waste source.
- Anaerobic digestion efficiency increased by up to 15% as a result of technology integration.

BAF Reactor
- It can be coupled to a Bio Activated Fuels (BAF) Reactor (patented system) to reclaim the oils in plastics to add to the fuel mix.
- Other by-products can be hydrogen gas, synthetic natural gas, biodiesel and biochar.

Biochar applications
- Uncontaminated char (biochar) has significant market value for use in soil enhancement and carbon sequestration.
- The char can also be used for co-firing in power stations.
Pyroformer™ - BAF Schematic
• TAN of organic phase mg KOH/g
• Sewage Sludge 19
• Deinking Sludge 33
• Spent Brewers Grain 60
• Wood 39.5 – 48 dependant on char recirculation
• These numbers are very low compared to numbers from Fast pyrolysis for wood between 75 and 140 in literature
150 kW dual fuel multi cylinder Internal combustion CI engine from NEK
Lister Engine Parameters

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Biodiesel</th>
<th>PO</th>
<th>PO-BD Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinders</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power (kW)</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed (rpm)</td>
<td>1000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Injection</td>
<td>Direct</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspiration</td>
<td>Nature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Downscaling of the technology

This is the view of how the containerised plant will look like once we have assembled all the components inside and the unit will be mobile so as to demonstrate it in various rural villages.
Technology can be build simplyfied and low cost!
Containerized mobile Pyroformer™ unit with engine
Extended concept for biogas plants

Pyrolysis & Reforming

- Biogas plant
- CHP
- Storage
- Char
- Oil
- Gas

Outputs:
- Power
- Heat
- Pellets
- Digestate
Extended concept for biogas plants

Pyrolysis & Reforming
The Biobattery

A flexible energy storage solution for the “German Energiewende”
Extended concept for biogas plants

**Pyrolysis & Reforming**

- **Digestate**
- **Biogas plant**
- **Pyrolysis & Reforming**
- **Conditioning**
- **Variable substrate**
- **Pyrolysis-water**
- **Oil**
- **Thermal storage**
- **Gasification**
- **Biomass residues**
- **Gas**
- **CHP**
- **Power**
- **Gas**
- **Biochar**
Extended concept for biogas plants

*Pyrolysis & Reforming*

- Variable substrate
- Digestate
- Biogas plant
- Pyrolysis-water
- Gas
- CHP
- Power
- Oil
- Thermal storage
- Gasification
- Gas
- Biomass residues
- Biochar
Mobile heat

*The mobile latent heat storage principle*
Extended concept for biogas plants

*Pyrolysis & Reforming*

- **Digestedate**
- **Biogas plant**
- **Pyrolysis & Reforming**
- **Conditioning**
- **Gas**
- **Oil**
- **Gasification**
- **Heat**
- **Biochar**
- **Biomass residues**
- **Variable substrate**
- **CHP**
- **Power**
Solid biofuel conditioning

**Mechanical pre-treatment (Brewers Spent Grain)**
Intermediate Pyrolysis systems can be

a) scaled in a wide range
b) used for a wide variety of feeds, single or in mixture with
   - different shape and moisture content up to 40 %
c) combined with filtration, gasification, BAF and CHP
d) used to run in pyroforming mode
e) used to produce pyrolysis oils of low acidity
f) used to produce PAH free biochar

The reactors have low mechanical friction, therefore low dust amounts are evolved to gas phase

The reactor is integrating a torrefaction section and in-situ reforming for better oil quality from pyrolysis