Thermochemical and Hydrothermal Conversion Processes

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Thermochemical/Hydrothermal Conversion of Biomass

Low Moisture Biomass (~10 wt %):
✓ Ablative Pyrolysis of Beetle-killed Trees

High moisture biomass (> 40 wt %):
✓ Hydrothermal Gasification/Liquefaction of Biomass
The beetle-killed trees problem

- MPB attacking Lodgepole pine: drought, warmer winters, aging forest
- More than 10 million acres of west forest affected
- Trees mortality causes a fire hazard
- Disposal methods include piling and burning (wastes energy, carbon and nutrients)

Applications for beetle-killed trees

Low moisture content of the dead trees → Checking of wood → Improper for solid-wood industry sector

Fast Pyrolysis → Bio-oil

Opportunity to reduce the volume of dead trees and produce a high-value product
Pyrolysis of biomass

Hypothesis: Beetle attack does not affect quality of bio-oil
Bio-oil as a liquid fuel for transportation?
Catalytic Fast Pyrolysis with a zeolite catalyst

Products:
- CO
- CO₂
- Char
- Water
- Aromatic Hydrocarbons
Mobile Pyrolysis Units

- Mobile units: reduce transportation costs for low-density biomass (50 dry tons/day)
- Bio-char can be used on-site as soil-amendment
- Process economics depends on bio-oil yield: 70 gal/ton is needed for feasibility (73 wt % conversion)
- Grinding estimated to be 7% of costs
Ablative Pyrolysis: “Melting butter in a frying pan”

Reaction rate not limited by heat transfer through particle

- no upper limit to particle size
- Reduced grinding costs

- Up to 81 wt % conversion has been observed
- Low reactor volume (only appropriate for small scales)
- Low capital and operational costs
An ablative pyrolysis reactor for beetle-killed trees

- Influence of decay stage on the quality of the bio-oil?
- What are the variables that control process yields?
- How to keep the bio-oil over 73 wt %?
- What is the maximum size of wood chips allowable?
- Does the low-density of the wood affect the ablative process?
- What is an optimum reactor design for the conversion?
Applications for High Moisture Biomass

Water as a solvent:
Avoids the drying step

Hydrothermal Liquefaction (HTU):
Bio-crude

Hydrothermal Gasification:
Bio-gas for FT
H₂
CH₄
CO
Hydrothermal Liquefaction
(Hydrothermal Upgrade, HTU)

Temperature: 280-380°C
Pressure: 5-40 MPa

Kw increases 1,000 at 200-300°C

Water self-ionization:
2 H₂O ⇌ H₃O⁺ + OH⁻
Wood liquefied at 340°C

Hydrothermal Gasification (SCWG)

Properties of Supercritical Water:

- High Temperature and Pressure
- Weakens H bonds
- Decreases dielectric constant
- Dissolves organic compounds:

Water above 374° C and 22 MPa
Cellulose dissolving in hot compressed water

Supercritical Water Gasification (SCWG)

Water as solvent:

- Avoids the drying step

- $\text{H}_2$ rich gas can be produced via the water-gas shift reaction:
  \[
  \text{CO} + \text{H}_2\text{O} \leftrightarrow \text{CO}_2 + \text{H}_2
  \]
  (water is also a reactant)

- Avoids phase change (no latent heat)
Energy Efficiency

Questions?
VERENA Gasification Plant, Germany

- 100 kg/h
- 700°C, 350 bar
- Residual biomass from the food and beverage industry, sludge
Hydrothermal Liquefaction Plant
Changing World Technologies (CWT, Carthage, Missouri)

- Converts wastes from turkey production (fatty acids) into diesel and fertilizers
- Fatty acids have chain lengths similar to gasoline and diesel (15-20 carbons)
- Elimination of carboxyl group results in diesel