Industrial Feed Handling of Lignocellulosic Feedstocks

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**User Facility Feed Processing & Handling Experience**

- Fully integrated pilot plant with commercial scale processing equipment
- Modular design allows the insertion of third-party equipment
- Extensive material characterization and data collection
- More than 1,000 tons of feedstock processed to a wide variety of conversion pathway specs
- Offering
  - Toll processing/piloting
  - Toll characterization
  - 3rd party testing & validation
  - Process development
  - Preprocessing R&D

Reconfigurable PDU is located in 27,000-ft³ high bay at INL’s Energy Systems Laboratory
Observations from the emerging cellulosic ethanol market

- In 2015, 2.0 million RINS generated from cellulosic ethanol
- ~3% of biorefinery production capacity
- “Feed handling” problems blamed for slow start-up
  - Grinding
  - Conveyance
  - Feeding
  - Solids handling up to and through conversion

![Graph showing effect of plant throughput on the MFSP of RDB](image1)

![Graph showing effect of plant throughput on return on investment](image2)
Biomass attributes related to feed handling problems

- Moisture
  - Grinder throughput
  - Particle size variability
  - Variation causes inconsistent mass and heat transfer in conversion

- Particle Size
  - Large particles (aka pin chips)
    - Cause plugging problems in bins, augers
    - Do not fully cook – plugging in downstream equipment, microbial contamination
  - Fine particles
    - High in ash
    - Dust – fire, explosion, and health hazards
    - Plugging of weep holes in digesters
    - Buffering capacity, increase chemical usage
  - Variation causes inconsistent mass and heat transfer in conversion

- Foreign material (dirt, metal)
  - Plugging, equipment wear
History repeats itself

- Rand Corporation study from 1980’s showed that plants that process bulk solids typically operate at less than 50% of design capacity the first year of operation
- DOE sponsored study followed significant difficulties in the start-up of new synthetic fuel plants
- Performance of 37 new plants using data provided by 25 companies
- Problems generally relate to an inadequate understanding of the behavior of particle systems (Bell 2005)

Image source: Merrow 1985
Why particle processes are so difficult

- A particle system is more likely to be inconsistent than consistent
- Particles can almost be described as a fourth state of matter
  - They can develop cohesive strength and transfer stresses like a solid
  - They can retain air and take on fluid-like properties
  - They are often compressible and elastic like a gas
  - Gases and liquids do not grow, agglomerate, aggregate or suffer attrition, particles do
- Material attributes can cause a transition from one state to another
Moisture effect on flowability

Screw Conveyor Current

6% Moisture
11 tons/hour

30% Moisture
2 tons/hour
Particle morphology effect on flowability

Feeding ground & chopped switchgrass

<table>
<thead>
<tr>
<th>Material</th>
<th>Feed rate (Dton/hr)</th>
<th>Duty cycle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grind</td>
<td>4.9</td>
<td>99</td>
</tr>
<tr>
<td>Chop</td>
<td>31.0</td>
<td>0 (flood)</td>
</tr>
<tr>
<td>Chop</td>
<td>29.8</td>
<td>35</td>
</tr>
</tbody>
</table>


Across a range of particle sizes and shapes the only consistent difference was morphology of particle tips

Pilot plant testing is recommended but seldom done

- Rand study makes a strong case for large scale, fully-integrated pilot plants using identical process components as the final plant.
- Often the performance or each stage of the process is determined by the preceding one.
- No one would ever scale-up a conversion process without piloting, so why is piloting feed processing not done?
- Three reasons for not piloting:
  1. Ignorance of the issues and potential problems
  2. Pride – engineers don’t think they need to
  3. Haste to get product to market
- Failure to build and operate integrated pilot plants will cost time and money.
Duplication of existing plants is common & risky

• Requirements for success are high
  – Identical feed materials and feedstock specs
    • Not only raw materials but also refined feedstock
  – Knowledge is shared freely among plants
  – Basic equipment in the process was optimally chosen initially
  – Products are consistent in quality and chemical nature

• Probability of success is low
  – Too many changes in the supplier/customer marketplace to exactly duplicate
  – Probable that the design of the first plant was not optimal to start with

Although processing steps are similar, systems for pulp & paper, pellet, and feed markets likely will not work for pioneer biofuels plants
Too much reliance is placed on vendor testing

- Test equipment may be significantly smaller than the full size process
- It is extremely unlikely that the actual production material will match the test material
- Tests are too short to realize the nuances of feed variability and cumulative effects (e.g., wear)
- Few vendors can provide fully integrated processes in their test laboratory
- Most (all) know their own equipment on an empirical basis
  - A vendor is likely to scale equipment for a new product based on prior experience with a different product
  - Lack the characterization facilities and technical skills to determine how old and new materials relate
- Pressure to make a sale forces them to be optimistic about capabilities of their equipment and own expertise
- Tests in vendor shops are better than no tests at all, but sometimes only slightly so
Our mindset about preprocessing may be indicative of the problem

- Where is preprocessing?
  - If the feedstock supply chain ends at the plant gate and conversion starts at the reactor throat, where is preprocessing?
  - Does this mean it gets overlooked?
- What is preprocessing?
  - Preprocessing is seen as a cost, with little if any value
  - Just grinding
  - How hard can that be?
Preprocessing solutions to feed handling problems

- Biomass is difficult because it is compressible, elastic, and cohesive
- These properties vary among types and physical and chemical properties
- Feedstock variability and the limitations of current feed handling systems to handle it is a significant factor
- Consistency = Reliability = Lowest Cost
- The role of preprocessing is not grinding or drying or densifying. It is to produce a consistent feedstock