Increasing Corn Throughput in Dry Grind Ethanol Process

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Dry Grind Ethanol Process

One bushel of Corn (24.5 kg or 56 lb)

Corn Dry Grind Facility

2.7 gal (10.2 L) of Ethanol

15 lb (6.8 kg) of DDGS

Ruminant Food
Conventional Dry Grind Corn Process

Corn → Grinding (Hammermill) → Water → Slurry → Blending → Saccharification & Fermentation → CO₂ → Liquefaction → Yeast & Glucoamylase → Ethanol (Dehydration column) → Centrifuge → Thin Stillage → Ethanol (Recycled back) → Overhead product (Recycled back) → Stripping/Rectifying column → Wet Grains → DDGS → Evaporator → Syrup → Thin Stillage → Ethanol
Ethanol Production in the US

- Currently 10.5 billion gals/yr production capacity
- Increase in ethanol production is coming for construction of new dry grind ethanol plants
Limitations to Dry Grind

- Liquefaction
  - High temperatures
  - Glucose inhibition
  - Slurry viscosity
- Fermentation
  - Ethanol inhibition
  - Metabolite inhibition

Liquefy

85 to 105°C
α-amylase

Saccharify and Ferment

30°C
glucoamylase
Limitations to Dry Grind

- Dewatering (thin stillage)
  - Recycling of inhibitory components
  - Fouling during concentration to syrup
- Coproduct processing
  - High temperatures
  - High capital cost

![Diagram showing the process flow from wet grains to DDGS, with steps including centrifuge, evaporation, and syrups]

To slurry
Thin Stillage

Centrifuge

Dry

DDGS
Typical Fermentation Profile

![Graph showing typical fermentation profile with time (SSF/hr) on the x-axis and ethanol concentration (% v/v) on the y-axis. The graph indicates that optimal fermentation occurs at around 88% ethanol produced, with the fermentation process peaking at around 99% and stabilizing at 100%. The graph also shows the relationship between ethanol concentration and % ethanol produced.]
Effect of Solids Content

- Higher solids result in higher glucose
  - Produced during liquefaction (up to 15% w/v)
  - Above 15% w/v inhibits yeast
  - Affects yeast growth, cell viability, total ethanol production
  - Osmotic stress and enzymatic inhibition
- 32 to 34% maximum solids
- Viscosity maximum
Effect of Ethanol

- Ethanol controls fermentation completion
  - Increases yeast membrane fluidity
  - Reduces membrane surface activity
  - Inhibition begins 10 to 13% v/v
- 18 to 21% v/v maximum
- Affects yeast viability and vitality
- Reduces enzyme performance
Overcoming Solids Limits

- **Conventional enzymes**
  - Separate processes, separate enzymes
  - 85°C liquefaction temperature
  - Produce high glucose concentrations

- **Granular starch hydrolyzing enzyme (GSHE)**
  - Mixture of enzymes
  - 48°C liquefaction or simultaneous with SSF
  - Lower glucose concentrations
  - Potential for higher solids
Corn Starch Treated with Granular Starch
Hydrolyzing Alpha and Glucoamylase
pH 4.5, 32°C

Source: USDA/ARS/ERRC and Genencor International
Granular Starch Hydrolyzing Enzymes

Overcoming Ethanol Limits

- Ethanol production and inhibition
  - Inhibition starts at 10 to 13% v/v
  - Interferes with glucose uptake
- In situ ethanol removal
- Vacuum stripping
  - Apply reduced pressure
  - Collect condensate
  - Cycle to control ethanol concentrations
GSHE and Vacuum Stripping

- Use GSHE for high solids fermentations
- Higher solids $\rightarrow$ higher ethanol productivity
- Use vacuum stripping to keep ethanol low
- Obtain high ethanol yields at high solids
GSHE and Vacuum Stripping Process

Corn → Grinding → Mash → Blending → CO₂ → Distillation

Water + GSH Enzyme → Mash → Ethanol

Yeast

Overhead product (Recycled back) → Dehydration column → Centrifuge

Ethanol → Thin Stillage → Evaporator

Wet Grains → Syrup → DDGS
Simultaneous Liquefaction, Saccharification, Fermentation & Distillation

Mash

Corn

Grinding

Water + GSH Enzyme

Mash

Blending

Vacuum

CO₂ + Ethanol

Yeast

DDGS

Dryer

GSHE and Vacuum Stripping Process

Vacuum Stripping System

- Vacuum Stripping System
- Temp control
- DC
- TC
- P
- Heated water Collection flask
- Vacuum Pump
- Traps
- 3 L Jacketed fermentor
- Heated water
Ethanol Profiles

- 30% Conventional
- 40% Conventional
- 45% Conventional
- 30% Vacuum
- 40% Vacuum
- 45% Vacuum

Ethanol concentration (% v/v) vs. Time (hr)
**Ethanol Yield**

- Ethanol yield (gal/bu):
  - Conventional: 2.0, 2.5, 3.0
  - Vacuum: 0.0, 0.5, 1.0

- 30% solids: 2.5
- 40% solids: 2.0
- 45% solids: 1.5

![Bar chart showing ethanol yield for different solids concentrations and methods.]
Possible Causes of Similar Ethanol Yields

- Oxygen from air
- Enzyme performance
- Yeast density
Residual Starch Analysis

- Conventional
- Vacuum
- Glucose

Solids content (% w/w)

30% solids

40% solids
Ethanol Yields at 3X dose, ½ inoculate

- Conventional
- Vacuum

<table>
<thead>
<tr>
<th>Solids Type</th>
<th>Conventional</th>
<th>Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% solids</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>40% solids</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>40% solids, 3X</td>
<td>2.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Solids Content

- 30% Conventional
- 40% Conventional
- 40% Conventional 3X
- 45% Conventional
- 30% Vacuum
- 40% Vacuum
- 40% Vacuum 3X
- 45% Vacuum

Solids content (% w/w) in wet grains for Beer and Stillage.
Process Implications

- Higher slurry solids
  - Reduced capital (smaller fermenter, distillation and other unit operations)
- Higher whole stillage solids
  - Less thin stillage
  - Reduced dewatering and drying costs
  - Wet grains sold directly as food for ruminants