PURDUE UNIVERSITY

CAPSTONE EXPERIENCE 2015

Title: Ethanol Production From DDGS

Agricultural & Biological ENGINEERING

Ryan Homburg (BE), Atisheel Kak (BFPE), Milind Patel (BE), and Rami Chakroun (BE)

Problem Statement and Background:

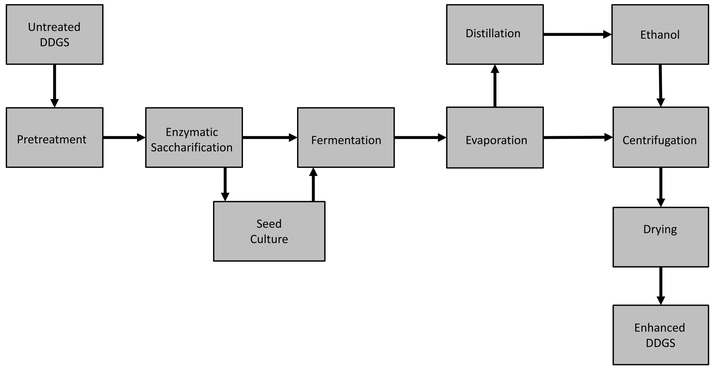
The goal of our project is to design a plant that can ferment DDGS in order to increase ethanol yield from the dry grind fermentation process. Furthermore, the compound left after fermentation will be richer in protein and other minerals, and it can be sold as a high quality animal feed, further enhancing our profits.

- DDGS
  - Byproduct from the initial fermentation of starch in corn
  - Contains roughly 35% unfermented sugars and 25% proteins [1].
- Unfermented Sugars
  - -Cellulose: polysaccharide consisting of linear chains of glucose.
  - -Hemicellulose: polysaccharide consisting of branched chains of mixed five and six carbon sugars.
  - - Hydrolyzing and fermenting these compounds is a cost-demanding process so most companies just sell the DDGS byproduct as animal feed.
  - - Since many animals can't digest cellulose, this limits the number of animals that can benefit significantly from DDGS feed.

Market Analysis

- Growing industry with over 200 ethanol plants across the U.S.
- 2.3% increase in ethanol production since last year even though there has been a sharp decrease in the price of gasoline recently.
- International exports of ethanol will be increasing due to a variety of circumstances in many countries (Brazil increasing % ethanol required in gasoline, UK shutting down a major ethanol plant)

Process Flow Diagram with Constraints and Explanations



Piece of Equipment	Total
Hold Tanks	$3,008,000
Fermentation Tanks	$7,000,000
Enzyme Tanks	$7,000,000
Seed Tank	$100,000
Heat Exchangers	$143,566
Pumps	$104,500
Distillation Tower	$20,000
Total Equipment Cost	$17,376,066

Pretreatment

Before a biomaterial can be converted to any form of simple sugar, it needs to be pretreated. We will pretreat the DDGS by adding liquid hot water to it while controlling the PH of the solution. The heat of the liquid will disrupt the cellulose chain, solubilizing it and preparing it for the hydrolysis process so a more efficient reaction occurs.

Saccharification/ Fermentation

In the enzymatic tanks a combination of cellulases and hemicellulases will be used to breakdown the carbohydrate chains into fermentable sugars. This mixture will be used in the seed and fermentation tanks to provide substrate for the recombinant bacteria strain to ferment into ethanol. The recombinant organism will be obtained by purchasing patent licensing rights and we will need FDA approval to sell our DDGS since it will contain a GMO.

Distillation

After fermentation, the mixture of water, ethanol, and DDGS enters the distillation process where ethanol is evaporated from the mixture, and condensed back into a liquid phase to be purified and sold as pure ethanol. The water and DDGS leave the bottom of the distillation column, where the DDGS will be dried to obtain animal feed. A key addition to the distillation process is a separating agent, ethylene glycol, which is used to obtain a high recovery of ethanol (95%) from the water-ethanol liquid mixture.

Drying

Following distillation, the DDGS will be dried to 11.2% moisture content. A conveyer dryer will be used with a length of 240 m and width of 3m. The residence time for the DDGS is 6 hours and 40 minutes. Evaporated water and steam is recycled into the pretreatment process.

Societal & Global Impact

- Estimates of only 53 years of oil reserves left, which makes ethanol very promising to be the new major form of fuel.
- Exporting ethanol would help the U.S. economy while also sustaining a fuel source abroad.
- Should this process be successful, we could develop similar plants next to current ethanol plants, which would improve efficiency of resources to produce ethanol and a higher protein animal feed, which results in less overall waste

Sustainability

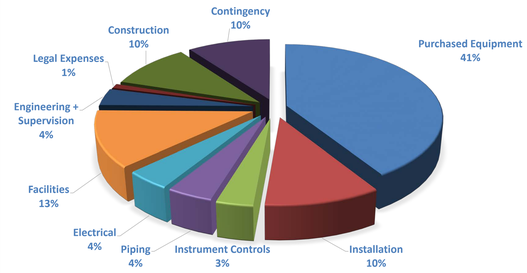
- By fermenting the byproduct DDGS from a current ethanol plant, we would be efficiently using parts of DDGS which are generally at a low value.
- Since our resultant DDGS will have a very small amount (close to 1%) of cellulose, the efficiency of our DDGS in animal feed will increase because it will be digestible by a wider range of animals.
- E85 and other fuel derivatives requires a certain percentage of ethanol in fuel, which will always be in demand due to the need for fuel. This makes ethanol production very sustainable in the long-term.

Economic Analysis

Although initial costs for purchased equipment are high, the life expectancy for the tanks and most of the heat exchangers is over 15 years. At that time we will have paid back our investment and generated more than enough savings from our annual revenue over the 6 years to purchase new equipment.

Annual Ethanol Production	9,553,444 gallons
Annual DDGS Production	201,322,320 kg
Annual Product Revenue	$69,398,574
Annual Product Cost	$64,590,453
Net Annual Revenue	$4,808,121
Total Capital Investment	$48,848,367
ROI	0.10
Payback Period	8.64 years

Breakdown of Total Capital Investment



Annual Product Revenue accounted only sales of DDGS and Ethanol. We sell our DDGS 10% more than the norm due to the high protein content, which is more useful for animals and cheaper overall for farmers. Ethanol will be sold at market price which is $1.585 per gallon.

Alternative Solutions & Improvement Recommendations

- Pretreatment
  - -Can use chemical degradation which speeds pretreatment but adds another cost and can leave residues that inhibit fermentation.
- Fermentation
  - -Use several smaller tanks to increase efficiency but adds costs due to extra pumps, piping, heat exchangers, and floor space.
  - -Simultaneous fermentation and saccharification to reduce number of tanks but have longer processing time
- Distillation
  - -Use different separating agents (DMF)
  - -Use a vacuum to decrease pressure and reduce cost
- Dryer
  - -Use different types of dryers (tray dryer/drum dryer) which yields faster drying but may degrade proteins in the DDGS

References

(1) Kim, Y., Hendrickson, R., Mosier, N., Ladisch, M., Bals, B., Balan, V., et al. (2007). Enzyme hydrolysis and ethanol fermentation of liquid hot water and AFEX pretreated distillers' grains at high-solids loadings. *ScienceDirect* , 5206-5215.
(2) Kim, Y., Mosier, N., Hendrickson, R., Ezeji, T., Blaschek, H., Dien, B., et al. (2007). Composition of corn dry-grind ethanol by-products: DDGS,. *ScienceDirect* , 5165-5176.
(3) Linninger, A. (2013). Distillation. Department of Chemical Engineering, University of Utah.
(4) Mokomele, T., Callanan, L., Clarke, K. (2011). Ethanol production from xylose and glucose by Zymomonas mobilis. DST-NRF Centre of Excellence in Catalysis (c*change), South Africa Department of Process Engineering, University of Stellenbosch.
(5) M. R. Wilkins, 1. R. (2006). Analysis of Heat Transfer Fouling by Dry-Grind Maize Thin Stillage Using an Annular Fouling Apparatus. Cereal Chem , 121-126.
(6) M. R. Wilkins, 1. R. (2006). Analysis of Heat Transfer Fouling by Dry-Grind Maize Thin Stillage Using an Annular Fouling Apparatus. Cereal Chem , 121-126

Instructors:
Dr. Martin Okos

Acknowledgements:
Anderson Clymers Ethanol LLC
Dr. Martin Okos
Dr. Nathan Mosier
Dr. Michael Ladisch

PURDUE AGRICULTURE
PURDUE UNIVERSITY

PURDUE ENGINEERING
Think impact.