Production of Cellulosic Ethanol from Mixed Paper
(Technical Paper)

An Analysis of United States Ethanol Production & Policy
(STS Research Paper)

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On my honor as a University Student, I have neither given nor received
unauthorized aid on this assignment as defined by the Honor Guidelines

for Thesis-Related Assignments.

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Introduction

For my Senior Thesis, I am going to investigate the use of cellulosic ethanol in the United States. For the technical portion of this, I am working with a team of students to design a chemical process utilizing recycled mixed papers to produce fuel-grade ethanol, with the goal of creating a process that is economically viable when compared to current production methods. For the STS portion of the thesis, I am going to research and analyze the use of cellulosic ethanol in the United States currently and attempt to determine what factors are currently limiting its use as a renewable and sustainable energy and fuel source. These two projects are closely related as they research factors that are currently impeding widespread adoption of cellulose-based production methods. These methods currently have reduced economic viability and incentive over current methods used in the United States that are already heavily invested into and are more profitable, especially methods that use corn as the primary feedstock. However, cellulosic ethanol has many benefits over corn-based production with regards to sustainability and land use that encourage further research towards an economically competitive process for future development.

Technical Project - Production of Cellulosic Ethanol from Mixed Paper

Society is currently searching for cleaner, sustainable alternatives to fossil fuels to meet the world's energy needs. A suitable alternative is needed since fossil fuels are in limited supply and release carbon dioxide to the atmosphere, contributing to adverse climate change. Many environmentalists support the adoption of electric vehicles coupled with making the power grid sourced from renewable energy as the way to reduce use of fossil fuels. However, issues associated with charging electric vehicles and the expense of their batteries are major barriers to widespread adoption. A better solution may be the use of biofuels as a replacement to gasoline in vehicles powered by internal combustion engines. One popular biofuel candidate is ethanol.

Life cycle emissions for ethanol are lower than those of gasoline because the carbon source for ethanol is from plants that recently obtained their carbon from the atmosphere, whereas, the carbon source for gasoline is crude oil with carbon that has been sequestered for millenia. And since the source material for ethanol-based biofuels is grown within a lifetime, it's considered a sustainable, renewable energy source, unlike fossil fuels.

Currently, corn ethanol is used extensively as a blended add-in for gasoline to allow for more complete combustion and lower emissions. Corn ethanol is cheap and easily fermented since corn kernels contain simple, fermentable sugars. However, production of corn ethanol competes with food production, effectively raising the price of food. Another common solution is using inedible, cellulosic sugar sources like corn stover, though corn stover is useful as fertilizer and animal feed. Moreover, for cellulosic ethanol, the cost of enzymes to break down cellulose and the price of feedstock make ethanol more expensive than gasoline to produce. Our project is an attempt at lowering the cost of ethanol production by using acid instead of enzymes to break down the cellulose and using a cheap and sustainable feedstock in the form of waste paper. Mixed paper was selected as a feedstock because it is available for low cost in large quantities and its theoretical yield of 128.3 gallons per dry ton is higher than corn stover, wood waste, and cardboard (Shi, Ebrik, Yang, & Wyman, 2009). Discarded mixed paper has no alternative use besides recycling, and currently, much of it is incinerated or stored in landfills at cost. This makes mixed paper incredibly cheap at $12 per ton (May 2020), and in the past has had a negative value (Resource Recycling, 2020). Mixed paper can also be readily obtained directly from municipal solid waste streams.

For this project, we will design a chemical process to produce fuel-grade ethanol from the cellulosic material in municipal mixed paper waste. The mixed paper feedstock will first be turned into a slurry, which will be pretreated using sulfuric acid (H_2SO_4). The pretreatment process will remove impurities, such as ink, from the feed stream. Sulfuric acid is then used to break cellulose into glucose and other sugars through a hydrolysis reaction (Kong-Win Chang, et al. 2018). After hydrolysis, the mixture is neutralized with lime (CaO) to make a calcium sulfate precipitate ($CaSO_4$) that is removed from the solution. Next, *Saccharomyces cerevisiae*, or brewer's yeast, is added and fermentation begins; the fermentation will take place in a series of four continuous stirred tank reactors (CSTRs) with a cell recycle stream as shown in Fig. 1.

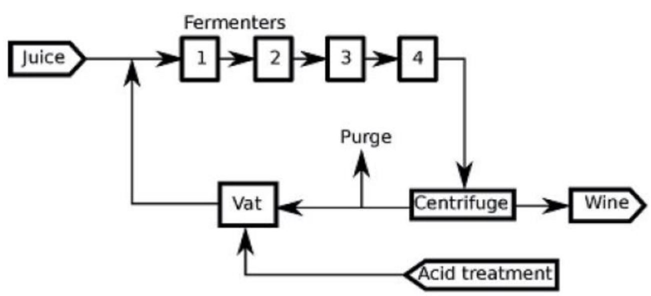

Fig. 1. Process flow diagram of fermentation scheme. Numbered fermenters are CSTRs (Fonseca, Costa, & Cruz, 2017).

A study by Fonseca, Costa, and Cruz using this method found that a continuous fermentation process will have a conversion of nearly 90% at a feed sugar weight concentration of 23% and even greater conversion rates at lower concentrations that are expected in a paper slurry (Fonseca, Costa, & Cruz, 2017).

The ethanol produced must be purified before it can be used as biofuel. This will be accomplished via distillation. Because an ethanol-water mixture forms an azeotrope, extractive distillation similar to the design in Separation Processes will be necessary and toluene will be added as the solvent for ethanol. A two-column distillation system will be used, as shown in Fig. 2 below.

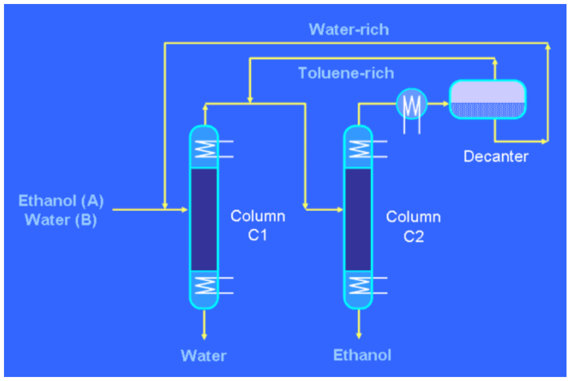

Fig. 2. Extractive Distillation of Ethanol and Water using Toluene (Separation Processes).

The first column isolates the water-ethanol azeotrope (water will come out of the bottoms product and the azeotrope will come out of the top). The azeotrope will then be mixed with toluene, which creates a minimum boiling ternary azeotrope when fed to the second distillation column. The new azeotrope is recovered out of the top of the column and can be recycled, and fuel grade ethanol is recovered as the bottom product (Separation Processes).

Based on research of previous processes, the recycled azeotrope must undergo another separation process using a decanter, allowing the toluene rich portion to be recycled into the second distillation column, while the water rich portion would be removed as waste or recycled into the feed to the first column (Separation Processes, n.d.).

This project will be executed by a five-member team over two semesters as part of CHE4438 and CHE4476. To divide the different parts of this project up, we have decided to divide into pairs. The parts of the project will be allocated as follows: Nick and Alicia will cover pretreatment, Nick and Michael will cover hydrolysis and neutralization, Brendan and Austin will cover fermentation, Alicia and Michael will cover distillation, and Brendan and Austin will analyze the overall utilities, material and energy balances, and the economics of the process. The entire group will be consulted to finalize major team deliverables and to work out problems that cannot be handled by the pairs alone. Data for understanding and calculating the pretreatment, hydrolysis, and fermentation necessary for this process will be taken from previously published literature about lab scale ethanol production from mixed paper, as well as public data about cellulose hydrolysis into glucose and yeast fermentation of glucose into ethanol. Microsoft Excel will be used for equation solving for the overall balances, utilities, and economics; MATLAB may be used for hydrolysis and fermentation data modeling; and Aspen Plus V11 will be used for overall process design and all distillation calculations.

STS Research Paper – United States Ethanol Production & Policy

Introduction

The purpose of this paper is to determine why cellulosic ethanol, a highly sustainable source of fuel, is not widely used in the United States over other competing methods and what factors could influence change in its use in the future. Sustainability and renewable energy sources are especially pertinent right now as concerns about carbon emissions and global warming have been increasing with the continuous rise of greenhouse gas emissions. Ethanol production is a major industry in the United States, producing more than 14 billion gallons every year since 2011, and has significant contributions to environmental concerns due to the current methods used to produce it (Renewable Fuels Organization, 2012). The most prevalent method, crop fermentation, has a large impact on the grain supply and requires a large amount of land from agriculture, which raise concerns about its sustainability (Heimlich, Houghton, Dong, Elobeid, Fabiosa, Hayes, & Yu, 2008). However, a new method of ethanol production could alleviate these concerns by using plant-based materials containing cellulose to produce ethanol through sugar fermentation.

Background

Ethanol is a substance that is widely used as fuel by blending it with other hydrocarbons and combusted to power engines. There are multiple commonly-used methods for producing ethanol including steam formation from ethene, crop fermentation, and biomass fermentation. Cellulosic Ethanol is produced through the last method, biomass fermentation, where plant cells - specifically, cellulose residing in the rigid cell wall of plant cells - is broken down into sugars and fermented into ethanol using bacteria. This method is the least commonly used for large-scale production despite being the most sustainable method of production. The most significant advantages to using cellulose as a feedstock for ethanol production are reduced carbon emissions compared to steam formation, sustainability when compared to steam formation, ability for feedstock diversity and recycling, as well as reduced land use and feedstock cost when compared to both steam formation and crop fermentation (Hill, Tilman, Polasky, & Hawthorne, 2008). Cellulosic Ethanol is also superior as it reduces the amount of crops that are taken out of the food supply and agriculture industry.

STS Framework & Methodology

I will primarily be using the Social Construction of Technology (SCOT) for my analysis. This framework states that the success of a technology is determined by the social contexts and principles that are highly valued in the society implementing it ("Social Construction of Technology", 2020). For this discussion, the technology would be the specific production method of ethanol where cellulose is used as a feedstock, and the society that is determining its success is the social groups in the United States. The most prominent social groups for this analysis would be the industrial companies that produce ethanol, the U.S. government, and ethanol consumers. Therefore, I plan to analyze the social values and policies in the USA with respect to ethanol production, specifically focusing on beliefs about fuel cost, carbon emissions and global warming, recycling and sustainability, and agriculture to figure out what aspects of current US society lead these social groups to favor corn-based ethanol production over cellulose based methods. The most important aspects will most likely be those that directly impact the financial viability of these methods, such as government subsidies, fuel composition and environmental emissions regulations, and the relative cost & availability of corn when compared to all cellulosic materials. Another important aspect that will be considered is the public opinion of ethanol consumers on how much the method of producing ethanol matters to consumers when compared to an increase in cost.

Conclusion

To accomplish this analysis, I will first explore the economics of cellulosic ethanol as compared to other ethanol production methods, to understand if its use is primarily restricted by investment and operating costs. Then, I would research the current United States policies surrounding ethanol production including regulations and subsidies, particularly those related to emissions and feedstock use. The goal would be to determine what values or policies are currently making corn-based production succeed more than cellulose based production and what policies or values in the USA are inhibiting cellulose-based ethanol production, to allow for future changes to encourage its use in the renewable energy sector.

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