Novel Production of 3rd Generation Biodiesel

Balancing Operational Safety and Costs: A Utilitarian Analysis

A Thesis Prospectus

In STS4500

Presented to

The Faculty of the

School of Engineering and Applied Science

University of Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science in Chemical Engineering

By

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November 3, 2023

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On my honor as a University student, I have neater given nor received unauthorized aid on this assignment as defined by the Hono Guidelines for Thesis-Related Assignments

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Introduction

A shift towards a greener and more sustainable society has increased the demand for cleaner fuel alternatives to the diesel of today. A potential alternative is biodiesel which boasts a 78% lower CO_2 emission according to the department of agriculture and the department of energy (Sheehan et al., 1998). However, the economic hurdles that the implementation of biodiesel faces are severely limiting the adoption of this alternative fuel source. The primary focus of the technical aspect attempts to make an economically viable manufactory for third generation, algae-based biodiesel. The novel nature of the production method coupled with the desire to maximize economic profit does raise safety concerns. Time and time again fringe industrial methods such as the Hawk's Nest tunnel disaster of the 1930s have sacrificed safety in the name of economic gain (*The Hawk's nest tunnel disaster: Summersville, WV* 2022). For this reason, and without disregarding the necessity of profitability, it is important that the safety measures employed in the biodiesel manufactory plant are sufficient to ensure accidents are few and of little impact. The exact metric by which the extent of safety measures is considered to be enough can be of legal nature or, as will be explored in the STS section of the capstone project, a mix between economic and societal parameters. That is to say, the STS part of this research focuses on determining the balance between the profitability of a venture and the safety of its participants through a utilitarian perspective. In turn, this will impact the exact extent to which the safety measures implemented in the technical design surpass the legal policies.

Technical Topic

In response to climate change and other environmental imperatives, our society has begun to actively seek sustainable alternatives to many contemporary, petrochemical-fueled technologies. Thus far, long-distance travel has resisted shifts to electrification, making the adoption of greener fuels a necessity (Gross, Oct. 2020). Algae-based biodiesel has emerged as a promising tool to help fight the global climate crisis. Algae-based methods can be more advantageous than first- and second-generation biofuel sources due to high energy content, rapid growth times, and reduced land and water requirements. However, industrial-scale algal biodiesel production remains constrained by its limited commercial feasibility (Prommuak et al., 2013). This capstone project aims to address these economic deficits.

The objective of our technical capstone project is to design a novel method of producing microalgal biodiesel by optimizing previous process strategies while subsidizing costs through the co-production of lutein as a high value byproduct to improve economic viability. Lutein, a carotenoid with anti-inflammatory properties, is widely recognized for its benefits in promoting eye health, particularly in preventing age-related macular degeneration. Additionally, research suggests potential positive effects in various clinical areas, including cognitive function, cancer risk reduction, and cardiovascular health improvement (Buscemi et al., 2018). The overall pathway is outlined in Figure 1.

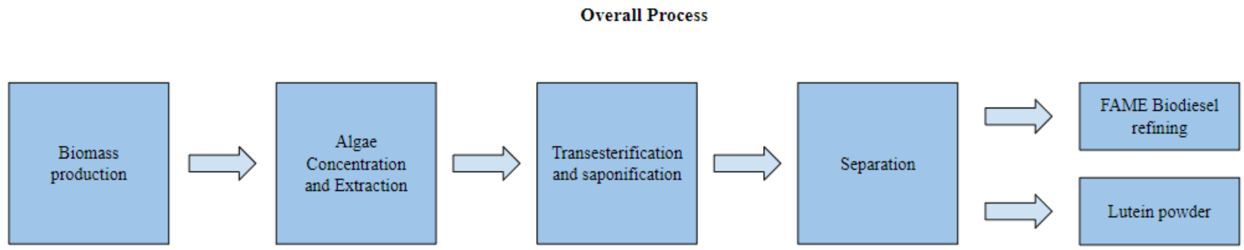

Figure 1. Overall process for FAME biodiesel and lutein.

We are drawing upon the insights presented by Tabernero et al. as inspiration for the development of our overall process. The first stage begins with the cultivation of *Chlorella vulgaris* in raceway ponds. Raceways offer an affordable and low maintenance method for growing algae (Griffiths et al., 2021). Agricultural waste will provide an inexpensive source of carbon and nitrogen. Paddles and spargers will be utilized to ensure complete mixing of nutrients and adequate aeration, therefore promoting a high rate of algae growth. Algae harvested at the end of the raceway will undergo a dewatering process to increase its concentration for further processing. This will involve a combination of mechanical centrifugation and a flocculation process assisted by nano magnetites described by Patel et al. to increase efficiency.

The downstream steps are modeled after the methodology outlined by Prommuak et al. but will be augmented to accommodate industrial scale production. Triglycerides and lutein fatty acid ester, crude forms of the desired products, will be removed from harvested algae via cell disruption. A scaled-up version of a Soxhlet extraction employs methanol and chloroform as solvents (Wang et al., 2023) to extract the lipids and dissolved lutein from the algal biomass. The remaining algae residue will be recycled back into the raceway as an additional carbon source. The chloroform and methanol will subsequently be removed to isolate the crude lipids, where they will then be converted to biodiesel and lutein through a coupled transesterification and saponification process. This process as well as subsequent separations needed to derive the final biodiesel and lutein powder products will be inspired by the flow diagram in Figure 2. Further refining of the biodiesel with a fractional distillation column may be able to achieve higher purity and thus increase the value of this product. The ultimate goal following the process design is to perform an economic analysis to determine the viability of microalgae biodiesel production alongside lutein co-production.

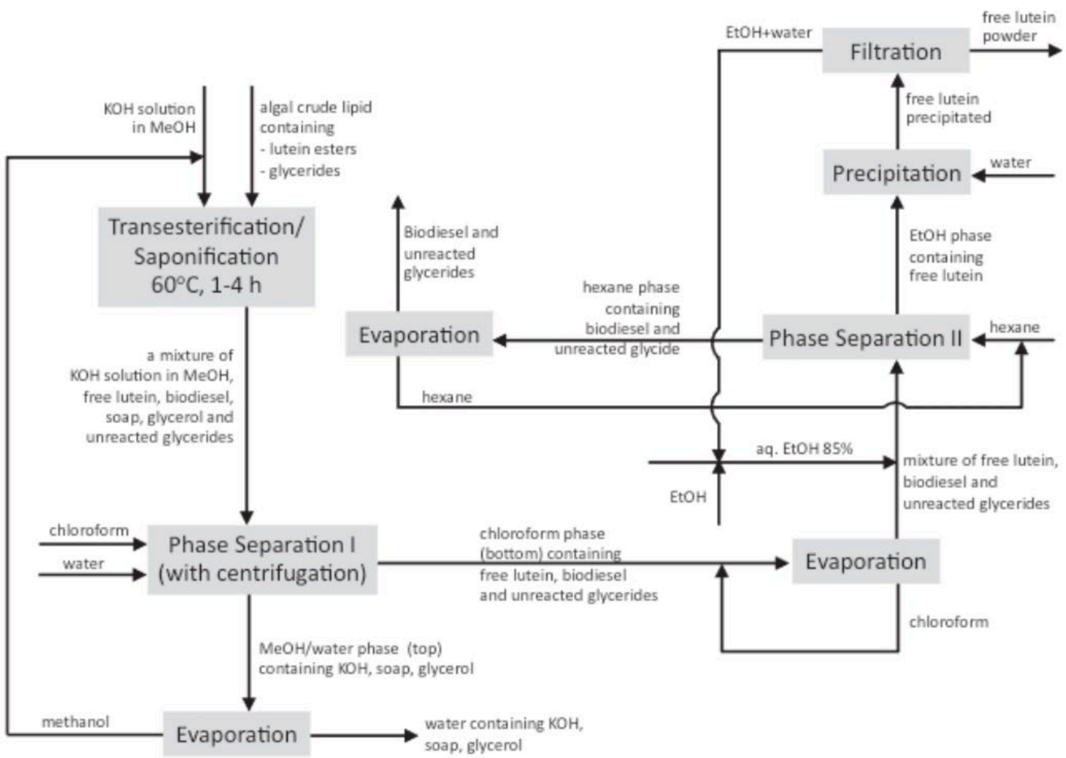

Figure 2: Reaction and separation to produce lutein and FAME biodiesel as presented by Prommuak et al. The final design will incorporate further separations for solvents used in reactions to improve overall functionality.

This project will be completed over the course of two semesters by our 5 person group. Certain aspects, including biodiesel refining and phase separation, will be modeled using the chemical process simulation software Aspen Plus. Since lutein and lipid production are well-established processes, we have access to an abundance of papers to reference and will utilize more specialized sources for each unit operation. To ensure an even distribution of work and timely completion of the project, we will assign team leaders to each process defined in Figure 1. Team leaders will oversee and delegate tasks like selection and calculations on specific operation units, ensuring a balanced workload and schedule flexibility. This approach ensures team members gain familiarity with all process aspects.

The final product of this design project will be a technical report containing material and energy balances, equipment designs, and an evaluation of the proposed process on economic, environmental, and safety grounds. This report will be produced in CHE 4476 in the spring of 2024. This project will align technology, innovation, and environmental responsibility in the pursuit of developing sustainable energy solutions.

STS Topic

The problem tackled by the STS portion of this research, striking a balance between profitability and safety, is one faced a lot in the development of ambitious and novel industrial methods such as in the hawk's nest disaster of the 1930s (U.S. Department of the Interior, 2021). Although at a glance, this matter may seem simple, the approach I am taking to consider it is multifaceted. In the interest of producing an answer that is relevant to the technical topic whose aim is to produce a profitable product useful to many, I believe a utilitarian approach that preserves the economical viability of the process is the desired outcome. It is this utilitarian perspective that can lead to the next aspect of this research, the various perspectives that will be taken. This necessitates the need for a combination of historic literary sources such as those found in the US Chemical Safety Board (CSB) as well as a variety of other databases (Bird F.E, 2005). Additionally, primary sources with both plant managers and, particularly, operators are of great importance due to their intrinsic alignment with the perspectives that I seek to explore. The analysis the data gathered from said sources would undergo is divided into two steps. First, several of the cost saving methods employed by previous scenarios gathered would be generalized and sorted according to the overall judgement derived from how different interviewees ranked their own views on what minimum safety should look like. All this would be used to answer, "to what degree can operational safety be sacrificed in regard to financial profitability and safety ?".

Conclusion

All in all, the culmination of both these parts will produce the following: for the technical aspect of the research, a plan and economic break down of a 3rd generation biodiesel and lutein production plant will be produced, and the STS aspect of the research will not only produce an articulated write up on the degree of expendability operational safety has for the sake of economic profit but also impact the safety measures presented in the plan for the production plan in the technical part.

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