Multi-Objective Optimization of Biodiesel Production using Superstructure Design

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Abstract— **Biodiesel as a fuel comprised of mono alkyl esters of long chain fatty acids derived from renewable lipid feedstock, such as vegetable oil and animal fat. Biodiesel production is complex process which needs systematic design and optimization. In this paper, a discussion about superstructure optimization is performed by multi-objective optimization and non-linear problem-solving algorithm. A lot of important biodiesel process stages are included in the projected superstructure.**

Keywords— Biomass; Biodiesel Production; Superstructure; Optimization; Multiple objective functions;

I. INTRODUCTION

In recent years, diminishing fossil fuel, global warming and environmental pollution have become major global issues. Development of environmentally friendly fuels Because of growing worries about greenhouse gases emissions, depleting fossil fuel supplies, and volatile petroleum fuel prices, biomass production is becoming increasingly essential. Bio-fuels emit less CO_2 gas as compared to fossil fuels, and by using bio-fuels as diesel fuel and other power sources, the quantity of Carbon di oxide in the air might be lowered [1]-[3]. The use of biomass fuels such as biodiesel and ethanol can help resolve such issues because these fuels are renewable sources of energy. Biodiesel fuels such as fatty acid methyl ester (FAME) produced by the transesterification of vegetable oils or animal fats with methanol have been characterized by aromatic-free compounds, high biodegradability, and low SOx and particulate matter content in diesel fumes.Biodiesel is an alternative fuel similar to conventional or 'fossil' diesel. Biodiesel can be produced from material that contains fatty acids [4][5]. Thus, animal fats and vegetable fats can be used as feed stocks for biodiesel production. The process used to convert these oils to Biodiesel is called transesterification. The use of heterogeneous catalysts allows a more environmentally friendly process to be used for biodiesel production. Following a sequence of bio-fuels raw material and an establish of preferred finished products and specific requirements, ascertain a versatile, durable, and inventive processing network with the goals of lowest cost and sustainability, take into consideration technological innovations, geographical position, and so on [6].

The main objective of this article is to identify the key issues for designing optimized bio-refineries by using system engineering (SE) tools and techniques. In this paper, firstly a review is presented on methods or pathways for the production of bio-fuels from biomass such as micro-algae, etc. Further superstructure based framework is modeled to optimize system design for sustainable and robust bio-diesel production from biomass. In this paper, a superstructure network model is presented with an optimized pathway for an optimal solution for the production of bio-diesel from biomass. Multiple objective functions are described here to optimized the processing pathway.

II. BIODIESEL PRODUCTION PROCESS

Through an esterification reaction, biodiesel is made from plant oils or processed meats and an ethanol. The process of converting fats and oils into biodiesel and glycerin is known as transesterification [7]-[10].

The main steps for biodiesel production consist of the following steps (Fig.1):

- Feedstock selection and harvesting: In this step, collection of biomass raw products from fields are performed. The collection of biomass should be done with respect to moisture content and its efficiency in terms of end product.
- Pre-treatment before extraction: Before biodiesel production, pre-processing of harvested feedstock is done. In this step different techniques are adopted such as drying, pyrolysis, palettization. Out of which drying and pyrolysis are most common methods. The drying of biomass reduces its moisture content whereas pyrolysis process is thermal decomposition of feedstock in absence of oxygen.
- Lipid extraction: This is most important step for biodiesel production that decides the quality quantity and cost efficiency of the method. This step results in production of biooil.
- Trans-esterification: This is the process in which the biooils (lipids) are chemically reacted with alcohol and catalyst. Mainly glycerol is used as catalyst. Basically in this step the viscosity of nonedible biooil is reduced by conversion of triglycerides into ester.
- Post-transesterification filtration and biofuel extraction: Finally in this step filtration of low viscous biofuel obtained in above step is performed for usage.

Apart from biodiesel production, some by-products are also generated such as glycerol that can be further utilized in many industries.

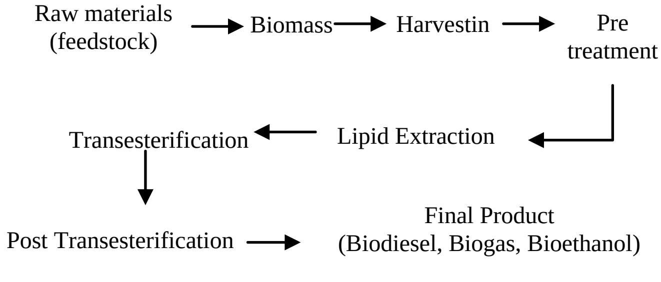

Fig.1. Pathway of biofuels production from biomass

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III. SUPERSTRUCTURE MODELLING

All potential alternatives in the processing network are represented by a schematic form, which is called the superstructure. Hence, the superstructure contains all candidates for feasible and optimal processing pathways. In formulating the superstructure, all the potential raw materials and products are specified and then linked through a series of tasks (unit operations and/or unit processes) such that the raw materials get converted into the products. Here provided a superstructure which comprised of the various filtering phase available options. Identify the optimal processing pathway for the synthesis of the final products, bio-diesel, from the provided raw material, micro-algae biomass, according to the optimal solution definition.

In superstructure design and optimization includes mathematical programming to find the optimal chemical process according to objective function [6]. A general superstructure representation is illustrated in Fig.2. To design and develop a superstructure for bio refineries, it is required to identify all the possible processing stages/steps that can lead to end products. The Fi g.2 represents the example of the superstructure with all possible alternatives for the processing stage. Depending on the desired end-products, the processing pathways are added to the superstructure.

Fig.2. General Superstructure Framework

Fig.3. Superstructure optimization flowchart

In superstructure optimization four main steps are performed as [17]:

- Problem identification to determine the scope of the metrics selection.
- Collection of data for required raw materials, process, and all possible alternative techniques.
- Establishment of connection among alternatives of process.
- Conversion of raw materials into desired products.

The most important step in superstructure design is to formulate the objective function for optimization [8]. An objection function determines the equality and inequality constraints to reach the best possible solution. In most of the research work, mixed-integer linear programming (MILP) is used. A general superstructure-based optimization representation is illustrated in Fig. 3.

IV. LITERATURE REVIEW

N.F. Nuh and M.Z. Nuh Nasir [11] introduced a complicated issue and optimized it using mixed-integer nonlinear programming (MINLP). Using available kinetic data, this project will use process system engineering (PSE) techniques to simulate and optimize the biodiesel process, as well as construct mathematical models for plant components in cases A, B, and C. The -constraint strategy described by Riju De et al. [12] is used to solve the optimization problem. The ideal temperature trajectory is generated using an orthogonal collocation on finite element technique. The state and control profiles were discretized using piecewise linear Lagrange's polynomials and the control problem was turned into an NLP problem using the collocation approach. The minimum batch end time was calculated to be 67.4 minutes. In order to achieve best reaction parameters, Masoud et al. [13] applied the GE algorithm to biodiesel. Furthermore, a multi objective genetic algorithm is used to achieve a stable optimization. A wide-ranging temperature could be described as the Pareto front to help with the final decision as the temperature point for optimizing the production of biodiesel. The goal of this study was to increase the amount of Ester and Alcohol in this manufacturing while reducing the amount of other products. Based on experimental data for biodiesel systems, Ahmed et al. [14] established a viable model of biodiesel system utilizing fuzzy logic. In order to determine the best operating parameters of the biodiesel system, a particle Swarm optimization (PSO) optimizer is used. In the optimization process, the decisive variables are pressure, number of passes and response time, thus maximizing the percentage of biodiesel recovery lipids. This study, led by L. Simasatitkul [15], proposed a new biodiesel manufacturing design methodology that included alkali catalysts, heterogeneous base catalysts, acid catalysts, enzymes and heterogeneous acid catalysts, among other things. In addition, a two-step technique of hydrolysis and esterification method were examined for the production of biodiesel. Kamal Pasha Mustafa [16]. The study reviews latest research on biodiesel in the field of process systems engineering focusing on biodiesel production, including process modeling and development, environmental assessment, management and integration of systems. Also underlined in this analysis are the challenges and prospects for developing sustainable enzyme biodiesel technologies that are environmentally friendly.

V. METHODOLOGY

Despite the successes experienced in the biodiesel industry as stated previously there still remain major challenges in the biodiesel industry. The main factors affecting the cost of biodiesel include: The cost of raw materials, the cost of processing, Reuse of the catalyst, Time Complexity. Optimal control of the transesterification batch reactor must satisfy two objectives: Maximization of catalyst at the end of the batch, Minimization of batch time, Minimization of Overall Production Cost. For these objectives, multi-objective optimization (MOO) is proposed. The superstructure is described for the problem of optimal process synthesis for biogas production from organic and animal waste resulting in multi-objective optimization problem. The optimization problem is used to determine the optimal processing route for the production of desired product, biodiesel, from the specified raw material, microalgal biomass. The objective function for the optimization is chosen as the maximization of the yield of the desired product but it can also include other objectives such as the minimization of the processing costs (the cost of the raw materials, utilities and chemicals), the amount of waste products and processing time. For a multi- objective optimization problem, the aim is to find a vector X* = {x1, x2….xn} which will satisfy the constraints.

$$\begin{cases} gi(X) \geq 0 & i = 1,2, \ldots.Q \\ hj(X) = 0 & j = 1,2,..P \end{cases}$$

And, will minimize the vector function:

F(X)= { f1(X), f2 (X)….. f M(X)}

X= {x1, x2….xn} ∈Ω

Where X= decision variables, the set Ω denotes the feasible region and M is the number of objective functions to be minimized. The quality of a solution is explained in terms of trade-offs between conflicting objectives. Let X ′ and X ′ ′ be two solutions of the M-objective minimization problem, both of which satisfy the aforementioned constraints.

VI. CONCLUSION

From the research, the proposed multi-objective optimization algorithm will reduce the overall cost of biodiesel production process as well reusage of catalyst. From the aspect of industry, the optimization finds the optimum pathway, also the minimum cost and may be beneficial for sustainable development due to the lower consumption. Overall, this research will successfully implement the process system engineering (PSE) to optimize the design and cost estimation.

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