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ENHANCING BIODIESEL PRODUCTION THROUGH OIL BLENDS AND OPTIMIZATION APPROACHES - A REVIEW

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ABSTRACT

The increasing negative impact of fossil fuel usage has necessitated a transition towards sustainable and clean energy sources and fuels such as biodiesel. This paper will provide a short overview on the importance of biodiesel fuel and the effect of utilization of oil blends in the production of biodiesel such as enhanced quality, reduced cost, and positive impact on the environment resulting from utilizing waste feedstock. The use of oil blends and various combinations in literature is discussed and summarized in this paper along with their impact on biodiesel production process and yield. In addition, some of the main technological and economic challenges faced in the production of biodiesel are outlined along with some insights into future directions for biodiesel production optimization using oil blends in order to enhance the efficiency of the process. Finally, different optimization approaches for the production process are also highlighted including Genetic Algorithm, Particle Swarm Optimization, and Simulated Annealing.

Keywords: Biodiesel, Oil Blend, Feedstock, Optimization, Challenges.

1 INTRODUCTION

The increasing cost of energy imports, environmental concerns [1, 2], and higher electricity requirements [3] have increased the demand for economically viable and environmentally friendly biofuels such as biodiesel [4], which is gaining popularity as a sustainable and efficient alternative to conventional diesel [5]. Many factors influence the overall cost of biodiesel production, including catalyst, type and availability of feedstock, manufacturing processes, and operational expenses, among others. Selection of the feedstock is mostly influenced by supply, price, and properties like cold flow and stability. Several nations produce biodiesel from both edible feedstocks including rapeseed, soya, cocoon, and palm oils as well as inedible oils like *Jatropha* [6], municipal waste, and agricultural residue [7]. Due to its faster growth

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and more efficient photosynthesis compared to other crops, researchers have also turned to macro- and microalgae feedstock to reduce the total costs of biodiesel production [6, 8].

A diverse range of oils and oil blends of different proportions have been utilized in biodiesel production as feedstock in order to enhance the properties of the product fuel. The biodiesel properties are greatly impacted by the fatty acid content of each oil comprising the feedstock mixture. Combining various oils in varying ratios can lead to improved quality and efficiency of the product fuel and optimization of the fuel characteristics [9]. Furthermore, despite the low free fatty acid content in some edible oils, their high cost and the use of these oils as food sources has led to the proposition of inedible and waste oils as feedstocks to reduce the cost and minimize the dependence on edible feedstock [10].

Moreover, researchers are presently focusing on the optimization of parameters that impact the amount of biodiesel yield, including reaction temperature and duration, catalyst amount, and alcohol to oil molar ratio [11]. An appropriate approach is necessary to speed up the production process, decrease the quantity of experimental trials, and identify the ideal parameter values [12] such as design of experiments using Response Surface Methodology (RSM) [13], and optimization techniques including Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Simulated Annealing (SA).

This paper discusses the use of various oil blends in biodiesel production to improve the properties of the biodiesel and reduce cost and dependency on edible feedstocks. The effect of several optimization approaches on the reaction rate and product yield and quality is also highlighted along with current challenges and future directions in the field of biodiesel production enhancement.

2 BENEFITS OF OIL BLENDS IN BIODIESEL PRODUCTION

Using blends of oil as feedstock can help enhance the produced biodiesel properties, improve its quality, as well as reduce cost of the feedstock since the availability and cost of the oil feedstock can be a constraint in the process of biodiesel production [14]. Moreover, the utilization of inedible oils has several benefits that include reducing the negative economic and food safety effects of using edible oils, adding value to the agricultural sector, decreasing the amount of money spent on imported fuels, slowing down the rate of deforestation, producing less carbon dioxide, and making better use of the current plantation [15]. Therefore, the use of oil blends as feedstock in the process of biodiesel production can be cost-effective and have positive environmental and sustainability impacts as well as result in enhanced biodiesel quality. Several studies have investigated the use of oil blends in biodiesel production to reduce cost or improve performance as summarized in **Table 1**. For instance, a study [16] investigated the possibility of producing biodiesel from a mixture of waste cooking oil and inedible jatropha oil by testing different mixing ratios of the feedstock. The optimum ratio of the blend chosen was 90:10 waste cooking oil to jatropha oil and resulted in a yield of 90.9%. The produced biodiesel was characterized and met the American Society for Testing and Materials (ASTM) requirements for acid value, kinematic viscosity, heating value, and oxidation stability. Biodiesel characteristics were further improved using antioxidants and mixing with petroleum diesel in a diesel to biodiesel ratio of 80:20 [16].



Researchers [17] studied the process of producing biodiesel from hazelnut oil, sunflower oil, and a hybrid feedstock of the two oils in a ratio of 50:50. The hazelnut oil feedstock produced a 97.5% yield, whereas the sunflower oil produced a 97.3% yield, and the hybrid feedstock resulted in a yield of 97.9% and the reaction conditions were a methanol to oil molar ratio of 6:1, catalyst concentration of 0.7%, and temperature of around 60°C. The biodiesel produced was suitable for industrial production since it satisfied the quality requirements defined by ASTM D6751 and EN 14214 standards. A significant barrier to the manufacture of biodiesel on a big scale is the availability of feedstock, thus the use of hybrid feedstock can guarantee a continuous supply of feedstock, even in instances of scarcity which is essential for the purpose of large-scale biodiesel production [17].

Another study [18] investigated the production of biodiesel from a blend of waste cooking oil and other non-edible oils of *Calophyllum Inophyllum*, *Ceiba Pentandra*, *Sterculia Foetida*, and *Jatropha Curcas* in a volumetric ratio of 70:30. Waste cooking oil was used in the blend since it is a cheap and sustainable feedstock option but suffers from low oxidation stability as well as reduced yield resulting from significant free fatty acid and water content. The three-stage process involved blending the feedstock, reducing FFA content, and optimizing the reaction parameters. The feedstock combination consisting of the waste oil and *Calophyllum Inophyllum* blend was chosen for biodiesel synthesis based on the determined physicochemical parameters of the crude oil mixtures which showed higher oxidation stability of this blend compared to the other mixtures. The results of the study demonstrated that optimizing the reaction parameters resulted in an enhanced experimental biodiesel yield of 94.12% which conformed to the specifications of ASTM D6751 and EN 14214 standards [18].

Adepoju et. al [19] utilized a quaternary oil blend that consisted of *Carica Papaya*, *Citrus Sinesis*, *Hibiscus Sabdariffa*, and waste oil for the production of biodiesel. The study explored the optimization of the process using response surface methodology tool to find the optimum process parameters. The four oils were blended in equal amounts of 25:25:25:25 in order to obtain biodiesel with a yield of 99.78 wt%. The characteristics of the produced biodiesel were evaluated, including density, viscosity, acid value, cetane number, higher heating value, iodine value, as well as saponification value and the findings showed that the biodiesel produced from this blend met biodiesel standards [19].

Moreover, a study [20] optimised the biodiesel manufacturing process parameters through the combination of sunflower and soybean oil. Sunflower and soybean oils were combined in a mixture of 50% sunflower oil and 50% soybean oil. It was discovered that a methanol: oil ratio of 19:1-21:1, 0.6 wt% catalyst concentration, 50-60 minutes reaction duration, and 475-525 rpm were the ideal conditions, resulting in a biodiesel of around 93.5%. The main goal was to examine how different blends of diesel and biodiesel mixtures affect engine performance, exhaust gas emissions, and combustion. Except for nitrogen oxide emissions, biodiesel blends reduced exhaust gas emissions as compared to diesel fuel. Biodiesel blends also had lower Brake Specific Energy Consumption and Brake Thermal Efficiency. Diesel and biodiesel made from a combination of sunflower and soybean oil might be combined up to 70% [20].

Table 1: Oil blend feedstocks in biodiesel production.

Feedstock	Ratio of feedstocks	Biodiesel Yield	Reference
Waste Cooking Oil and Jatropha Oil	90:10	90.9%	[16]
Hazelnut oil and Sunflower Oil	50:50	97.9%	[17]
Waste Cooking Oil and Calophyllum Inophyllum Oil	70:30	94.12%	[18]
Carica Papaya, Citrus Sinesis, Hibiscus Sabdariffa, and Waste Oil	25:25:25:25	99.78%	[19]
Sunflower Oil and Soybean Oil	50:50	93.5%	[20]

3 OPTIMIZATION APPROACHES

Optimization approaches can be useful in optimizing reaction parameters that influence the product yield and quality as well as reduce the reaction time. Studies have examined several methods including Genetic Algorithms, Particle Swarm Optimization (PSO), and Simulated Annealing (SA) as summarized briefly in **Table 2**.

3.1 Genetic Algorithm

Genetic Algorithm (GA) is an optimization technique that is adapted from the process of natural selection. It is a population-based search algorithm that makes use of the idea of the survival of the fittest. The new populations are created by iteratively applying genetic operators to individuals in the population. The main components of GA are chromosomal representation, selection, crossover, mutation, and fitness function computation [21]. GA can enable optimization in challenging solution domains. These algorithms are suitable issue solvers, especially when no derivatives are present and the fitness landscape has sections that are out of condition [22]. In GAs, a variety and large number of solutions for a particular problem can exist. The resulting solutions undergo a recombination and mutation process, which in turn produces new offspring and is repeated for several generations. Every single is assigned a certain fitness value based on the objective function, and those that are fitter are more likely to mate and generate more fit individuals. This process, which continues until it reaches the desired outcome criterion, guarantees the creation of more fit or better solutions in subsequent generations. These algorithms have the benefit of getting better results over time and are most suited for situations where the search region is big and there are plenty of factors [23].

Genetic algorithms have been applied to solve many optimization problems and several studies have reported its application to optimize many processes including the production of biodiesel. For instance, a study [24] utilized response surface methodology (RSM) to optimize the biodiesel production from chicken fat oil using ultrasound-assisted systems and investigated the effect of various parameters such as the alcohol-to-oil molar ratio, catalyst concentration, and reaction time on the conversion percentage of fatty acids to biodiesel. The GA uses the regression equation as a fitness function and optimizes the function to conform with the given restrictions. The optimized parameters were found to be a catalyst loading of 0.97%, a molar ratio of 7.13:1, and a reaction period of 9 minutes and the



ultrasound-assisted method produced better outcomes and required significantly less time compared to traditional approaches [24].

In another study [25], a GA was used along with an artificial neural network (ANN) to optimize the production of biodiesel from *Simarouba glauca* oil. The relationship between three input parameters: methanol to oil ratio, temperature, and time, and the output variable which is the level of FFA of the of the crude oil was predicted using Box-Behnken and artificial neural network linked genetic algorithm-based models and the predicted values from the RSM and ANN were compared using statistical parameters. The comparison showed that the expected FFA values for FFA acquired using both models were equally significant as those obtained experimentally. GA was employed to find the best process parameters for minimal FFA levels in the biodiesel by using the output of the ANN model to calculate the fitness function values for the GA routine, which gradually converged towards the optimal solution. The optimum values for the oil-to-alcohol ratio, temperature, and time were determined and the study concluded that the global random search and high biological system prediction accuracy of the ANN model made it more effective than the RSM model [25].

3.2 Particle Swarm Optimization

Particle Swarm Optimization (PSO) works by forming a flock of fictional birds or particles with specific velocities in a 3-D space. Memory of the domain locations is retained by the particles, which distinguishes PSO as a better method. The technique works iteratively by adjusting the particle placements over and over until it converges at a position that is close to ideal. The locations are updated, and the particles are directed to migrate in the direction of the best particle in the swarm after each iteration. The particles quickly approach an acceptable optimal value close to the global best location after a few repetitions [26]. PSO has achieved widespread interest from academics due to its simplicity, and effective performance in a range of application domains [27].

For example, a study [28] discussed the optimization of biodiesel fuel properties to reduce nitrogen oxides (NO_x) emissions in a diesel engine. The study focused on the usage of oleic acid as a biodiesel addition and investigated the impact of various engine loads and compression ratios on NO_x emissions and engine performance. In order to achieve the best NO_x emissions and Brake thermal efficiency (BTE) without compromising engine performance, the researchers employed experimental tests and a multi-objective PSO technique to determine the best combination of oleic acid content, compression ratio, and engine load. ANOVA analysis was performed and showed that all three parameters significantly affected NO_x emissions and regression equations for both BTE and NO_x were devised which were employed as objective functions in the PSO. The optimized values that maximized the BTE and minimized the NO_x emissions were 10% OA, 17.5 compression ratio (CR), and 81% engine load which led to NO_x emissions of 111 ppm and BTE of 30.9% [28].

3.3 Simulated Annealing

The Simulated Annealing (SA) approach is an optimization technique that does not use derivatives. The origin of SA is from metallurgical annealing, and it is based on the idea of Markov Chains, a probabilistic method for estimating the global optimum of a specific objective function. The objective function value is computed with each parameter set throughout the process, and the difference between the values with the old and new parameter settings is calculated. If the new parameter set minimizes the value of the objective function, the move is always approved, and in other cases, the move is permitted

with a transition probability [29]. SA technique is quite versatile and may be used in a wide range of single-objective, multi-objective constrained, or unconstrained optimization problems in many different scientific and engineering domains [30].

Table 2: Optimization Approaches in Biodiesel processes.

Feedstock	Input Variables	Output parameters	Optimization Technique	Reference
Chicken Fat oil	- Alcohol-to-oil molar ratio - Catalyst concentration - Reaction time	Conversion percentage of fatty acids	RSM and Genetic Algorithm	[24]
Simarouba Glaucou oil	- Oil-to-alcohol ratio - Temperature - Time	FFA oil content	Artificial Neural Network linked Genetic Algorithm	[25]
Pongamia	- Oleic content - Compression ratio - Engine load	Acid - NOx emissions - Brake thermal efficiency	Multi-Objective Particle Swarm Optimization	[28]

4 CHALLENGES AND POTENTIAL SOLUTIONS

4.1 Technological Challenges

While conventional production methods like transesterification have historically been and still are the most prominent biodiesel production method, the efficiency of such approaches has largely plateaued due to limited potential for further enhancement and high costs. Consequently, biodiesel fuel struggles to replace petroleum-based diesel in the current market. This has increased the demand for novel, environmentally friendly, and enhanced technologies in biodiesel production that can not only accelerate reaction times while maintaining good quality, but also reduce energy consumed in the process [31]. Therefore, numerous methods have emerged to accelerate the reaction and reduce energy and catalyst such as ultrasonic, microwave, hydrodynamic cavitation, reactive distillation, supercritical, rotatory, and plug flow reactors [31, 32].

4.2 Economic Challenges

The cost of the feedstock, operational expenses, and the selling price of the generated biodiesel and its byproducts have a direct impact on how economically viable biodiesel manufacturing is. The operational expenses comprise fixed charges like taxes, general expenditures like research and development, as well as direct production costs including raw materials and labour [33]. Once the process has been optimised under lab settings, one of the key elements that must be considered is the economic viability. The raw material plays a significant role in the biodiesel value chain, for instance, the oil content of the raw material can have a great impact on the product characteristics. For determining the economic



viability, it is necessary to examine the cost of raw materials as well as material loss, energy loss, and reactor efficiency. A variety of simulation techniques can help validate the feasibility by considering many elements and input conditions including flow rate, pressure, temperature, plant capacity as well as a thermodynamic model [34]. Moreover, the cost of the raw material can also be reduced by optimizing the blend of feedstock used.

5 FUTURE DIRECTIONS IN ENHANCEMENT AND OPTIMIZATION OF BIODIESEL PRODUCTION USING OIL BLENDS

Based on the status of biodiesel related research, there are requirements for rigorous development and focus on the use of mixed oil feedstocks in order to enhance fuel quality through oil blends while also reducing cost. Other challenges that can be addressed include developing appropriate reactor designs and incorporating efficient and cheap catalysts. The utilization of machine learning techniques shows great potential for optimizing the production process parameters. Additionally, the exploration of cost-effective pre-treatment methods could improve the quality of biodiesel sourced from lower-grade feedstocks [35]. The advancement of biodiesel research also necessitates governmental and state-level formulation of policies that encourage its growth and enforce its utilization. Such measures would not only increase demand, thereby promoting greater production, but also secure additional funds and subsidies for this purpose. Additionally, incorporating tax exemptions within the biodiesel synthesis process could prove advantageous, enabling competitiveness against cheaper fossil fuels [36].

6 CONCLUSION

The use of different oils blended as biodiesel feedstocks has proven to be beneficial in mitigating some of the challenges faced in biodiesel production. This strategy can be very advantageous by enhancing the quality of the produced biodiesel such as the viscosity, oxidation stability, fatty acid content, and heating value. Since there are concerns regarding the use of edible oils, mixing edible and non-edible or waste oils can reduce competition and utilize waste in environmentally friendly ways while reducing the cost of the used feedstock, which is a significant factor that can greatly influence the cost of the biodiesel production process. Moreover, utilizing optimization techniques such as genetic algorithms, particle swarm optimization and simulated annealing can have a positive impact on both the yield and quality of the product fuel as well as the reaction time. Biodiesel production process has some technological and economic constraints that can hinder large-scale commercialization of the process. Therefore, different technologies are emerging, and several approaches can enhance the process and reduce the energy and time required in order to implement industrial scale production.

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