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OPTIMIZATION OF THE TRANSESTERIFICATION PROCESS FOR BIODIESEL SYNTHESIS FROM WASTE COOKING OIL

Vandana Rajpoot
Research Scholar
Dhanendra Kumar Rai and Manish Kumar
Dept of Biotechnology
P K University, Shivpuri MP
rajpootvandana2208@gmail.com

ABSTRACT

This study set out to find the best way to optimize transesterification so that waste cooking oil may be converted into biodiesel with as little resources used as possible. This study utilised the quantitative experimental approach to cover 100 distinct batches of alcohol-to-oil ratios (3:1, 6:1, 9:1, and 12:1) with catalyst concentrations ranging from 0.5% to 2.5%. The location of this study was Jhansi, India. The data also showed that a catalyst concentration of 1.5% and an alcohol to oil ratio of 9:1 yielded a good biodiesel output. This provided strong evidence that these factors were the most important in deciding the effectiveness of the transesterification process. An alternative source of sustainable feedstock for biodiesel could be used cooking oil. The ecologically friendly biodiesel production can be based on this, which can be derived practically from home garbage collections with potentially harmful repercussions. These findings demonstrate the wider monetary and ecological advantages of recycling oil for renewable energy applications, which in turn promotes waste management and sustainable energy practices, and they aid in the creation of more effective techniques for biodiesel synthesis.

Keywords: *Transesterification, Waste Cooking Oil, Biodiesel Yield, Renewable Energy Applications, Sustainable Energy Practices, Waste Management Strategies, Eco-Friendly Solution.*

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1. INTRODUCTION

This demand has been due to the immense rise in energy and is imperative for the socio-economic development of human civilization. Such a surge has come from rapid growth in the population and affluence. Countless sectors in the economy like agriculture, industries, transportations, commercial and household sectors, demand energy in their operation process. The majority of fuel sources utilized for energy, to date, are fossil fuels that encompass petroleum, coal, and natural gas. These energy sources account for nearly 81.1% of global energy demand.

The large-scale use of fossil fuels led to environmental pollution issues due to increased demand for sources of energy. This reason triggered the increase in people who become conscious of how technology affects the environment, and in this regard, there has been investigation in alternative sources of energy, for instance, wind power, hydropower, solar energy, biomass, and biofuels. Waste cooking oil can be transformed into biodiesel, which is a diesel fuel alternative obtained from vegetable oils or animal fats. This can be done through different catalysts.

Used as frying oil in restaurants and hotels, waste cooking oil is now mostly dumped in the environment; it causes a lot of troubles for the environment, society, economy, and even health. A lack of appropriate disposal leads to an increase in organic pollutants within bodies of water and this affects the fish stocks, aquatic living organisms, and people around. This is a waste cooking oil-based application for the production of biodiesel, which not only recycles the waste cooking oil but also gives renewable energy with reduced pollution levels. In addition to that, it reduces the associated costs of management of trash and provides three solutions - economic, environmental, and waste management responsibility.

Due to their versatility, ease of separation, reusability, and Eco compatibility, heterogeneous catalysts have been given a lot of attention as potential catalysts for the synthesis of biodiesel. An interesting option is calcium oxide nanoparticles, since they present a high basicity in comparison with homogeneous catalysts, are non-corrosive, offer a low price, low solubility, and can be manipulated easily. In addition, since they are nontoxic to the ecology, they are an attractive choice for a catalyst use.

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2. LITERATURE REVIEW

Rocha-Meneses et al. (2023) delved into key issues such as reactor types, catalysts, and other parameters influencing biodiesel production. Crucial optimisation strategies that may be applied to increase the production of biodiesel from used pan oil were also addressed. Energy demand and supply for the primary end-use sectors, which include electricity, heating, cooling, and transportation, have been growing steadily since the 1970s due in part to sustained economic growth. It means that people are seeking an alternative source of energy that consumes less fossil fuel. Biodiesel seems to have hope in the transport sector compared to the conventional fuels. However, the factor that has been considered to be a major limitation is the costliness of the feedstocks of biodiesel, although widely commercialized. This paper talks about the application of used cooking oil as a feedstock for the production of biodiesel through transesterification, approaches toward improving the process, making it more efficient and lowering the cost of biodiesel, and finally doing our best to outline the current and future problems in this area, which if solved, may make this age-old method more economically viable.

Ulakpa et al. (2022) helped with future predictions, RSM offered a solid statistical method for constructing an empirical model of the operating parameters and ideal operating conditions. Being able to recover and reuse the developed catalyst without reducing its catalytic activity was vital. Biodiesel may be made from used cooking oil using a bentonite clay catalyst supported on sodium hydroxide, which was created and assessed in this research. Through impregnation, the transesterification yield was used to find the optimal NaOH/bentonite catalyst. Both scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) were employed to discern functional groups in the catalyst, allowing for its shape to be characterised. After synthesising the catalyst, it was used in FAME synthesis through the RSM-CCD central composite design. The catalyst for the transesterification process was 4 weight percent, the reaction duration was 4 hours, the temperature was 600 degrees Celsius, and the stirring speed was 350 revolutions per minute. The methanol to oil ratio was 9:1. With a 9:1 methanol: oil ratio with a 4-weight percent NaOH: bentonite catalyst, the biodiesel output was 91.2% after 4 hours of continuous stirring at 60 degrees Celsius. Research was conducted to determine the effect of response factors on biodiesel yield. The established workability of RSM, the effective catalyst produced, was further solidified. The chemical and physical properties of the fuel that were measured were benign.

Degfie et al. (2019) researched ways for biodiesel from used cooking oil (WCO) to act as a renewable fuel energy source, making it one of the key raw materials of many liquid fuel's applications. Advantages in multiple spheres like waste management, environmental perspective, and economies form part of reasons that favour using a CaO Nano-catalyst for waste cooking oil and methanol recovery processes in converting used cooking oils to biodiesels. We synthesized a CaO Nano-catalyst by a thermal-decomposition method, calcined it at 500 °C, and characterized it by x-ray diffraction (XRD) and scanning electron microscopy (SEM). At a high level of purity, the XRD data showed Nano-scale crystal sizes, with an average particle size of approximately 29 nanometers. The pictures captured by the scanning electron microscope revealed the porosity structure and morphology of the synthesized nanocatalyst. So far, among only a few cases of maximum conversion, the latest case had an estimated 96% conversion that came with the fulfillment of the experimental conditions. These are: 50 °C in reaction, a 1:8 ratio of WCO oil to methanol, loading rate of 1% by weight of catalyst, and a 90-minute reaction time. The biodiesel's characteristics were evaluated using American fuel standards (ASTM D6571). Atmospheric pressure and stir at 1500 rpm for all reactions.

Janbarari and Behrooz (2020) suggested design is able to handle different feed grades without grossly violating any of the constraints, unlike designs produced by deterministic formulation. Biodiesel manufacturing frequently employs waste cooking oil (WCO), which is usually collected from restaurants and other sources for economic reasons. The quality of oil obtained might experience changes in such a way that the components within the WCO processed in this biodiesel synthesis process become undetermined. Accordingly, the objective was to identify a method for synthesising an alkali-catalysed procedure. The feed stream of the feed WCO contains inconsistent quality hence a Gaussian random variable was set to model its quality. Subsequently, a methodology based on chance constraints was selected as the solution approach, and a stochastic optimisation method was proposed for the design of the plant. Attention was paid to how the proposed method will impact the operational and design features. The results show that the stochastic formulation can handle feed quality variations with a safety margin. In addition, the

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facility's economic performance was analyzed under various scenarios. A plant that follows the proposed stochastic approach for its design has a fixed capital investment amount that is 11.9% higher and also revenue that is on par with the nominal scenario.

3. RESEARCH METHODOLOGY

This research utilized a quantitative experimental methodology in assessing the influence of the alcohol-to-oil ratio and concentration of the catalyst on the biodiesel synthesis process from used cooking oil. For establishing ideal conditions in biodiesel synthesis, data collected from 100 experimental batches were analyzed using frequency and percentage distributions, presented as bar graphs.

3.1. Research Design

This work uses a quantitative experimental research approach to find out how different transesterification reaction parameters, such catalyst concentration and alcohol-to-oil ratio, affect biodiesel production from spent cooking oil. To find the optimal catalyst concentration and alcohol-to-oil ratio, this method involves conducting a battery of controlled laboratory tests. The goal here is to find the optimal combinations of these variables that will maximise biodiesel output.

3.2. Data Collection

Data was collected using a number of experimental batches which underwent the transesterification process with varying levels of catalyst concentrations and alcohol-to-oil ratios. The amount of catalyst as a percentage of the oil weight was varied to test each alcohol-to-oil ratio. The frequency distribution of these variables was compiled together with the number of batches that were processed at each combination for study. Although the biodiesel yield of each batch has been followed, the frequency and percentage distribution of the catalyst concentrations and alcohol-to-oil ratios used are the major focus in this study.

3.3. Sample Size

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This involved 100 experimental batches, which are samples in the experimental plan, and were unique in every alcohol-to-oil ratio with a unique concentration of the catalyst. The processing and analysis of these batches found the best condition for the production of biodiesel.

3.4. Research Area

The study was conducted in Jhansi, a place with diverse sources of waste cooking oil from nearby homes, eateries, and food facilities. Jhansi was selected as the research location because it provided a representative sample of sources of waste cooking oil and a setting that was favorable for the experiment.

3.5. Data Analysis:

The experimental results were summarised by performing data analysis by frequency and percentage distribution. Below are the activities carried out to analyze the data:

- **Frequency Distribution:** There was a tally of the experimental batches run for each parameter, including alcohol-to-oil ratio and catalyst concentration. Both the alcohol-to-oil ratio and the catalyst concentration were noted according to how often they occurred.
- **Percentage Calculation:** The frequency of each category was divided by the total number of batches, which was 100. The result obtained then multiplied by 100 to get the percentage distribution of every category (for example, catalyst concentration of 0.5%, 1.0%, etc.).
- **Graphical Representation:** Also, bar graphs Figures 1 and 2 are used for presenting the results visually to present the distribution of the catalyst concentration and alcohol-to-oil ratio more understandably in visual terms.
- **Interpretation:** The frequency and percentage distributions were then evaluated to identify patterns and suggest ideal parameters for the production of biodiesel, such as the most commonly tested catalyst concentrations and alcohol-to-oil ratios.

4. DATA ANALYSIS AND INTERPRETATION

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The section below discusses the concentration of catalyst used in the transesterification process in the production of biodiesel from spent cooking oil. Table 1 presents the frequency distribution and matching percentage of batches processed with different catalyst concentrations as a percentage of the oil weight. To maximize the yield of biodiesel, this research helps to identify the most frequently tested and, at the same time possibly ideal catalyst concentration. Additionally, Figure 1 provides a summary of the data distribution in graphical form from the frequency table.

Table 1: Table of Catalyst Concentration Frequencies

Catalyst Concentration (% wt of oil)	Frequency (Number of Batches)	Percentage (%)
0.5	10	10%
1.0	25	25%
1.5	40	40%
2.0	15	15%
2.5	10	10%
Total	**100**	**100%**

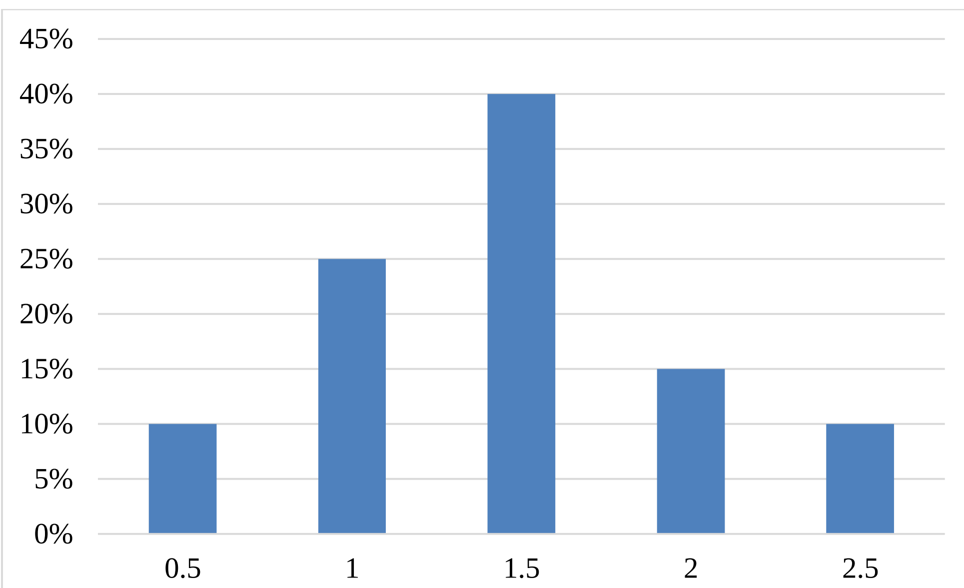

Figure 1: Graphical representation of Table of Catalyst Concentration Frequencies

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The most commonly run catalyst concentration as indicated by the frequency table is at 1.5%, used in 40% of all batches, an indication that 1.5% may be close to an ideal concentration for a biodiesel synthesis. Coming up is 1.0% that was utilised in 25% of batches. Perhaps this concentration had been tested mainly to ascertain its efficiency at much lower levels. 10% of batches contained 0.5% used as a lower limit, while 15% and 10% of batches contained concentrations at 2.0% and 2.5%, respectively, with the latter probably a check of the effects of higher catalyst levels. The overall implications for optimisation suggest more work will be necessary to balance the use of the catalysts with biodiesel yield, as it appears that between 1.0% and 1.5% will be critical.

Table 2. The frequency and percentage distribution of the different alcohol-to-oil ratios used during the transesterification process in biodiesel production. The results above reflect the number of experimental batches performed at every ratio as well as the percentage. From this data, there is an obvious trend where the optimum values preferred certain ratios more than others during optimization.

Table 2: Table of Alcohol-to-Oil Ratio Frequencies

Alcohol-to-Oil Ratio	Frequency (Number of Batches)	Percentage (%)
3:1	15	15%
6:1	35	35%
9:1	40	40%
12:1	10	10%
Total	**100**	**100%**

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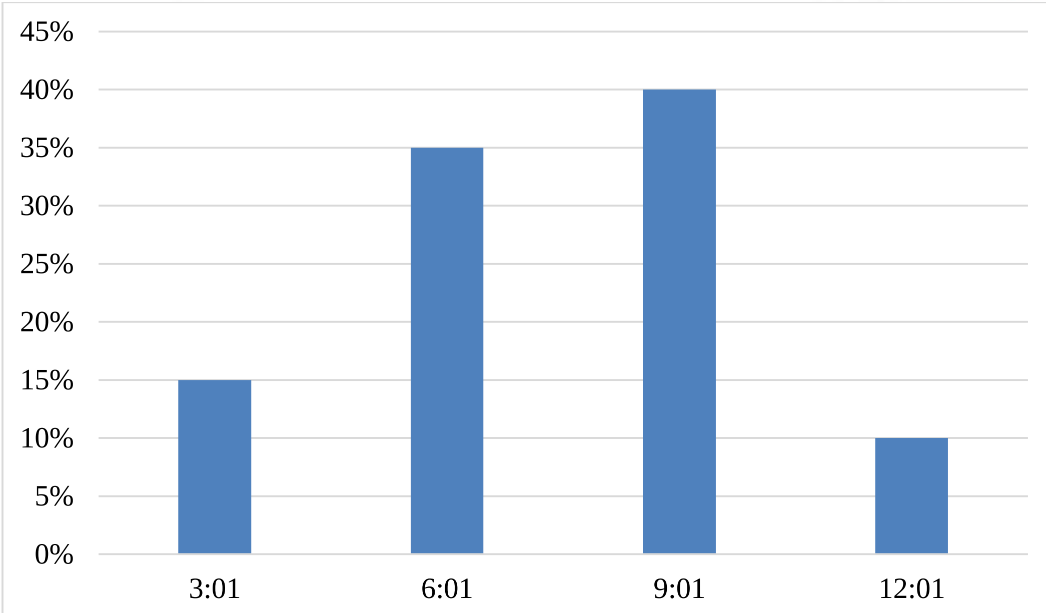

Figure 2: Graphical representation of Table of Alcohol-to-Oil Ratio Frequencies

According to the frequency table, the most commonly tested alcohol-to-oil ratio is 9:1, taking up 40% of all experimental batches. Thus, this could be the optimum ratio to provide the maximum amount of biodiesel. The ratio of 6:1 has been used for 35% of the batches and thus ranked as the second most frequently tested and may be assumed to be viable in certain instances to provide reasonable results. On the other hand, only 15% and 10% of the batches, respectively, tested the 3:1 and 12:1 ratio, which indicates that the transesterification procedure was not very effective or feasible. Overall, the results suggest that the ratio of 9:1 plays a crucial role in optimizing the synthesis of biodiesel.

5. CONCLUSION

This study details an improved transesterification method for producing biodiesel from leftover cooking oil. A catalyst proportion of 1.5 and an alcohol to oil ratio of 9:1 provide the best results when set up as described above. All of these things work together to reduce resource consumption and increase biodiesel output. So, they provide a way to make biodiesel from used cooking oil that is both cheap and good for the environment. The findings further highlight the significance of optimising the alcohol-to-oil ratio and catalyst concentration for biodiesel production. It is believed that these ideal circumstances can increase the amount of waste cooking oil that is accepted as a feedstock for renewable energy solutions.

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