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Recent Advancements in Increasing the Efficiency of the Biodiesel

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ABSTRACT

In light of depleting fossil fuel reserves and rising energy demands, there is a growing demand for renewable energy sources. Biodiesel is one of the prospective alternative energy sources that can be produced from renewable and low-grade sources using various techniques. It has been found to reduce environmental deterioration and improve engine efficiency. Biodiesel production processes have been plagued by numerous obstacles and complications, limiting their predicted advancement. It is produced from a variety of feedstocks using a number of processes, including transesterification, micro-emulsion, direct mixing, and pyrolysis. Transesterification, which uses several catalysts, is the most widely used of these processes. Nanotechnology has led to the creation and modification of nanocatalysts with desirable characteristics such as improved thermal stability, increased surface area, and higher catalytic activity. This review discusses the application of advanced nanotechnology for maximum yield at low cost. This study will also focus on the application of data-based technologies as one of the remedies aimed at deescalating the challenges associated with biodiesel synthesis.

Keywords: Biodiesel, renewable energy, transesterification, nanoparticle, nanotechnology, efficiency, environmental deterioration

Introduction

Despite significant advancements in the efficiency of non-renewable energy sources, the governments of emerging countries are eager to create biofuel. Additional significant factors affecting the increased interest in biofuels include the depletion of global crude oil sources, rising prices, and worries about global warming. These elements greatly motivated the search for alternate renewable fuel sources [1]. The most widely used biofuels include bio-alcohols, biodiesel, bioethers, biogas (Mostly a mixture of CH4 and CO2), biosyngas (a mixture of CO and H2), and high-density biofuels. Due to its many well-known benefits, biodiesel has by far garnered the most interest from the industrial and research sectors among them. In addition to the sustainability advantages of renewability, biodegradability, and low toxicity [2].

1. Feedstocks used in biodiesel production

Oil seeds, soybeans, wheat, rapeseed, potatoes, coconuts, barley, sunflower, sugarcane, sugar beet, and corn are examples of first-generation feedstocks (FGFs), which are food crops. The main barriers, however, are the conflict over whether food or fuel is more important [1]. Despite being renewable, FGF might not be a viable solution to satisfy the world's energy needs because of its disadvantages. Non-edible crops such as lignocellulosic material, cereal straw, sugar cane bagasse, cassava, miscanthus, forest residues, municipal solid wastes, vegetative grasses, Jatropha, and wood were identified in order to find second-generation biofuel feedstocks (SGFs) [3]. Various stages of the usage of SGF for biofuel production are underway. However, the cost of producing ethanol from second-generation biofuel feedstocks is high due to the multiple technological challenges that must be overcome and the need for pilot-scale demonstration facilities (Naik et al., 2010). Second-generation biofuels must be generated utilizing expensive and sophisticated techniques, which continues to be a major hurdle to their commercialization. In order to resolve the issue between using food as fuel and other problems associated with the usage of FGF and SGF, algae were introduced as a third-generation feedstock (TGF) of sustainable biofuel feedstock. [1]. As a sustainable replacement for a sizable portion of fossil fuels, bioethanol and biodiesel made from plants are currently emerging [3].

2. Physicochemical Properties of biodiesel

Before using the fuel in an engine, its physicochemical properties are assessed or experimented with. It is important to make sure the biofuels meet international standards. The basic physicochemical characteristics of plant-based biofuel as well as its thermal characteristics have been outlined by numerous researchers that have studied the fuel. In addition to summarizing the features and their impact on performance, emission, and combustion characteristics, this evaluation is based on the most recent generation of fuels, or (low viscous) LV fuels, used in diesel engines. The physicochemical characteristics of the fuel are affected more strongly by the functional group parameters' influence and the chemical composition of the fuel [4].

2.1 Cetane number

The cetane number determines a fuel's ability to ignite. Hydrocarbon (HC) atoms are the building blocks of all HC fuel. The cetane number of the fuel increases as the number of hydrocarbon atoms in the chain grows; conversely, the cetane number falls as the number of double bonds increases, demonstrating that the cetane number is inversely related to the level of fuel saturation [5]. Since the carbon chains in eucalyptus oil are naturally alicyclic hydrocarbons, these oils have a higher cetane value while having double bonds.

2.2 Kinematic viscosity

It represents the fuel's ability to flow and is the most significant characteristic. Indicating the fuel's resistance to flowing, viscosity also has a significant impact on the fuel's spray qualities, which include its atomization and penetration capabilities. Soot deposits are reduced and thermal efficiency is improved by LV fuels' adequate atomization. The fuel's low viscosity also enhances its penetration ability, allowing for the burning of very small fuel droplets [6].

2.3 Density

The fuel's density serves as a gauge for estimating how much fuel is flowing into the injector. The extraction feedstock and the process of converting LV fuel are two of the most crucial aspects that affect the density of the fuel. The engine's ability to run smoothly is potentially impacted by the fuel density, which also has a significant impact on how the nozzle is designed [7]. The attribute has a direct impact on how the fuel is atomized, which could have an impact on how effectively the engine uses heat. The density of the biodiesel fuel is about 860-890 kg/m2.

2.4 Flashpoint

When fuel vapor is exposed to an ignition source, it flashes, indicating the presence of the flashpoint (FP) property. The property is highly helpful when evaluating the volatile fuel vapor being fired into the combustion chamber [8]. Diesel fuel has an FP of 52– 96 °C, while several biodiesels have an FP of 150 °C. This also denotes the fuel's safety feature. When compared to LV fuels, biodiesel made from low-volatile vegetable oil has a very high FP.

2.5 Calorie Content

The calorific value (CV) of a fuel is the quantity of heat energy released during the burning or combustion of a unit value of the fuel [8]. So, for an (internal combustion) IC engine, the CV of the fuel is a crucial and desirable component. Compared to regular diesel fuel, the CV of LV fuel is lower.

2.6 Boiling point

The boiling point of a substance can be used to calculate its volatility. The temperature at which a material's vapor pressure reaches atmospheric pressure is known as the substance's boiling point. The relationship between a substance's volatility and boiling point is inversely proportional [9]. The bonding of molecules within a chemical or biofuel may also be explained by the BP.

2.7 Biodiesel stability

Both oxidation during storage (in contact with air) and hydrolytic degradation (in contact with water) can have an impact on the quality of biodiesel. The biodiesel's oxidative stability and hydrolytic stability can be used to distinguish between the two procedures. Biodiesel oxidation might take place during storage prior to distribution or within the fuel system of the vehicle itself. Long-term storage stability or aging and stability at high temperatures or pressures while the fuel is pumped through an engine's fuel system are two different aspects of biodiesel stability [10].

3. Methods used to produce biodiesel

The most common technologies that allow us to use various forms of oil and fat feedstock as fuel in diesel engines include the direct use of oils or their blending, micro-emulsion, pyrolysis, and transesterification.

3.1 Pyrolysis

Pyrolysis is a chemical process that results in the cleavage of bonds and the production of a variety of tiny molecules when thermal energy is applied in the absence of air or oxygen or when heat is applied in the presence of a catalyst. The temperature range for pyrolysis is 400–600 °C. Depending on the pace of pyrolysis, the process generates gases, bio-oil, and char.

The pyrolysis process can be split into three subclasses based on the operating conditions: traditional pyrolysis, fast pyrolysis, and flash pyrolysis. For the separation of the different fractions after pyrolysis, distillation equipment is required. Additionally, the final product is less environmentally favourable because it resembles gasoline that contains sulphur. It occasionally produces more gasoline than diesel fuel and some low-value minerals [22].

3.2 Micro-emulsification

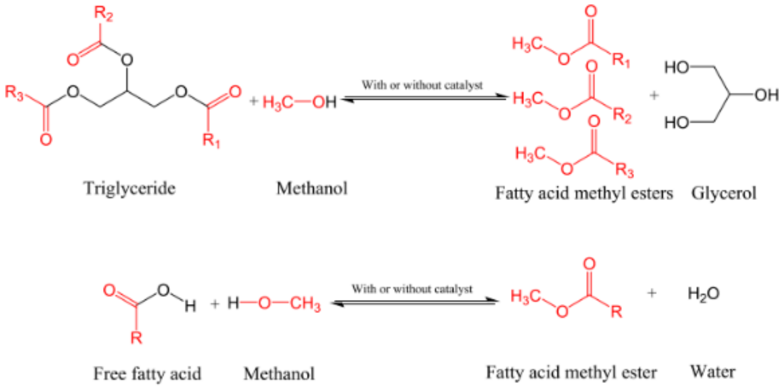
According to Mahanta et al. [21], vegetable oils with an ester and dispersant (co-solvent) or vegetable oils with alcohol, a surfactant, and a cetane improver, with or without diesel fuels, can be used to create micro-emulsions. The maximum viscosity criterion for diesel fuel was reached by all micro-emulsions including butanol, hexanol, and octanol.

3.3 Dilution/Blending

For direct and indirect diesel engines, direct usage of vegetable oils has generally been regarded as unsatisfactory and impracticable. This product has several evident issues, including its high viscosity, acid composition, free fatty acid content, gum development owing to oxidation and polymerization during storage and combustion, carbon deposits, and thickening of the lubricating oil.

3.4 Transesterification

Transesterification is the main convenient method to produce biodiesel from oil and fat feedstock types, which chemically resembles petroleum diesel. Through this method, oils, and fats (triglycerides) are converted to their alkyl esters with reduced viscosity to near diesel fuel levels. This product is thus a fuel with properties like petroleum-based diesel fuel, which enables it to be used in existing petroleum diesel engines without modifications. Generally, transesterification is a reversible reaction that simply proceeds by mixing the reactants usually under heat and/or pressure. However, if some kind of catalyst is added to the reaction, it will be accelerated. As illustrated in Scheme 1, biodiesel can be produced through esterification and transesterification reactions of vegetable oils or animal fats with low molecular weight alcohol in the presence or absence of catalysts (Gardy et al., 2014, 2016, 2017; Likozar and Levec, 2014a; 2016). Transesterification of vegetable oils using homogenous base catalysts produces an estimated 90% of the world's biodiesel Gardy and colleagues (2016).



Scheme 1. Biodiesel production from triglyceride/ free fatty acid (FFA) [20]

4. Nanotechnology

The field of nanotechnology can be broadly defined as the development of molecular-scale machines and devices that are a few nanometers (10^{-9} m) wide, much smaller than a cell. Currently, a variety of nanomaterials, including nanofibers, nanotubes, and nanometals, are used to assess the impact of nanoparticles on the development and production of biofuels/biodiesels [11]

The application of nanotechnology and nanomaterials in biodiesel research has proven to be a practical tool for providing effective ways to improve production quality at an affordable price. Nanoparticles (NPs) have various advantages over biodiesel synthesis due to their small size, unique properties, and qualities, including a high surface area to volume ratio, significant crystallinity, catalytic activity, adsorption capacity, and stability [12].

4.1 Catalysts used in biodiesel production

The speed of the reaction is accelerated by the catalyst, improving the product yield. In order to produce biodiesel, the transesterification process uses a variety of catalysts. However, considering past reviews, these can be categorized into four categories primary groups, including heterogeneous and homogeneous catalysts biocatalysts, nano catalysts, and catalysts. Both homogeneous and heterogeneous catalysis can be used to carry out transesterification or alcoholysis. In general, homogeneously catalyzed processes proceed more quickly and with less loading than those that are heterogeneously catalyzed [19].

4.1.1 Homogeneous catalysts

A series of reactions are catalyzed by a chemical that is in the same phase as the reaction system in homogeneous catalysis. The homogeneous catalyst is the most common catalyst for use in the production of biodiesel because it is easy to use and takes less time to complete the reaction. Catalysts that are both acidic and basic fall into this category. In order to dissolve homogeneous catalysts, the solvent is typically in the same phase as all the reactants.

The complicated and frequently unprofitable process of removing homogeneous catalysts from the media makes it difficult or impossible to reuse them.

4.1.2 Heterogeneous Catalysts

The phases or states of heterogeneous catalysts differ from those of the reactants. These are the kinds of catalysts that frequently produce active sites during a reaction with their reactants (Melero et al., 2009). Because it takes place in a three-phase system with a solid (heterogeneous catalyst) and two immiscible liquid phases (oil and methanol), the heterogeneously catalyzed methanolysis process is extremely complex. Along with methanolysis, other processes including the saponification of glycerides and methyl esters and the catalyst-assisted neutralization of FFAs also take place. The main drawbacks of this catalysis include higher oil/alcohol ratios and higher temperatures than in homogeneous catalysis. Other benefits include improved catalyst reusability, simplicity in separation and purification, and others. Differential catalysts. Acid and base catalysts are two categories of heterogeneous catalysts. According to Di Serio et al. (2008), these catalysts can be categorized as Bronsted or Lewis catalysts. However, both sorts of sites may be present in many circumstances; as a result, some of them may be used as catalysts for both types of reactions.

4.1.3 Biocatalysts

Chemical catalysis is an energy-intensive process that results in undesirable byproducts that make it difficult to separate the desired product from glycerol, di-, and monoacylglycerols. These barriers can be removed by using biocatalysts. Enzymes, usually referred to as biocatalysts, are obtained from living things that facilitate chemical reactions without changing their own chemical makeup (Amini et al., 2017a, b). Extracellular lipases and intracellular lipases are the two main categories of enzymatic biocatalysts that are typically utilized in the manufacture of biodiesel. The enzymes that have been extracted from the microbial broth and purified are known as extracellular lipases. Contrarily, intracellular lipase persists within the cell or in the cell's production walls.

4.1.4 Nanocatalysts

Due to their high catalytic effectiveness, nanocatalysts have recently attracted a lot of attention for the generation of biodiesel (Qiu et al., 2011). These catalysts are more active than traditional catalysts because of their large surface area. These catalysts also have a high surface-to-volume ratio, excellent saponification resistance, high stability, and good reusability (Rahmani Vahid et al., 2017). Before these catalysts can be employed to produce biodiesel, they must first be characterized. To date, various techniques have been employed to accomplish this. X-ray diffraction (XRD) is the technique most frequently employed for characterizing the composition and crystallinity of these catalysts.

5. optimization of the efficiency of biodiesel production using nanomaterial-based catalysts

For the manufacture of biodiesel, Nanotechnology has garnered a lot of interest in recent years (Nizami and Rehan, 2018). Chemical methods for making nano-catalysts include sol-gel, microemulsion, hydrothermal, polyol, and chemical vapor; physical methods include high-energy ball milling, inert gas condensation, laser pyrolysis, pulse vapor deposition flash spray pyrolysis, electro spraying, and melt mixing; and biological methods include microorganism assisted biogenesis, bio templates assisted biogenesis, and plant extracts assisted biogenesis. Numerous nano-catalysts have been studied, including those using alkaline earth metal oxides (Zhao et al., 2013a, b), supported metal oxides (Montero et al., 2010), and magnetic catalysts (Gardy et al., 2018; Ambat et al., 2019; Ghalandari et al., 2019). Recently, several research on surface-modified (impregnation) nanoparticles (NPs) with increased surface acidity/basicity have been reported (Toh-Ae et al., 2014; Radoman et al., 2015). In biodiesel production techniques that utilize inexpensive raw materials with FFAs, it is crucial to create novel catalysts with higher catalytic activity. The advantage of acid-based catalysts is that they can facilitate the simultaneous transesterification of triglycerides and esterification of FFAs without the generation of soap (Lee and Wilson, 2015) [20].

6. Vegetable oil used in the compressed ignition engine

A potential replacement for diesel in IC engines is biodiesel made from vegetable oils. Due to its wide availability in India, eucalyptus oil is a non-edible oil that may serve as a source of biodiesel. Given its high cetane number and lack of sulfur, biodiesel produced from eucalyptus oil is an excellent substitute for traditional diesel fuel.

A mechanical expeller is used to extract oil from seeds. Approximately 60% of the seed's oil content is in the form of cineole. In Fig. 1, a transesterification reaction is depicted. The reaction, which may be basic, acidic, or enzymatic in nature, is typically sped up by a catalyst. Alkyl groups are represented by R1, R2, R3, and R4 [14,17, 18].

A three-necked round bottom flask was charged with 500 ml of oil in a typical experiment, as depicted in Fig. 2 Potassium methoxide catalyst was dissolved in a known quantity of solution.

The oil sample was mixed with the solution and the remainder of the necessary amount of methanol. The flask was placed on a heating mantle after being properly closed. For a sample of eucalyptus oil, the system was maintained at about 50 degrees Celsius. The response time was 60 minutes. The product is divided into two layers, an ester layer, and a glycerol layer, as a result of gravity. Both the ester layer and the glycerol layer are predominately composed of methyl ester and methanol. 24 hours were given for the solution to settle [16].

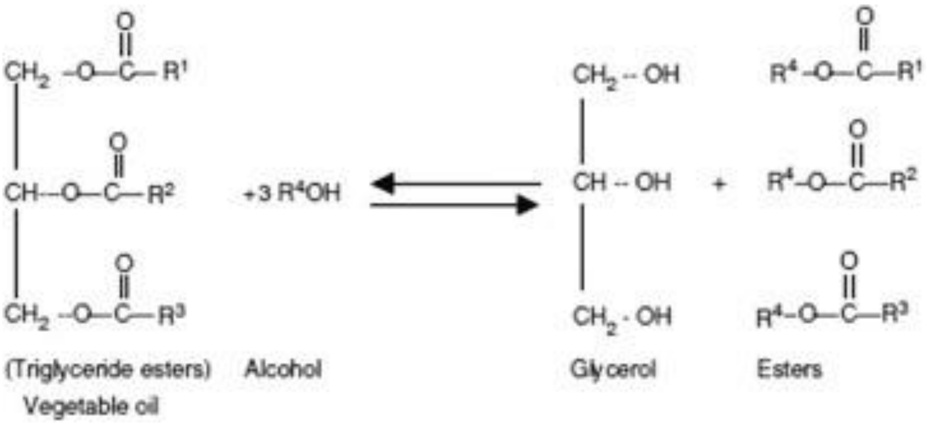


Fig 1. Transesterification of the reaction [14]

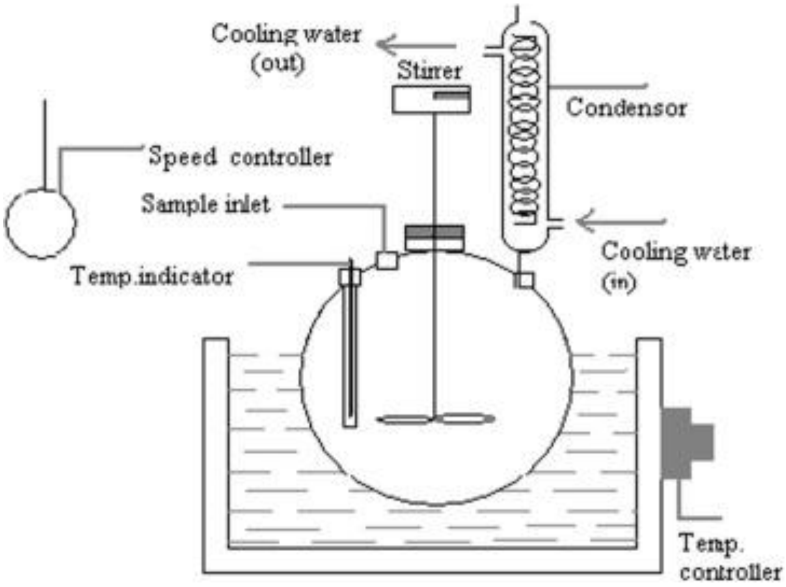


Fig 2. Experimental setup for the transesterification reaction [15]

With the aid of magnetic separation, glycerine, and biodiesel are separated, and the latter is subsequently refined. The yield of biodiesel obtained in this experiment was around 86%.

7. Application of Machine learning (ML) based technology

The development of biodiesel has been constrained by several difficulties and complications in the production process. One of the solutions to defuse the difficulties connected with biodiesel synthesis is the development of data-based technology. Based on the findings of earlier research in the field, techniques for prediction, modelling, and optimization of the biodiesel production process were examined. Diverse techniques, such as Artificial Neural Networks (ANN) (Fig 3), Genetic Algorithms (GA), Linear Regression, Random Forests Regression (RF), and Support Vector Machines (SVM), among others, have been used to monitor, predict, optimize, control, and make decisions in crucial biodiesel research areas as a result of the increased application of ML algorithms. A branch of artificial intelligence known as ANN is a computational network built using neurobiological networks that functions similarly to the human nervous system (Kukreja et al., 2016; Techopedia, 2022).

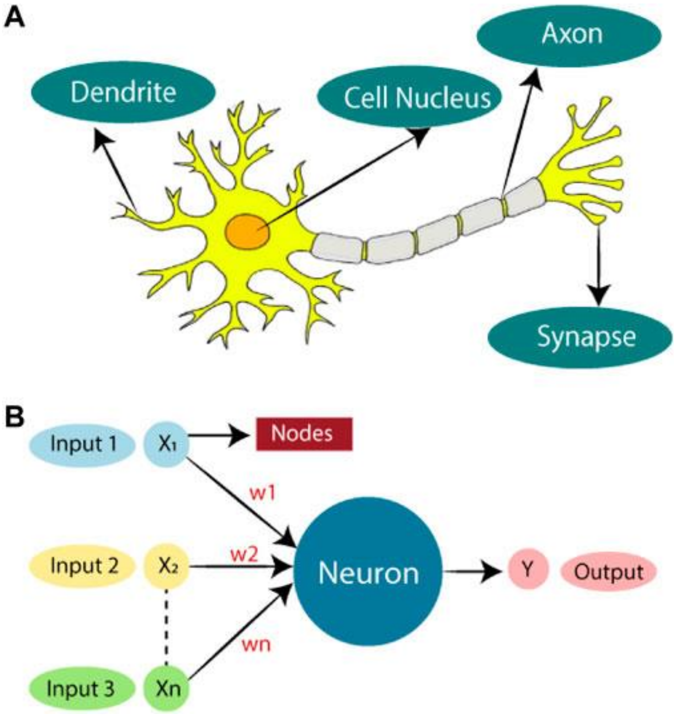


Fig 3. (A) Biological neural network (B) artificial neural network. Adapted from (Java point, 2021).

Data collection, data processing, network architecture construction, training, model testing, and result validation are typically steps in the implementation of ANN models. The key stages to be taken in creating a typical ANN model for biodiesel research were described by Aghbashlo et al. in 2021 (Fig 4). Undoubtedly, the most significant component in determining the success of a successful modelling process is the collection and preparation of data. Enough reliable data must be gathered in order to guarantee the model's effectiveness and integrity (Bali and Singla, 2022). To improve the training process and increase the integrity of the ANN model, the acquired data must be analyzed [13].

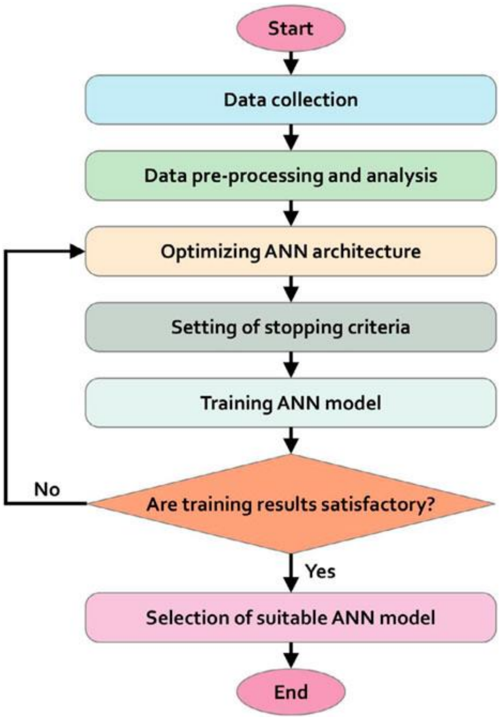
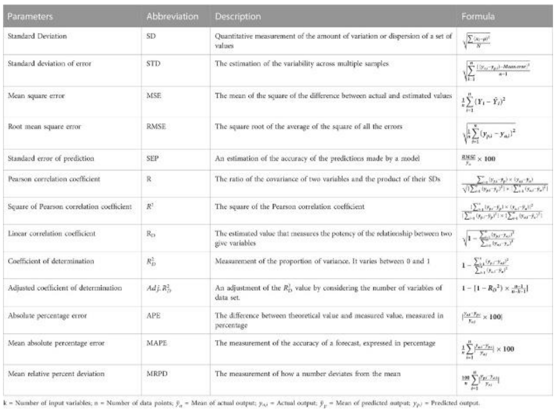


Fig 4. A typical flowchart for ANN model (Aghbashlo et al., 2021).

To make sure the result fits in line with expectations, the accuracy and dependability of the result need to be verified. To gauge the accuracy and dependability of the model output, several statistical measures have been defined, including standard deviation, standard deviation of error, mean square error, root mean square error, square of Pearson correlation coefficient, etc. Some of the statistical measures frequently used to assess the precision and dependability of ANN and other ML models are listed in Table 1.

Table 1. Statistical parameters commonly used in ANN models (Khair et al., 2017; Ofoefule et al., 2019; Galvan et al., 2020).



Parameters	Abbreviation	Description	Formula
Standard Deviation	SD	Quantitative measurement of the amount of variation or dispersion of a set of values	$\sqrt{\frac{\sum (x_i-\mu)^2}{N}}$
Standard deviation of error	STD	The estimation of the variability across multiple samples	$\sqrt{\sum_{i=1}^{n}\frac{[(y_{a,i}-y_{p,i})-Mean\ error]^2}{n-1}}$
Mean square error	MSE	The mean of the square of the difference between actual and estimated values	$\frac{1}{n}\sum_{i=1}^{n}(Y_i-\hat{Y}_i)^2$
Root mean square error	RMSE	The square root of the average of the square of all the errors	$\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_{p,i}-y_{a,i})^2}$
Standard error of prediction	SEP	An estimation of the accuracy of the predictions made by a model	$\frac{RMSE}{\bar{y}_a}\times 100$
Pearson correlation coefficient	R	The ratio of the covariance of two variables and the product of their SDs	$\frac{\sum_{i=1}^{n}(y_{p,i}-\bar{y}_p)\times(y_{a,i}-\bar{y}_a)}{\sqrt{[\sum_{i=1}^{n}(y_{p,i}-\bar{y}_p)^2]\times[\sum_{i=1}^{n}(y_{a,i}-\bar{y}_a)^2]}}$
Square of Pearson correlation coefficient	R^2	The square of the Pearson correlation coefficient	$\frac{[\sum_{i=1}^{n}(y_{p,i}-\bar{y}_p)\times(y_{a,i}-\bar{y}_a)]^2}{[\sum_{i=1}^{n}(y_{p,i}-\bar{y}_p)^2]\times[\sum_{i=1}^{n}(y_{a,i}-\bar{y}_a)^2]}$
Linear correlation coefficient	R_D	The estimated value that measures the potency of the relationship between two give variables	$\sqrt{1-\frac{\sum_{i=1}^{n}(y_{p,i}-y_{a,i})^2}{\sum_{i=1}^{n}(y_{a,i}-\bar{y}_a)^2}}$
Coefficient of determination	R_D^2	Measurement of the proportion of variance. It varies between 0 and 1	$1-\frac{\sum_{i=1}^{n}(y_{p,i}-y_{a,i})^2}{\sum_{i=1}^{n}(y_{a,i}-\bar{y}_a)^2}$
Adjusted coefficient of determination	$Adj.R_D^2$	An adjustment of the R_D^2 value by considering the number of variables of data set.	$1-[1-R_D^2)\times\frac{n-1}{n-k-1}]$
Absolute percentage error	APE	The difference between theoretical value and measured value, measured in percentage	$\lvert\frac{y_{a,i}-y_{p,i}}{y_{a,i}}\times 100\rvert$
Mean absolute percentage error	MAPE	The measurement of the accuracy of a forecast, expressed in percentage	$\frac{1}{n}\sum_{i=1}^{n}\lvert\frac{y_{a,i}-y_{p,i}}{y_{a,i}}\rvert\times 100$
Mean relative percent deviation	MRPD	The measurement of how a number deviates from the mean	$\frac{100}{n}\sum_{i=1}^{n}\lvert\frac{y_{p,i}-y_{a,i}}{y_{a,i}}\rvert$

k = Number of input variables; n = Number of data points; $\bar{y}_a$ = Mean of actual output; $y_{a,i}$ = Actual output; $\bar{y}_p$ = Mean of predicted output; $y_{p,i}$ = Predicted output.

8. Process parameters affecting biodiesel production

Following the selection of raw materials (feedstock, catalyst, and alcohol), manufacturing technique, and reactor, the selection of process parameters is a crucial decision. The characteristics of the manufacturing process have a direct impact on the conversion efficiency, yield, and overall performance of biodiesel production. Alcohol-to-oil ratio, catalyst concentration/dosage, reaction temperature, and reaction time all play important roles in the success or failure of biodiesel synthesis [13].

8.1 Alcohol to oil ratio

The alcohol to oil ratio has a significant impact on conversion efficiency and biodiesel production. The oil and catalyst are dissolved and dispersed in the alcohol during the transesterification process. Alcohol serves as a medium for triglycerides to combine with a catalyst to produce biodiesel and glycerol. As a result, a larger alcohol to oil ratio is required to boost biodiesel yield (Okolie et al., 2022). A very high alcohol-to-oil ratio, on the other hand, might result in excess methanol in the system, resulting in increased production costs, a complex separation and purification procedure, low conversion efficiency, and, ultimately, poor biodiesel yield during the transesterification reaction. In general, methanol-to-oil ratios of 6:1 and 9:1 are indicated as the ideal molar ratios for optimal biodiesel production (Musa, 2016; Abusweireh et al., 2022).

8.2 Catalyst type and concentration

The type and concentration of catalysts used have a significant impact on product quality and purity, production cost, ease of separation and purification, conversion rate, conversion efficiency, and biodiesel productivity. In most cases, higher catalyst concentration/dosage results in better biodiesel yield. Transesterification reactions with insufficient catalyst quantity and concentration proceed slowly, resulting in unreacted feedstock, low-quality biodiesel, and low biodiesel production. Excess catalyst dosage in the transesterification reaction, on the other hand, causes agglomeration, lowers mass and surface interaction among the reactants, and has a major impact on biodiesel yield (Mofijur et al., 2021; Xie and Li, 2023). While most researchers recommend a catalyst dosage of 2-10 wt% to achieve 75% to 100% biodiesel yield, the deployment of appropriate statistical tools to measure the reliability and validity of the ML models is critical to ensuring cost effective and optimal biodiesel yield (Teo et al., 2022; Xie and Li, 2023).

8.3 Reaction temperature

The temperature of a transesterification process influences feedstock conversion, biodiesel output, and reaction kinetics. Increased reaction temperature reduces the viscosity and volatility of the reactants, promotes miscibility of the reacting materials, and improves the molecular interaction between the oil, alcohol, and catalyst. When determining the reaction temperature, the alcohol used should also be taken into consideration. Ethanol appears to tolerate higher temperatures than methanol, the other alcohol widely utilized in transesterification reactions. While ethanol can be heated to around 78°C, the recommended optimum reaction temperature for transesterification reactions involving methanol is 65°C. Operating at temperatures below 65°C results in a slow reaction rate, poor conversion efficiency, and low biodiesel production, whereas raising the reaction temperature over 70°C increases methanol evaporation, lowers the methanol to oil ratio, and impedes the biodiesel synthesis reaction [13].

8.4 Reaction time

The duration of the transesterification reaction is measured by reaction time. Choosing an appropriate reaction time guarantees that enough product is formed and that the whole reaction is completed within the reaction duration. The yield of biodiesel has been seen to rise with reaction time when more time is allowed for the reactions to occur. Elkelawy et al. (2020) and Narowska et al. (2019) showed a corresponding increase in biodiesel production with increased reaction time in a separate investigation. They attributed this trend to the availability of sufficient time to finish the reactions. However, with a longer reaction time, they discovered a decrease in biodiesel production due to the achievement of equilibrium and the activation of soap generation.

8.5 Agitation speed

In any chemical reaction, the intensity with which the reactants are mixed has a substantial impact on the production of the outcome. The reacting materials are combined and agitated during transesterification to ensure that they are well disseminated. Mixing the reacting materials enables improved solubility of the oil in methanol, better reaction at all portions of the reactor, and enhanced product production. Tabatabaei et al. (2019) and Likozar and Levec (2014) investigated the effect of mixing speed on biodiesel yield and discovered that higher mixing speeds result in higher product yield and that a speed of around 400 rpm is best for maximum biodiesel yield. A faster mixing speed promotes soap production and increases energy usage.

9. Conclusion

The need for renewable energy, the growing population, and environmental sustainability has all contributed to rising demand for renewable fuel. A type of liquid biofuel known as biodiesel is a renewable, affordable, biodegradable, and ecologically friendly fuel that can take the place of diesel fuel made from fossil fuels. To ensure the efficient conversion of the varied feedstocks to high-quality biodiesel, several non-linear parameters that were involved in the production of biodiesel must be considered. Factors like the choice of feedstock, the condition of the feedstocks, the choice of catalysts, the technique of conversion, the reaction time, the process temperature and pressure, the speed of stirring or agitation, the molar ratio of alcohol to oil, the concentration and size of the catalysts, the choice of reactor, etc. affects the yield, characteristics, and use of biodiesel as well as conversion efficiency. The usage of standard ML technologies in biodiesel research offers the optimization of biodiesel yield.

The development and deployment of simple, easy-to-use, and robust modern technology for monitoring and controlling the complete biodiesel production environment is required. More training and capacity building are recommended to ensure a better understanding and wider application of technologies throughout the biodiesel value chain, including raw material selection, oil extraction, feedstock pre-treatment, reactor selection and configuration, biodiesel purification and quality assurance, biodiesel utilization, and emission reduction in biodiesel-powered engines. Policies and programs aiming at boosting the production and use of biodiesel for a variety of purposes in order to decarbonize the environment should be adopted and consistently implemented. The government should democratize and promote the use of biodiesel and other biofuels, particularly at the home level, to alleviate the pressure on fossil-based diesel fuels and the associated consequences.

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