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Sensitivity analysis of catalyzed-transesterification as a renewable and sustainable energy production system by adaptive neuro-fuzzy methodology

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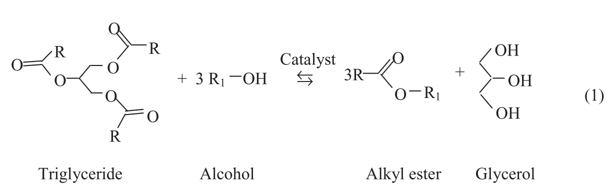
A B S T R A C T

The current study aims at introducing a fast and precise method for analyzing the operation of renewable and sustainable energy systems. Accordingly, ultrasound assisted transesterification as a novel method of biodiesel synthesis and biodiesel synthesis using mechanical stirring were selected as the two main systems for renewable energy production. It is necessary to analyze the parameters which are the most influential on transesterification yield estimation and prediction in order to assess transesterification yield. ANFIS (adaptive neuro-fuzzy inference system) was used in this study for selecting the most influential parameters based on five input parameters (operational variables). The effectiveness of the proposed strategy was verified with the simulation results. Experiments were conducted to extract training data for the ANFIS network. Furthermore, RSM (response surface methodology) was used to design the experiments and analyze the interactive and individual effects of the five independent variables in order to evaluate the results predicted by ANFIS. The obtained results clearly demonstrated the effects of operational variables on the final transesterification yield.

1. Introduction

Only an insignificant amount of primary energy consumed today is supplied renewable sources (5%) such as wind, solar, biomass and geothermal sources, while the fossil-based resources such as natural gas, coal and crude oil account for 24%, 29% and 35% of global energy consumption, respectively. Moreover, a peak of global oil production is expected to appear between 2015 and 2030. Therefore, fossil resources, as the lone source of energy can no longer accommodate global energy requirement in the long run. Aside from scarcity of fossil fuels and their increasing costs, emission from the combustion process is the other challenge. Industries, buildings and transportations are the three largest consumers of energy. Based on the current scenario, the carbon dioxide (CO_2) emissions and the energy consumption by transportations sector between 2015 and 2030 are estimated to be 80% above the levels of today. Such challenges have forced researchers to look for sustainable solutions and develop alternative fuels which promote environmental preservation, higher energy efficiency and sustainable development. Accordingly, biofuels produced from animal fats, oil crops and biomass feedstocks have received much attention. Biofuels offer many benefits over fossil fuels due to their non-toxicity, renewability, biodegradability, availability, less greenhouse gas emissions and contribution to sustainability. Biodiesel is one of the main and most popular biofuels. Traditionally, fatty acid alkyl ester (biodiesel) is produced from transesterification of triglyceride sources with an alcohol (short-chain *i.e.* methanol or ethanol) in the presence of an alkaline or acidic catalyst, as in Eq. (1):



(1)

Poor mass transfer between the reactants on account of their immiscible nature is the major limitation of transesterification,

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Table 1
Analyzing transesterification using ANN-based algorithm method.

Triglyceride Source	Catalyst/ Loading	DOE	No of Data	Synthesis Method	MeOH:oil molar ratio	Temp C	Time min	ANN Algorithm	ANN	RSM	Opt	Ref
Beniseed	Mango, wt% 0.5–0.9	CCRD	30	MS	3:1–7:1	40–60	40–60	QP	99.99	98.85	Y^{*}	[23]
Neem	KOH, wt% 0.5–1.5	CCRD	30	US	3:1–9:1	30–50	10–50	MLBP	99.9	99.1	N	[24]
Fish oil	KOH, wt% 1.25–1.92	CCRD	20	US	6:1–12:1	65	13–47	MLP RBF	99.94 99.45	97.62	Y	[25]
Muskmelon	KOH, wt% 0.5–1.5	CCRD	30	US	3:1–9:1	30–50	10–50	MLBP	99.1	86.9	Y^{*a} Y	[26]
Shea Butter	KOH, v/v 0–0.2	CCRD	30	US	1.7:1–5:1	40–60	45–65	I BP	99.94	99.74	Y^{a} Y	[27]
Sesame	$Ba(OH)_2$ 0.5–2.5 wt%	CCD	2 7	US	4.5–7.5	25–40	20–50	MLBP	99.7	98.0 3	Y^{d} Y	[28]
Jatropha	TPA, wt% 2.5–4.5	CCD	30	US	5:1–25:1	54	10–50	MLBP	96.0	96.1	Y^{a} Y	[29]
Thevetia peruviana	CPP, w/v 1–5	BBD	30	MS	0.09:1–0.3:1	30–70	30–120	IBP	99.99	99.47	Y^{*} Y	[30]
Vinyl acetate	Enzyme, 50–200 PLU	CCRD	27	MS	–	40–60	60–300	IBP. BBP. QP	99.99	99.97	Y^{*} Y	[31]
Polanga	KOH, w/v 0.26–0.44	CCD	26	MS	Et:oil, v/v 0.2:1–.23:1	35–42	45–52	BBP GA	99.99 99.6	99.97	Y^{d} Y	[32]
Chicken fat	KOH, wt% 0.75–1.25	BBD	15	US	4:1–8:1	45	3–9	GA	94.30	–	Y^{*a} Y	[33]
Jatropha	*R. oryzae* lipase, –	CCD	30	Shaking	3:1–7:1	30–50	1–17 h	MLBP	97	98	Y^{*} Y	[34]
Waste goat tallow	H_2SO_4,wt% 40–60	FCCD	15	MW	20:1, 32:1	50–70	2.5 h	MLBP	99.66	99.07	Y	[35]
Neem	KOH, w/v 0.5–1.5	CCD	34	MS	0.11:1–0.2:1	30–70	30–90	GA BBP	99.1 96.17	98.3	Y^{*} Y	[36]
Waste-oil glyceride	Lipozyme 0.42 g/mL	–	70	MS	EtOH:oil 2:1–3:1	38	28 days	MLP-FF	–	–	N	[37]
Caso	NaOH, 0.5–0.9	CCD	30	MS	3:1–7:1	40–60	40–60	QP	99.91	99.83	Y^{*}	[38]
Sunflower	NaOH 0.8–1.2	FFD	456	MS	EtOH:oil 6:1–12:1	30–85	5–15	MLBP	99.40	96.9	Y^{*a} Y	[39]
[A]wco	HA, wt% 5–15	CCD	30	MS	30:1–110:1	55–75	6–22 h	MLBP	98.5	99.87	Y^{*d} Y	[40]
[A]wco	HA, wt% 7.5–12.5	CCD	30	MS	30:1–110:1	55–75	55–75	MLBP	98.5	99.85	Y^{a}	[40]
Soybean	KOH, wt% 1–2	FFD	27	MS	3:1–9:1	40–60	1 h	RB SCG LM GDA	99.52 99.35 99.65 99.34	–	N	[41]
Oleic acid	$BMIM-HSO_4$ 0.025–0.055	CCD	26		5:1–12:1	30–75	2.5–6 h	ANN–GA FFBP	85.4	95%	Y	[42]
Sunflower	KOH, 0.3–0.7(%)	CCD	81		4.5:1–7.5:1	20–40	40–60	MLBP	96.6	75.8	Y^{a}	[43]
Sunflower & Soybean	Enzyme, 1–5 wt%	CCD	321	–	4:1–12:1	50–190	1–5h	MLBP	99.99	–	N	[44]

Note: US: ultrasound transesterification; MS: mechanically stirring; MW: microwave; WCO: waste cooking oil; HA: heteropoly acid; TPA: tungstophosphoric acid; CPP: calcinated plantain peels; CCD: central composite design; CCRD: central composite rotatable design; BBD: Box–Behnken design; FCCD: face centered central composite design; IBP: incremental back propagation; BBP: batch back propagation; QP: quick probability; RB: resilient backpropagation; SCG: scaled conjugate gradient; LM: Levenberg–Marquardt; GDA: gradient descent with momentum; MLBP: Levenberg–Marquardt back propagation; MISO: multi-input single output; MLP: multilayer perceptron network; RBFN: radial basis function network; FFBP: feed-forward back propagation; FF: feed forward; Y: optimization with RSM; Y^{*}: optimization with ANN; Y^{a}: optimizing the number of hidden neurons; Y^{b}: optimum ANN architecture; Y^{d}: analyzing and selecting the best Bp algorithm among ten different.

which strongly affects the reaction yield. Recently, alternative mixing techniques, such as oscillatory flow reactors, centrifugal reactors and separators, static mixers and new energy resources (microwaves or ultrasound) have been proposed to strengthen the mass transfer between reactants during biodiesel synthesis through transesterification [1,2]. Ultrasound technology appears very promising in terms of eliminating mass transfer restrictions due to generation of cavitation bubbles. Cavitation bubbles are desirable micro reactors that enhance mass transfer [3]. Moreover, bubble oscillations and rupturing form micro streams and pressure shock waves generate a fine micro emulsion that improves mass transfer between the reactants. Destruction of bubbles also leads to intensive energy accumulation that generates over-heated and pressurized regions called “hotspots,” which are highly reactive [4,5]. Accordingly, in this study, the novel and traditional method of transesterification for producing biodiesel was analyzed. Apart from the production process or equipment used, accurate analysis and control of the process to make sure that the process is operated under optimum conditions can assist manufacturers to produce biodiesel in a shorter duration, with less alcohol or catalyst consumption and lower cost. Such analytical method should be fast, precise and be able to make prediction from small data sets. Accordingly, ANN (artificial neural network) modeling technique has gained much attention in recent years. ANN has been successfully applied in various biodiesel-related fields (*i.e.* production processes, properties, factors contributing to biodiesel quality and its chemical compositions). Such works have completely been reviewed by Jahirul et al. [6].

Considering the objective of the current study, the most recent works that have used ANN in analyzing the most significant parameters during biodiesel production process are summarized in Table 1. Most researchers have indicated higher accuracy of ANN over RSM in analyzing the process. However, the “black box” approach is the main limitation of ANN approach. In other words,