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An ultrasound-assisted system for the optimization of biodiesel production from chicken fat oil using a genetic algorithm and response surface methodology

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ABSTRACT

Biodiesel is a green (clean), renewable energy source and is an alternative for diesel fuel. Biodiesel can be produced from vegetable oil, animal fat and waste cooking oil or fat. Fats and oils react with alcohol to produce methyl ester, which is generally known as biodiesel. Because vegetable oil and animal fat wastes are cheaper, the tendency to produce biodiesel from these materials is increasing. In this research, the effect of some parameters such as the alcohol-to-oil molar ratio (4:1, 6:1, 8:1), the catalyst concentration (0.75%, 1% and 1.25% w/w) and the time for the transesterification reaction using ultrasonication on the rate of the fatty acids-to-methyl ester (biodiesel) conversion percentage have been studied (3, 6 and 9 min). In biodiesel production from chicken fat, when increasing the catalyst concentration up to 1%, the oil-to-biodiesel conversion percentage was first increased and then decreased. Upon increasing the molar ratio from 4:1 to 6:1 and then to 8:1, the oil-to-biodiesel conversion percentage increased by 21.9% and then 22.8%, respectively. The optimal point is determined by response surface methodology (RSM) and genetic algorithms (GAs). The biodiesel production from chicken fat by ultrasonic waves with a 1% w/w catalyst percentage, 7:1 alcohol-to-oil molar ratio and 9 min reaction time was equal to 94.8%. For biodiesel that was produced by ultrasonic waves under a similar conversion percentage condition compared to the conventional method, the reaction time was decreased by approximately 87.5%. The time reduction for the ultrasonic method compared to the conventional method makes the ultrasonic method superior.

1. Introduction

Approximately 100 years ago, Rudolf Diesel invented the diesel engine, which worked with vegetable fuel [1]. All of the oils have a high viscosity and require specific injection pumps and injectors. When mixing this oil with oil derivatives, the high viscosity problem can be partially solved. Therefore, because of this fuel's advantages, many researchers have attempted to produce biodiesel. Several methods have been used to produce biodiesel fuel, and there are three common methods: microemulsion, pyrolysis and transesterification [2]. Among the mentioned methods, the transesterification method is commonly used for biodiesel production because of its higher yield and lower energy consumption. In recent years, a wide range of studies have been conducted on biodiesel production from feedstock that has a low cost. Frying oils [3–6], new vegetable species [7–9] and animal fats [10–14] have been researched. The last type of low-cost feedstock, which is commonly high in free fatty acids, has not been developed in depth [15]. The free fatty acids (FFAs) can react with alcohol to form esters (biodiesel); this reaction is very useful for the handling of oils that are composed of fats that have high FFAs, as is shown in Eq. (1).

$$\underset{\text{FFA}}{R_1-COOH} + \underset{\text{alcohol}}{ROH} \overset{H+}{\rightarrow} \underset{\text{fatty acid ester}}{R-O-CO-R_1} + \underset{\text{water}}{H_2O} \tag{1}$$

It is typical to employ a 6:1 methanol-to-oil molar ratio during acid esterification, although higher ratios have been used, also [16]. Canakci and VanGerpen used a two-step method, a pre-treatment to reduce the FFAs in yellow grease from 12% (and brown grease from 33%) to less than 1%, and the transesterification reaction was completed with an alkaline catalyst to produce biodiesel [10,11].

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Because of a lack of amalgamation between oil and alcohol, the mixture efficiency is one of the determining factors in the reaction yields [17]. For more agitation and effective surface contact between the alcohol and oil molecules, ultrasonic waves can be used. Ultrasound has proven to be a very useful tool in enhancing the reaction rates in a variety of reacting systems. Ultrasound has successfully increased the conversion, improved the yield, changed the reaction pathway, and/or initiated the reaction in biological, chemical, and electrochemical systems [18–20]. Ultrasound is defined as sound that has a frequency that is beyond the frequencies that the human ear can respond to. The normal range of hearing is between 16 Hz and approximately 18 kHz, and ultrasound is usually considered to lie from 20 kHz to beyond 100 MHz [19,21]. The chemical effects of ultrasound derive from several nonlinear acoustic phenomena, of which cavitation is the most important. Acoustic cavitation is the formation, growth, and implosive collapse of bubbles in a liquid that is irradiated with sound or ultrasound. When sound passes through a liquid, the sound consists of expansion (negative pressure) waves and compression (positive pressure) waves [22]. Under appropriate conditions, acoustic cavitation can lead to implosive compression in such cavities. Such implosive bubble collapse produces intense local heating, high pressures, and very short lifetimes [12,21].

Sonochemistry is generally performed in a liquid medium. During each ‘stretching’ phase (rarefaction), provided that the negative pressure is sufficiently strong to overcome the intermolecular binding forces, a fluid medium can be torn apart, producing tiny cavities (micro bubbles) [23,24]. In the subsequent cycles, these cavities can grow and then collapse violently, and at the same time, there is a release of large amounts of energy. Experimental results have shown that almost 5000 K temperatures and 1000 bar pressures are produced during this collapse (Fig. 1) [24].

Application of ultrasound for soybean oil and methanol treatment with a 100% conversion percentage in 10–20 min has been reported. Ultrasound can also be used to increase the transesterification reaction rate in corn oil, grape seed oil, palm oil and certain other oils [25]. In biodiesel production that uses ultrasonication, ultrasound waves and cavitation phenomenon can increase the mass transfer between the oil phase and methanol, and this transfer can serve as an alternative to mechanical mixing and heating in the conventional method [25]. Biodiesel from animal fats compared with biodiesel that is of vegetable origin has the advantage of having a higher cetane number, which is the most significant indicator of diesel combustion behavior [26]. Artificial intelligence techniques have been utilized for the prediction, control, and optimization of bioprocess systems [27–29]. Genetic algorithms [30] are an artificial intelligence-based stochastic non-linear optimization formalism that is usually used to optimize complex functions. The regression equation is employed as a fitness function for the genetic algorithm (GA), and the GA optimizes the function in accordance with the constraints that are provided. There are several research articles that have reported the implementation of GAs for optimizing a regression equation [31,32].

In this study, the feasibility of biodiesel production from non-edible chicken fat that is usually wasted in poultry slaughterhouses or has been converted to lower economic products with low justification has been investigated. Additionally, the effect of factors such as the alcohol-to-oil molar ratio, the catalyst concentration and the reaction time on methyl ester (biodiesel) production is considered. Experimental results were optimized using the theoretical optimization methods of response surface methodology (RSM) and genetic algorithms (GAs).

2. Materials and methods

To obtain biodiesel fuel, the chicken fat was chopped into small pieces and exposed to an 80 °C temperature. Then, using hexane solvent 4:1 (v/v) and hexane-to-oil at 65 °C, its oil was extracted [33]. Finally, the extracted oil was methylated using the Metcalf standard method (Fig. 2), and the prepared sample was injected into a gas chromatography device to determine the fatty acid profile and molecular weight of the used oil.

For a free fatty acid (FFA) content of more than 1%, the following equations (based on the weight ratio) were used for the titration and calculation of the catalyst rates [34]:

$$\%\mathrm{FFA} = \frac{0/5 \times A \times N \times W_{\mathrm{cat}}}{W} \tag{2}$$

$$\mathrm{KOH(gr)} = \frac{[\%\mathrm{FFA}] \times 0/197}{0/86} + \%1 \tag{3}$$

where A = catalyst volume for oil titration (mL), W = the sample value (g), N = normality, W_{cat} = molecular mass of the catalyst (g), which is 56.1 for KOH.

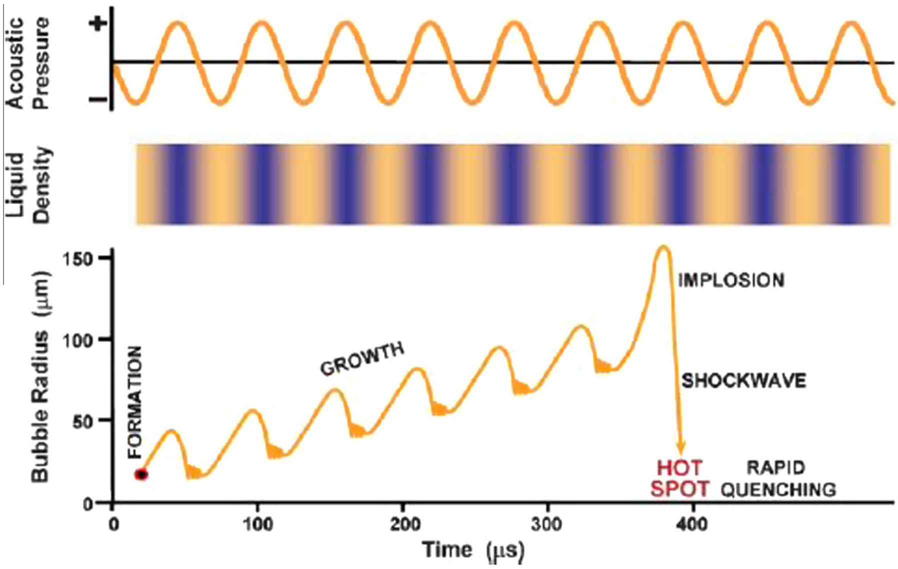

Fig. 1. Schematic representation of acoustic cavitation [24].