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# Preparation of biodiesel with the help of ultrasonic and hydrodynamic cavitation

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**Abstract**

An alkali-catalyzed biodiesel production method with power ultrasonic (19.7 kHz) has been developed that allows a short reaction time and high yield because of emulsification and cavitation of the liquid–liquid immiscible system. Orthogonality experiments were employed to evaluate the effects of synthesis parameters. Furthermore, hydrodynamic cavitation was used for biodiesel production in comparison to ultrasonic method. Both methods were proved to be efficient, and time and energy saving for the preparation of biodiesel by transesterification of soybean oil.


*Keywords:* Biodiesel; Ultrasonic; Hydrodynamic cavitation; Energy consumption

## 1. Introduction

Biodiesel fuel, chemically consisted of fatty acid methyl esters (FAMEs) produced by methanolysis of natural triglycerides, such as animal fats and vegetable oils, is a kind of biomass energy [1]. It is known as an alternative of conventional petrodiesel due to its renewability and better combustion performance [2,3]. The conventional biodiesel technology involves the use of a base or acid catalyst at or near the boiling temperatures of the triglyceride/methanol mixture. In recent years, the researches on enzymatic and supercritical transesterification are active [4,5]. David et al. [6] reported that the methoxide base-catalyzed methanolysis of soybean oil at 40 °C (methanol:oil = 6:1) to synthesize FAMEs proceeded approximately 15 times more slowly than butanolysis at 30 °C. It was interpreted to be the result of a two-phase reaction in which methanolysis occurred only in the methanol phase. So a cosolvent was introduced into the reactants and the methanolysis was improved obviously. Freedam et al. [7] studied the kinetics of sodium methoxide-catalyzed methanolysis of soybean oil and found that the reaction had a low activation energy of 33–83.7 kJ $mol^{-1}$. The interaction of reagents was considered as the determined step of the above process.

It is known that power ultrasonic is a useful tool for strengthening mass transfer of liquid–liquid heterogeneous system [8]. In this process, cavities would be created by the irradiation of power ultrasonic with sufficient energy in the immiscible liquids. As a result, micro fine bubbles are formed. The asymmetric collapse of the cavitation bubbles disrupts the phase boundary and impinging of the liquids creates micro jets, leading to intensive emulsification of the system. Carmen et al. [9] had studied the effect of power ultrasonic of different frequencies on the transesterification reaction of vegetable oils with short-chain alcohols. Hydrodynamic cavitation [10] is another technology developed recently and allows the generation of cavity collapse conditions similar to acoustic cavitation, thereby enabling different applications requiring different cavitational intensities, which have been successfully carried out using acoustic cavitation phenomena but at much lower energy inputs

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as compared to sonochemical reactors. In the present work, power ultrasonic and hydrodynamic cavitation reactors were applied to prepare biodiesel through sodium hydroxide-catalyzed methanolysis of soybean oil. Finally, energy consumption of mechanical stirring (MS), hydrodynamic cavitation (HC) and power ultrasonic (PU) was estimated.

## 2. Methods

### 2.1. Materials

The molecular weight ($M_W$) of soybean oil was calculated from its saponification value (SV) and acid value (AV), and is given in Table 1, Methanol, NaOH, potassium dihydrogen phosphate and other reagents were used as purchased.

### 2.2. Reaction and optimization

The reactions were carried out in an ultrasonic reactor with a jacket, as presented in Fig. 1. The horn of the transducer was submerged 2 cm in the reactive mixture. The temperature of the reaction mixture was controlled by a water bath. Vegetable oil (100 g) was poured into the reactor at the beginning of each reaction for warm-up. The reaction started when a quantitative amount of methanol liquor dissolved in NaOH was poured into the heated reactor. Orthogonality experiments were designed with 4 factors and 3 levels, which are listed in Table 2. Hydrodynamic cavitation system setup is presented in Fig. 2. For cavitation, the process was carried out similar to that described in the literature [11].

Table 1
Properties of the vegetable oil

| Properties | AV (mgKOH/g) | SV (mgKOH/g) | IV ($gI_2$/100 g) | $M_W$ (g/mol) |
|---|---|---|---|---|
| Soybean oil | 0.2 | 193.9 | 129.2 | 868.9 |

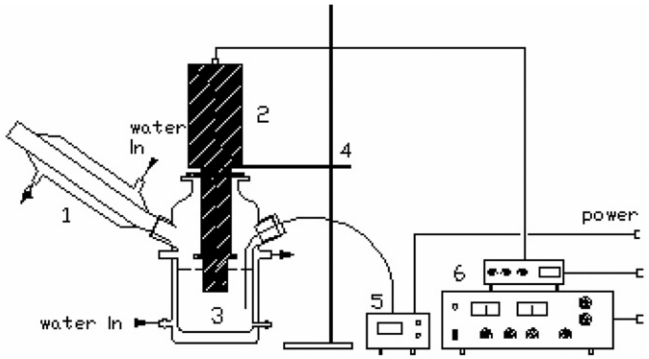


Fig. 1. Schematic diagram of ultrasonic system setup. 1– condensator; 2 – transducer; 3 –ultrasonic reactor; 4 – stand support; 5 – thermometer; 6 – ultrasonic generator.

Table 2
Orthogonality experiments design

| Factor | A, power/W | B, molar ratio | C, pulse frequency | D, temperature/°C |
|---|---|---|---|---|
| I | 100 | 3:1 | 0.4 | 25 |
| II | 150 | 4.5:1 | 0.7 | 35 |
| III | 200 | 6:1 | 1.0 | 45 |

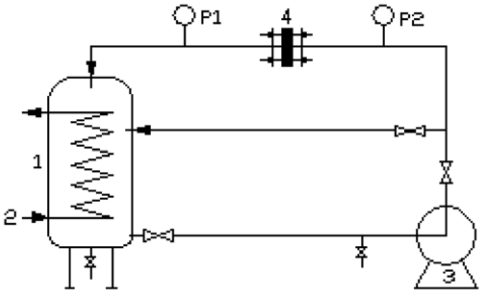


Fig. 2. Schematic diagram of hydrodynamic cavitation system setup. 1– tank; 2 – cold water; 3 –pump; 4 – orifice plate.

### 2.3. Analysis

Samples were analyzed by a capillary gas chromatograph (GC) with a FID detector.

## 3. Results and discussion

### 3.1. Orthogonality experiments

FAMEs yields in 30 min and orthogonality analysis are listed in Table 3. According to range magnitude of the factors surveyed, substrate molar ratio was the primary factor, while temperature and pulse frequency of ultrasonic were secondary. The order of the effect on FAMEs yield of the factors was substrate molar ratio > temperature > pulse frequency > ultrasonic power. In this study, the optimal reaction conditions might be 6:1 substrate molar ratio, 45 °C, continuous ultrasonic and 150 W ultrasonic power.

The stoichiometric substrate molar ratio was 3:1. But in this case, FAMEs yield was low. To obtain a high yield, the substrate molar ratio must be increased [12]. Continuous ultrasonic (pulse frequency = 1) could induce strong emulsification of the methanol–oil phases in a short time. During the experiments, it was observed that higher the ultrasonic power, shorter was the entire mixing time. As presented in Table 3, continuous ultrasonic could give a short reaction equilibrium time of 10–20 min and almost 100% yield under 6:1 substrate molar ratio. Pulse ultrasonic (pulse frequency < 1) was proved to be an efficient way to save energy and enhance mass transfer [13]. But as pulse frequency was lower than 0.7, macro-stirring effect of the ultrasonic was too mild to mix the immiscible reactants well. However, in the case of ultrasonic power of 200 W, the yield of FAMEs decreased. The possible reason was that methanol