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Biodiesel production via peanut oil extraction using diesel-based reverse-micellar microemulsions

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ABSTRACT

Vegetable oils have been studied as a feasible substitute for diesel fuel, and short term tests using neat vegetable oils have shown results comparable to those of diesel fuel. However, engine problems arise due to the high oil viscosity after long-term usage. Vegetable oil/diesel blending as biodiesel fuel has been shown to be one technique to reduce vegetable oil viscosity. The goal of this research is to demonstrate the feasibility of producing this biodiesel fuel via vegetable oil extraction using diesel-based reverse-micellar microemulsions as an extraction solvent. In this extraction technique, peanut oil is directly extracted into the oil phase of the microemulsion based on the "likes dissolve likes" principle and the product of the extraction process is peanut oil/diesel blend. The results show that diesel-based reverse micellar extract oil from peanuts more effectively than both diesel and hexane alone under the same extraction condition. An extraction efficiency of 95% was achieved at room temperature and short extraction time of 10 min in just a single extraction step. The extracted peanut oil/diesel blend was tested for peanut oil fraction, viscosity, cloud point and pour point, which all meet the requirements for biodiesel fuel.

1. Introduction

Concerns over current energy shortages and environmental restrictions have raised interest in the development and use of non-petroleum-based renewable fuels. Vegetable oils are one option being considered for use as renewable fuels as they have been shown to have a performance comparable to that of diesel fuel [1–4]. However, long-term usage of vegetable oils in diesel engines causes engine durability problems such as injector coking and ring sticking [5]. These problems are mainly due to the high viscosity of vegetable oils [6–8]. Several methods have been evaluated for reducing the viscosity of vegetable oils including: a dilution technique in which vegetable oils are blended in small portion with diesel; a microemulsion technique in which microemulsions with vegetable oils or blends of vegetable oil and diesel are formed with or without additives such as methanol, ethanol, or butanol; and a biodiesel technique, in which vegetable oils are cracked and converted into their esters or biodiesels [6,7,9]. In this research, we focus on the extraction of peanut oil using reverse micellar (water-in-oil or W/O) microemulsions of diesel to produce a blend of peanut oil and diesel as a technique to extract oil from the seeds (in place of hexane) while reducing the viscosity of the extracted peanut oil for biodiesel application.

Due to the limited effectiveness of mechanical pressing alone [13], hexane extraction of oilseeds is commonly used for the separation of oil and meal products in vegetable oilseeds [10–12]. Other methods of extracting oil from oilseeds include aqueous extraction [14,15], aqueous-microemulsion based extraction [16,17], enzymatic aqueous extraction [18] and reverse micellar extraction [19]. Among these methods, which are often used to extract oil for cooking purposes, solvent extraction using hexane has been the most popular method that gives high oil extraction efficiency [10,11]. However, hexane is toxic and hazardous, and thus requires airtight and leak-proof equipments as well as highly-skilled labor. Therefore, in this research, we used reverse-micellar microemulsions of diesel as the extraction solvent to extract oil from peanut seeds into the oil phase of the microemulsion to produce blends of peanut oil and diesel. This work extends our previous research [16,17] by (1) using reverse-micellar microemulsion (W/O) based extraction versus aqueous-microemulsion based extraction before and (2) the result of the extraction process is a low viscosity fuel itself in this work while in the previous work the result was a separate vegetable oil phase requiring additional processing to reduce viscosity.

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Several research groups have studied the simultaneous extraction of vegetable oil and proteins by using reverse micelles, but their work focused primarily on the extraction of proteins [19,20]. In their work, the oil extraction mechanism was based on the solubilization of vegetable oil in the reverse-micellar microemulsion of isooctane and of protein in the water pool of the reverse micelles. However, in our work, the extraction product was not edible oil [19,21], but instead was a blend of vegetable oil and diesel that can be used as biodiesel fuel.

A number of researches have studied the feasibility of using vegetable oil/diesel blends or their W/O microemulsions as diesel fuels [6,7,9,22]. In these studies, it was shown that vegetable oil/diesel blends with a ratio of up to 20% of vegetable oil or W/O microemulsions with a ratio of vegetable oil/diesel of up to 40% of vegetable oil can be used in diesel engines without modification. Therefore, based on these findings, we aim to produce blends of vegetable oil and diesel or their W/O microemulsions via the extraction process.

The proposed mechanism of vegetable oil extraction using reverse-micellar microemulsions is based on the "like dissolves like" principle, which is similar to that of solvent extraction technology. This principle means that a polar solute is more soluble in a polar solvent while a non-polar solute is more soluble in a non-polar solvent [11]. Reverse-micellar microemulsions have oil as the continuous phase and water as the inner core of the micelles. As a result, vegetable oil is extracted directly into the oil phase and/or into the hydrophobic core of the reverse micelles while the protein is simultaneously extracted into the water pools of the micelles [19]. Besides having a similar number of steps in the extraction process, a notable advantage of this method is reduced emulsion formation and thus requires fewer refining steps compared to those in edible oil extraction.

Microemulsions are thermodynamically stable emulsions that contain water and oil domains separated by surfactant films [23]. Microemulsions can exist in four forms as the well known Winsor-Type microemulsions. Winsor-Type I (oil-in-water or O/W) microemulsions solubilize oil into spherical, normal micelles within the continuous water phase while Type II (water-in-oil or W/O) microemulsions solubilize water in reverse micelles which occur in the oil phase. Type III (middle phase) microemulsions exhibit three phases, excess oil and water phases in equilibrium with a bicontinuous phase when lamellar micelles are formed in the system [24]. In a middle phase microemulsion, increasing surfactant concentration causes the volume of the middle phase to increase until all the oil and water coexists in a Type IV single phase microemulsion [23]. This study will use Type II water-in-oil (W/O) microemulsions as the extraction solvent to extract vegetable oil to produce a blend of vegetable oil and diesel.

The overall goal of this research is to extract oil from peanuts using W/O microemulsions of diesel to produce blends of vegetable oil and diesel for biodiesel application. We hypothesize that the extraction of oilseeds using reverse-micellar microemulsions is based on the "like dissolve like" principle and thus will extract vegetable oil directly into the oil phase of the microemulsion because oil is the continuous phase of W/O (reverse micelle) microemulsions. Thus, there are four objectives: (1) to formulate diesel-based W/O microemulsions; (2) to compare the oil extraction efficiency using diesel as the solvent versus formulated diesel-based W/O microemulsions; (3) to study the effects of various extraction parameters such as solid-to-solvent ratio, extraction time, extraction shaking speed and extraction temperature on the oil extraction efficiency; and (4) to analyze the quality of the extracted oil blends as biodiesel including the viscosity, the fraction of peanut oil and diesel, the free fatty acid and the cloud and pour point of the fuel.

2. Materials and methods

2.1. Materials

Biosurfactants were chosen in this work to illustrate the ability to achieve our goal of a surfactant-based system and also to demonstrate that if we can achieve our goal with the limited selection of biosurfactants, it will be even easier to do so with the abundant choice of conventional surfactants. Biosurfactants used in this research are rhamnolipid and sophorolipid. Rhamnolipid (JBR) biosurfactant was purchased from Jeneil Biosurfactant Co. (Saukville, Wisconsin) with 15 wt.% active and an average molecular weight of 577. Rhamnolipid biosurfactant was originally a blend of 50 wt.% monorhamnolipid (MW = 504) and 50 wt.% dirhamnolipid (MW = 650) as shown in Fig. 1a and b [25]. Sophorolipid (SPL) biosurfactant was synthesized and donated by the United States Department of Agriculture (USDA) with highly purity (∼100 wt.% active) and specific molecular structure as shown in Fig. 1c [26]. In addition, soy bean lecithin, sodium bis(2-ethyl) dihexyl sulfosuccinate (SBDHS) (Fisher Scientific), and oleyl alcohol (Sigma Aldrich) were also used (see Table 1).

In this study, peanuts were used as the oil seed to investigate the oil recovery efficiency of diesel-based reverse-micellar microemulsion extraction. Peanuts were purchased from America's Best Nuts Co. (Rocky Mountain, North Carolina) as blanched. Peanut oil

Table 1
Surfactants used in this work.

Surfactants	Molecular weight
Rhamnolipid (JBR)	577
Sophorolipid (SPL)	688
Lecithin	770
Sodium bis(2-ethyl) dihexyl sulfosuccinate (SBDHS)	445
Oleyl alcohol (OA)	268

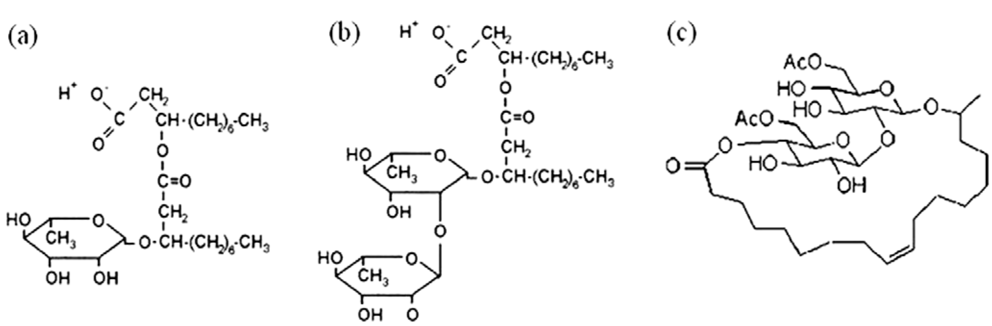

Fig. 1. Structures of the rhamnolipids: (a) monorhamnolipid, (b) dirhamnolipid (adapted from [25]) and (c) Sophorolipid (Ac = Acetyl) (adapted from [26]).