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Review of biodiesel composition, properties, and specifications

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ABSTRACT

Biodiesel is a renewable transportation fuel consisting of fatty acid methyl esters (FAME), generally produced by transesterification of vegetable oils and animal fats. In this review, the fatty acid (FA) profiles of 12 common biodiesel feedstocks were summarized. Considerable compositional variability exists across the range of feedstocks. For example, coconut, palm and tallow contain high amounts of saturated FA; while corn, rapeseed, safflower, soy, and sunflower are dominated by unsaturated FA. Much less information is available regarding the FA profiles of algal lipids that could serve as biodiesel feedstocks. However, some algal species contain considerably higher levels of poly-unsaturated FA than is typically found in vegetable oils.

Differences in chemical and physical properties among biodiesel fuels can be explained largely by the fuels' FA profiles. Two features that are especially influential are the size distribution and the degree of unsaturation within the FA structures. For the 12 biodiesel types reviewed here, it was shown that several fuel properties – including viscosity, specific gravity, cetane number, iodine value, and low temperature performance metrics – are highly correlated with the average unsaturation of the FAME profiles. Due to opposing effects of certain FAME structural features, it is not possible to define a single composition that is optimum with respect to all important fuel properties. However, to ensure satisfactory in-use performance with respect to low temperature operability and oxidative stability, biodiesel should contain relatively low concentrations of both long-chain saturated FAME and poly-unsaturated FAME.

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1. Introduction

1.1. Background

Interest in biodiesel is continuing to increase in the U.S. and throughout the world. This is motivated primarily by: (1) concerns about greenhouse gas (GHG) emissions and global climate change, (2) a desire for renewable/sustainable energy sources, and (3) an interest in developing domestic and more secure fuel supplies. In recent years, several countries (and states) have embarked on legislative and/or regulatory pathways that encourage increased use of biodiesel fuel – using both incentives and prescriptive volumetric requirements. For example, in the U.S., the Energy Independence and Security Act (EISA) of 2007 established a 0.5 billion gallon/year (bg/y) requirement for biomass-based diesel fuel in 2009, with this amount increasing to 1.0 bg/y by 2012 [1].

With the biodiesel landscape being in a state of rapid flux, the Coordinating Research Council (CRC) recently sponsored Project AVFL-17 to define the state-of-knowledge regarding biodistillates as blendstocks for transportation fuels. Utilizing an extensive literature review, this project investigated numerous topic areas, including policy drivers, fuel volumes and feedstocks, production technologies, fuel properties and specifications, in-use handling and performance, emissions impacts, and life-cycle analyses. Results of this literature review are available in a project final report [2] and in a series of papers derived from this report [3–5].

More recently, CRC sponsored an updated review of the biodistillate literature. In this case, the focus was on biodiesel – as opposed to the broader category of biodistillate fuels – and was limited to fewer specific topic areas. The complete final report from this updated study is available from the CRC website [6]. The subject of this paper is limited to a review of biodiesel compositions and properties, and the relationships between composition and properties.

1.2. Definitions

Biodiesel is defined by ASTM as "a fuel comprised of monoalkyl esters of long-chain fatty acids derived from vegetable oils or animal fats, designated B100" [7]. Congress has adopted a similar definition for "biomass-based diesel," with the additional requirement that the fuel have life-cycle greenhouse gas (GHG) emissions that are at least 50% less than baseline life-cycle GHG [1]. The vegetable- and animal-derived feedstocks used to produce biodiesel are known as triacylglycerides (TAGs), or more simply, triglycerides. Biodiesel is produced by a chemical process known as transesterification, by which the triglycerides are reacted with alcohols, in the presence of a catalyst, to produce fatty acid alkyl esters. A byproduct of transesterification is glycerine, also known as glycerol. Since the most common alcohol used to produce biodiesel is methanol, another name for biodiesel is fatty acid methyl esters (FAME). Unless otherwise indicated, the term "biodiesel" refers to neat material – i.e. 100% FAME, often designated as B100. Lower concentrations, such as B20, are properly referred to as "biodiesel blends," not biodiesel itself.

Renewable diesel fuel (also known as Green Diesel) is produced by catalytic hydroprocessing of the same triglyceride feedstocks used to produce biodiesel [8,9]. In this process, an alcohol is not required, the products are hydrocarbons rather than fatty acid alkyl esters, and no glycerol byproduct is formed. The general term "biodistillate" is used to refer to both biodiesel and renewable diesel.

Terminology regarding "1st Generation" and "2nd Generation" biofuels are in popular usage, but have no legal or regulatory meaning. Generally, the term "1st Generation" refers to biofuels produced from commonly available, edible feedstocks using well-established conversion technologies. Most biofuels in use today are classified as 1st Generation. This includes ethanol produced via fermentation of sugars (from corn, sugar cane, sorghum, etc.) and biodiesel produced via transesterification of triglycerides (from vegetable oils and animal fats). The term "2nd Generation" can refer to biofuels produced from either advanced, non-food feedstocks, or produced via advanced processing technology (or both). Examples of advanced feedstocks include lignocellulose and non-edible triglycerides (such as jatropha and algae). Examples of advanced processing technology include catalytic hydroprocessing of triglycerides to produce renewable diesel, and thermal conversion (gasification and pyrolysis) of lignocellulose. Because of their imprecise and variable meanings, this paper avoids use of the terms 1st Generation and 2nd Generation (and related terms).

2. Biodiesel composition

Biodiesel fuel can be produced by transesterification of virtually any triglyceride feedstock. This includes oil-bearing crops, animal fats, and algal lipids. The literature contains hundreds of references of biodiesel production from a wide variety of feedstocks. At present, however, the dominant feedstocks are soybean oil in the U.S., rapeseed oil in Europe, and palm oil in southeast Asia [2,10]. Animal fats (especially beef tallow) and used cooking oil (also called yellow grease) represent significant niche markets