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# Emulsification of animal fats and vegetable oils for their use as a diesel engine fuel: An overview

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ABSTRACT

Vegetable oils and animal fats represent promising alternatives to diesel engine fuel because they can be obtained from different feedstocks and renewable sources; also their properties are close to diesel fuel. The direct use of these biofuels as a diesel engine fuel can cause several problems in engine performance and emissions. In order to obtain a more engine-friendly fuel, it is necessary to change the biofuels' properties for which different methods have been used. One of the possibilities is using emulsification techniques in order to obtain emulsified biofuels (emulsions or microemulsions); through this method it is possible to lower viscosity and improve the atomization. However, emulsification techniques applied to vegetable oils and animal fats have not been studied thoroughly. For this reason, this paper presents an overview on the formulation and characterization of the emulsified biofuels using vegetable oils and animal fats, as well as the main experimental results reported about its use as a diesel engine fuel in the scientific literature.



**Contents**



## 1. Introduction

Diesel engines are mainly used in industrial, transport and agricultural applications due to their high efficiency and reliability [1].

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The development of internal combustion engines followed a dual strategy over the past years: improvement of engine performance and reduction of pollutant emissions [2]. However, diesel engines remain an important source of pollution, due to their emissions: black smoke, hydrocarbons (HC), nitrogen oxides ($NO_x$), particulate matter (PM), sulfur oxides ($SO_x$) and carbon monoxide (CO).

On the other hand, the increasing petroleum price and environmental concern due to global warming has accelerated the search for renewable fuels for diesel engines [3]. In addition, the fossil fuel demand is continuously increasing the depletion of fossil fuel stocks [4]. Researchers as Ashraful et al. [5] indicate that global energy demand is increasing dramatically, e.g. in 1980, fuel consumption was 6630 million tons of oil equivalents (Mt), it almost doubled in 2012 to 12,239 Mt; according to the International Energy Agency estimation, the global energy demand is expected to increase by 53% by 2030. For this reason, one of the new challenges for the twenty-first century is to find solutions in order to reduce the exhaust emission and dependency on fossil fuels.

Current limitations of fuel resources and restrictions on environmental pollution have directed research programs worldwide to introduce new techniques and methodologies that not only ensure rationalization of fuel consumption but also keep emissions at ultra-low levels from different combustion devices [6]. This situation has motivated the scientific community around the world to study alternative fuels, specifically biofuels. However, biofuels will only be beneficial if they are cultivated in a sustainable way with both biodiversity and the "food vs. fuel" debate in mind [7]. Therefore, it is important that researches are carried out on biofuels obtained from non-edible crops, non-edible vegetable oils and waste products.

Researchers as Tan [8] and Senthil [9] pointed out that animal fats and vegetable oils represent promising alternatives to conventional fuel (diesel fuel) because of their very similar properties. Vegetable oils and animal fats can be obtained from different alternative sources around the world (such as non-edible feedstocks). The non-edible vegetable oils are natural liquids and according to No [10] present advantages as fuels such as: availability, renewability, biodegradability, lower sulphur content and aromatic content. The disadvantages of non-edible vegetable oil as a diesel fuel are higher viscosity, low volatility, the reactivity of unsaturated hydrocarbon chains, and higher percentage of carbon residue [10]. These advantages and drawbacks can be extended for animal fats.

The direct use of these biofuels in diesel engines causes several problems such as a less efficient combustion process due to the poor atomization process and changes in the ignition delay. Researchers as Meher et al. [11] indicate that due to the high viscosity and lower volatility of the vegetable oils and especially animal fats, the formation of deposits in engines can be expected, due to incomplete combustion and improper vaporization characteristics. These problems are associated with the large triglyceride molecules and their high molecular mass [11].

In order to obtain an economic and environment-friendly engine fuel from renewable feedstocks such as vegetable oils and animal fats, it is necessary to change the biofuels' properties such as: viscosity, surface tension, free fatty acids, phospholipids, sterols, odorants, moisture content, etc. For this reason, different methods have been used, such as preheating, blending, dual fuel operation, transesterification, cracking/pyrolysis and emulsification.

Among these methods previously mentioned, blending and dual fuel operation with diesel fuel only partially solves the problems with the physical–chemical properties and their negative effects on the engine. A dual fuel engine also needs modifications in the engine's design [12]. In addition, dual fuel operation with alcohol induction has been reported to result in higher emissions (HC and CO) [12] and lower performance [13]. Though blending of oils with alcohols is a simple process, significant improvements in performance and emissions are not reported in the literature [12]. In spite of blending methods having been experimented with for nearly 100 years, according to Abbaszaadeh et al. [14] the use of blends of vegetable oils and/or direct use of vegetable oils has generally been considered to be not satisfactory and impractical for both direct and indirect diesel engines.

Researchers as Senthil et al. [12] stressed the advantage of the fuel preheating technique such as easy conversion of the normal diesel engine to work on highly viscous fuels, needing no modification of the engine. In addition, investigations reported that preheated animal fat and vegetable oils in diesel engines resulted in improved brake thermal efficiency and reduced smoke and particulate emissions [12,15,16]. Nevertheless, the preheated method is not a generalized practice fundamentally because an external heating system is necessary which means an additional cost and installation (thus, recommended only for stationary engines).

Another possibility is the pyrolysis of triglycerides to obtain products suitable for diesel engines[17–22], with physical–chemical properties comparable to those specified for petroleum based fuels [14]. However, it is important to take into account that mechanisms for the thermal decomposition of triglycerides are likely to be complex, because of the many structures and multiplicity of possible reactions of mixed triglycerides [14]. Also, the equipment for thermal cracking and pyrolysis is expensive for modest throughputs [14]. In addition, while the products are chemically similar to petroleum-derived gasoline and diesel fuel, the removal of oxygen during the thermal processing also removes any environmental benefits of using an oxygenated fuel [14].

Transesterification is the most common method applied to vegetable oils and animal fats in order to obtain a friendly engine diesel fuel (commonly named biodiesel). Biodiesel is used as engine diesel fuel (blended or neat) and cetane improver. Its physical–chemical properties are comparable with diesel fuel and in some cases are standardized (e.g.: ASTM D6751, EN 14214, etc.). Several investigations have been developed about biodiesel production from different feedstocks [23–27] and their engine performances and exhaust emissions [5,28–34]. Despite its many advantages as a renewable alternative fuel, biodiesel presents a number of problems that must be resolved before it will be more attractive as an alternative to petroleum diesel (e.g.: lower volatility and heating value, poor low-temperature properties, higher $NO_x$, plugging of the fuel oil filter and blocking of the fuel injector) [35].

Transesterification is a complex and cumbersome process [12] and depending on the quality of the feedstock (free fatty acids and water percentage) different steps are necessary. The cost of biodiesel is the major hurdle to its commercialization in comparison to petroleum diesel. The raw material cost, i.e. the cost of the oil feedstock amounts to about 60–70% of the production cost [35,36]. The biodiesel production is an expensive process and its cost it also affected by the price of catalysts (expensive and difficult to recover), specific equipment (reactors, centrifuges, separators, etc.) and instrumentation. These drawbacks were also noticed by Atmanli [37] and Agarwal [38]. During the transesterification, it also results in certain by-products such as glycerol which cannot be used as fuel in engines [13].

The formulation of emulsified biofuels is a potential solution for solving technical efficiency problems associated with the high surface tension and viscosity of vegetable oils and animal fats. The effects of the emulsified fuels on the engine performance (see Section 5.1) are different from one study to another [39]. The physical–chemical properties of emulsified fuel also play a decisive role in the behaviour of the engine performance and exhaust emissions. Nevertheless, a lot of researches [12,13,40–53] reported important reductions in exhaust emissions (e.g.: $NO_x$) compared with diesel fuel and other methods to use biofuels in diesel