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# Blending scenarios for soybean oil derived biofuels with conventional diesel

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## ARTICLE INFO

### Article history:

Received 2 September 2011

Received in revised form

29 November 2012

Accepted 5 December 2012

Available online 11 January 2013

### Keywords:

Hydrogenation

Cetane number

Lubricity

Diesel engines

Biofuels

## ABSTRACT

Binary and ternary blends of fossil diesel fuel, conventional biodiesel and hydrotreated vegetable oil (HVO), both derived from soybean oil, have been proposed as a means to increase the fraction of renewable energy in automotive fuels and to boost the blending possibilities depending on the desired fuel characteristics. Biofuels can be obtained in a specialized bio-refinery for a combined production of biodiesel and HVO or in a conventional refinery (with savings of costs as a consequence of the already existing installations). Two examples of these scenarios have been set out, and the most important physical and chemical properties of the final fuel blends measured and compared. The results proved that fuel properties depend greatly on the scenario considered, and consequently the biofuel production path must be carefully decided if the fuel potential is to be fully exploited. While a simultaneous production of HVO-diesel and a later blend with biodiesel fuels produced a neutral fuel in terms of cetane number and sooting tendency, the combined production of HVO-biodiesel to be afterwards blended with fossil diesel fuel is able to change the cetane number from 45 to 65, approximately, and reduce soot by roughly 30%.

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## 1. Introduction

Biofuels have been promoted during the last decade by governments as a mean to reduce oil dependence and greenhouse emissions. Mandatory targets for 2020 have been set worldwide [1,2]. For the long term, according to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050 [3]. To reach this objective, an increasing contribution of second-generation biofuels (derived from lignocellulosic biomass) is expected. However, commercial-scale production costs of second-generation biofuels have been estimated to be

at least 1 \$ kg<sup>-1</sup> for synthetic diesel, and in fact there are no second-generation biofuels commercially available yet [4]. Meanwhile, soybean oil became the major oil feedstock for the production of biodiesel fuels, although recently other feedstocks have gained market share because neither the soybean ecological sustainability (it reduces GHG from 40% [1] to around 50% [5]) nor the economical output of its biodiesel production pathway (the price of soybean oil needs to be no more than 0.75 \$ kg<sup>-1</sup> if the biodiesel industry is to make any profit [6,7]) are proven to be sufficient to date compared to other oils. Although the trading price for soybean oil (and for other oils) is subordinated to market speculators, broadening

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<http://dx.doi.org/10.1016/j.biombioe.2012.12.002>

the production alternatives might help the industry to reduce the production costs and to make biofuels, including those derived from soybean oil, more competitive. This, together with the potential to differentiate the assortment of diesel biofuels (especially in dieselized countries), would help to build the bridge from the current industry of first generation diesel biofuels to a more renewable and sustainable industry in the future.

The alternative to the conventional transesterification of vegetable oils is to remove the oxygen from the structure and hydrogenate the double bonds in the triglyceride chain, through conventional hydrotreating catalysis, where the degree of isomerization can be adjusted by modifying the reactor conditions [8]. This process can be integrated either in conventional refinery hydroprocessing installations or in new biorefineries, in both cases with interesting potential for lowering capital costs for the process [9]. In addition, many of the physical properties of the resulting biofuel (herein referred to as hydrotreated vegetable oil, HVO) are closer to those of petroleum-diesel than those of biodiesel fuels. As a consequence, the wide number of property combinations derived from ternary HVO-biodiesel-diesel blends may open the possibility of designing on-demand diesel fuels, or to optimize the fuels for a specific diesel technology, depending on the injection system, aftertreatment systems, engine size, etc.

The search for blend proportions under two approaches (to obtain: (i) optimized fuels which maximize any improvement in performance/emissions; or (ii) neutral fuels which eliminate any deterioration) has been the main objective of some previous studies. In the first approach, Theinnoi et al. [10] tested an optimized fuel blend (50% synthetic paraffinic fuel – 50% biodiesel) which kept the combustion pattern at the same phasing compared to a conventional diesel fuel while improving the engine efficiency and the smoke- $\text{NO}_x$  trade-off. Similarly, Nabi and Hustad [11] proposed several blends composed of FT fuel and jatropha biodiesel which greatly reduced CO, THC, smoke and PM emissions at the expense of higher fuel consumption and lower thermal efficiency. Finally, Pinzi et al. proposed optimized biodiesel contents to fit the specifications under the standard limits [12].

In the second approach, McCormick et al. [13] determined the aromatic content that a diesel fuel should have, by blending with paraffinic fuels, to obtain 20% biodiesel blends (from soybean oil among other feedstocks) that would not lead to the increase in  $\text{NO}_x$  emissions observed before blending with paraffinic fuels (therefore becoming neutral). Rounce et al. [14] designed a neutral diesel fuel (the optimized volume fractions were 15% biodiesel, 15% synthetic fuel and 70% diesel fuel) aiming to have the same in-cylinder pressure and heat release traces compared with those of a conventional diesel fuel and, consequently, avoiding an engine recalibration. However, to fully exploit the benefits of all the fuels involved, both types of approaches should be combined when proposing optimal blends.

The European Normalization Committee (CEN) developed a CEN Workshop Agreement (TS 15940:2012) specifying requirements and test methods for marketed and delivered paraffinic diesel fuels for use in diesel vehicles, either coming from FT synthesis (XTL) or from hydrotreating (HVO) [15]. Currently this committee is preparing a new standard which

(in parallel to the current standard EN-590:2009 [16]) will allow the use of biodiesel blends up to B7 in HVO fuels. However, this type of blend is not realistic today due to the small production of HVO. A more realistic approach would be to propose specifications for ternary HVO-biodiesel-diesel blends, since HVO fuels (similarly as biodiesel fuels) cannot be considered presently to be any more than a minor component contributing, alternatively or simultaneously to biodiesel, to increase the renewable fraction of diesel fuels.

The present manuscript focuses on these HVO-biodiesel-diesel blends, with special attention on the ternary blends. The study presents some of the most important physical and chemical properties included in fuel quality standards (density, viscosity, cetane number, cold flow and lubricity). The fuel heating value and the smoke point, which are not included in such standards but play a significant role in the engine performance and emissions, were also measured.

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## 2. Production and blending scenarios

In order to compare their characteristics when used for blending, both the HVO and biodiesel fuels were blended at volume fractions of 10, 20, 25, 30, 35, 40, 45, 50, 55, and 75% with ULSD. These two collections of binary blends correspond to two different scenarios of biofuel penetration in the diesel fuel market. Although biodiesel blending is much more prevalent than HVO blending, depending on the feedstock availability, both scenarios could either compete in the future to fulfil the mandatory fractions of renewable fuel required by European and US directives or become complementary rather than competitive by means of ternary blending. With this aim, two additional scenarios, (a) and (b), have been determined as future production and commercial supply systems: (a) an oil refinery which injects a certain amount of vegetable oil in its own petroleum hydroprocessing installations, and (b) a bio-fuel plant that uses a vegetable oil feedstock for a combined production through both transesterification and hydro-processing. In case (a), the produced fuel could then be blended with biodiesel fuels from the conventional biodiesel industry, leading to ternary blends. In case (b) the produced biofuel could also be blended with conventional diesel fuel from refineries, also leading to ternary blends.

From a previous work focused on HVO-diesel binary blends (the former being derived from soybean oil) [17], a volume fraction of 25% HVO in diesel fuel was selected as the base fuel in case (a) and it is abbreviated as 25HVO/75Diesel. This blend was selected because it has improved cetane number and sooting tendency, while keeping reasonable lubricity and cold-flow properties, as shown in Section 4. With regard to case (b), a 50% (volume fraction) biodiesel-HVO blend, both derived from the same soybean oil, was selected as the base fuel (abbreviated as 50HVO/50Biodiesel), since there are no *a-priori* reasons to prefer one production process over the other before detailed economic and sustainability studies are performed. The fuel matrix used for testing fuel and blend properties is shown in Fig. 1 through a ternary diagram. Each of the three corners represent a pure fuel, while the binary blends lay on the sides (HVO-diesel blends on the left-side and biodiesel-diesel blends on the right-side). The two lines

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