Contemporary Engineering Sciences, Vol. 11, 2018, no. 11, 507 - 514
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2018.8246

Environmental Assessment of Biodiesel Improved with Nanoparticles

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Abstract

In recent years, some studies have focused on improving the characteristics of biodiesel for use in engines. The nanoparticles have been tested as additives of said mixtures. However, its application must be analysed from an environmental point of view. In this paper, environmental analysis of combustion of biodiesel using nanoparticles as additive was studied. Main environmental impacts were observed when using the blend with additive in categories as eutrophication, global warming, acidification and abiotic depletion. As a result, we found that the high content of fossil fuel within the B10 blend caused significant impacts over the studied categories.

Keywords: Biodiesel, diesel, nano-additive, environmental impact

1. Introduction

Biodiesel is a biofuel that is generated from renewable lipids such as vegetable oils. It is used in compression-ignition engines and heating boilers [14]. It is considered as one of the most interesting biofuels, and especially when obtained from palm oil due to the fact that weather conditions in some countries, oil content, and yields favour its production.

Besides contributing to reduce oil dependence, biodiesel also offers higher lubricity and cetane number when compared to diesel. However, it promotes corrosion, sedimentation, and specific issues related to lubricity [7].

In order to fulfil established requirements or to obtain beneficial effects on any type of fuel, many additives such as cetane improvers, additives for smoke suspension and detergent additives have been developed [15]. By using these materials, competiveness of enhanced biodiesel could be increased when consumption conditions and quality of emissions are improved [10]. Since this fuel is currently being used in blends with diesel, exhaust gases are still a controversial topic. Hence, fuel additives have received a high acceptance within the scientific community.
Among the variety of commonly used fuel additives, nanoparticles stand out as catalysts of the combustion reaction thanks to their large surface area and high reactivity. These characteristics are useful for potential applications [8].

Different studies [1, 4, 11, 13] have already tested the catalyst action of the nanoparticles on the combustion reaction. Despite the fact that the experiments reflected beneficial effects when using the additives, it is of great importance to measure the environmental impact that is caused by the synthesis and liberation of these nanoparticles to the atmosphere. The results of these analyses should be compared to possible improvements on the exhaust gases from combustion.

2. Methodology

Life Cycle Assessment (LCA) was applied under the methodology that is proposed by the ISO 14040 regulation. The analysis is divided in four main stages: *(i)* objective and scope, *(ii)* inventory analysis, *(iii)* impact analysis, and *(iv)* interpretation. These stages are not strictly sequential; but rather iterative. The level of detail progressively increases after each successive iteration [2].
A functional unit was initially established in order to describe the main function of the analysed system. This works as a reference to normalize inputs and outputs in a mathematical sense. Limits were also established to determine which processes were included in the study.
Once the processes to be analysed were delimited, gathering of data and calculation procedures were started in order to quantify the environmental effects that are associated to the selected functional unit by considering each energy and mass input and output.
Selection of impact categories was subsequently performed for each environmental consequence that is considered in this study: abiotic depletion (AD), acidification (AC), eutrophication (EU), global warming (GW100), stratospheric ozone depletion (OD), human toxicity (HT), fresh water aquatic ecotoxicity (FAET), marine aquatic ecotoxicity (MAET), and photochemical oxidant formation (PO).

Inventory data was assigned to the different categories according to the type of risk that could be exerted on the environment. Finally, impact analysis was performed for the use of the nano-additive in the B10 blend. For this specific case the functional unit is considered as the energy that is produced when consuming 1 kg of B10 fuel blend with 10 ppm alumina nanoparticles (Al_2O_3). In order to analyse the combustion with additive, 1 kW-h of energy generated by the engine is set as functional unit.

Production process of biodiesel includes planting, extraction, oil refining, and transesterification. This study considered a biodiesel inventory from palm oil (*Elaeis guineensis*), since it represents one of the species with higher yields of biodiesel. The inventory for diesel production was obtained from approximated data about the characteristics of Colombian crude oil. In this analysis, a low-sulphur crude (0.5 – 0.8%), similar to the one that is extracted in Colombia were considered [3]. Inventory for the production of the nano-additive was obtained from the mass and energy requirements of the synthesis process by sol-gel method [6] using citric acid and aluminium nitrate.

3. Results and Discussion

The impact derived from production of 1 kg palm oil biodiesel was considered. All stages from planting to biodiesel production plant were included, taking into consideration extraction and oil refining in order to analyse the system in an independent way.
Figure 1 shows the influence of the production process of refined palm oil on most of the categories, with an impact over 67% in each one of them.

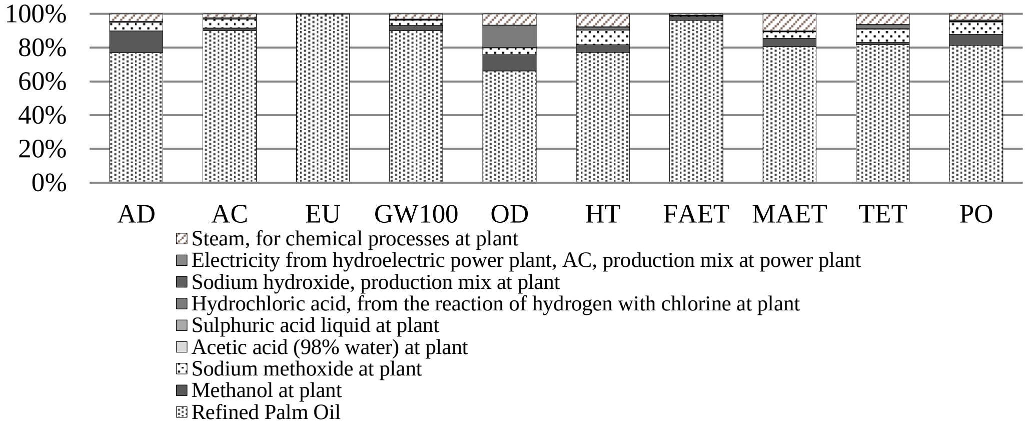

Figure 1. Characterization of biodiesel production

These high percentages are reflected in the fact that producing refined oil demands a series of transformations that start from planting. This initial stage requires soil adaptation with pesticides and fertilizers (both organic and inorganic) that affect the ground conditions [9]. Furthermore, considerable quantities of energy are needed in the oil extraction process, when compared to the remaining stages. Mechanical

treatment [12] and the use of steam for fruit treatment (which is occasionally produced by combustion of harvest wastes) are implemented frequently.
The above conditions prove that the notorious impact on the studied categories is caused by the number of inlets that the system requires in terms of both mass and energy, as well as the precedent processes in which outputs are also considered as by-products and emissions to the environment.
Once every category was normalized to a common unit, it was evident that eutrophication presented the highest impact in the form of chemical products that are used for soil preparation before and during planting. These products increase the amount of macronutrients that are released to the medium, thus promoting the growth of biomass in water sources and reducing oxygen content, which is essential for life in the ecosystems [5].

Individual analysis of the system also required the consideration of producing 1 kg of low-sulphur diesel. Figure 2 shows the results of the impact analysis. It can be observed that the oil refining process contributes significantly in each studied impact category. This derives from the fact that such process demands the implementation of units with high mass and energy consumption, and thus, large footprints on the environment.

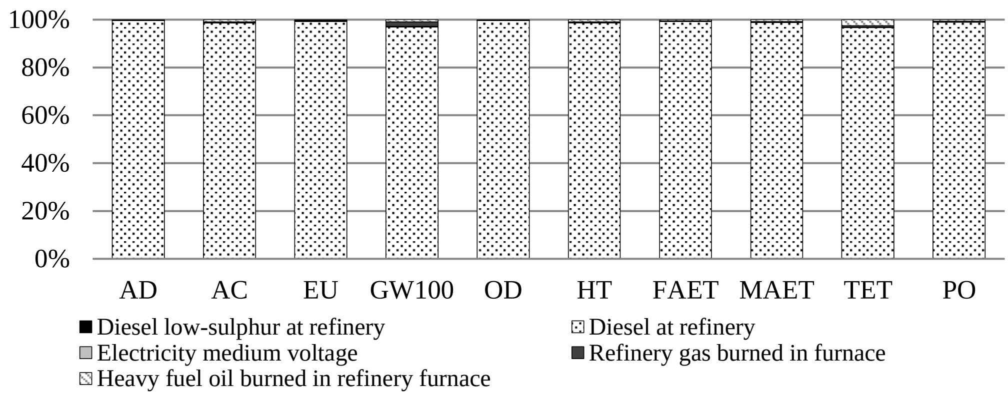

Figure 2. Characterization of producing 1 kg of fossil diesel

A comparison between the normalized categories highlights abiotic depletion as the one that generates the highest impact, since it relies on the use of one of the resources with greatest demand nowadays (crude oil). Marine eco-toxicity also stands out with a considerable impact that is caused by the emissions and the use of oceans as sumps. This situation represents an important influence on the welfare of ecosystems, since it alters the normal conditions of each habitat.

By studying the analysis of combustion process of the 1 kg B10 blend with addition of 10 ppm of nanoparticles (Figures 3-6), it was evidenced that high impacts are generated in the acidification, eutrophication, and global warming categories when producing mechanical energy.

Emissions of NO_x, CO_2, SO_2, and particulate matter are the main causes of this phenomenon once they have been released to the atmosphere after fuel combustion. The effect of biodiesel on the eutrophication category is also notorious. Such effect is attributed to the agricultural origin of this fuel (use of agrochemicals). Eutrophication presented the highest impact in the form of chemical products that are used for soil preparation before and during planting. These products increase the amount of macronutrients that are released to the medium, thus promoting the growth of biomass in water sources and reducing oxygen content, which is essential for life in the ecosystems. On the other hand, the greater proportion of diesel generates a considerable impact on all categories, and mainly on both abiotic and ozone depletion. Emission of contaminant gases to the atmosphere are considered to be the main cause of these impacts, which at the same time intensify climate change.

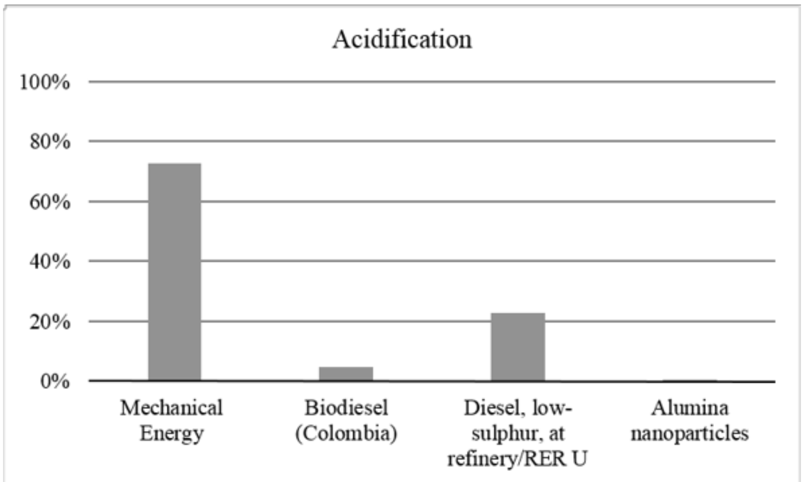

Figure 3. Total acidification impact for the processes.

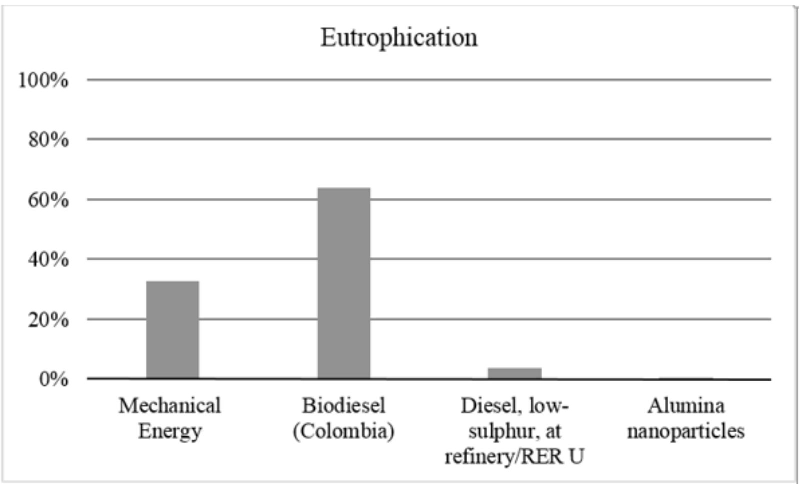

Figure 4. Total eutrophication impact for the processes.

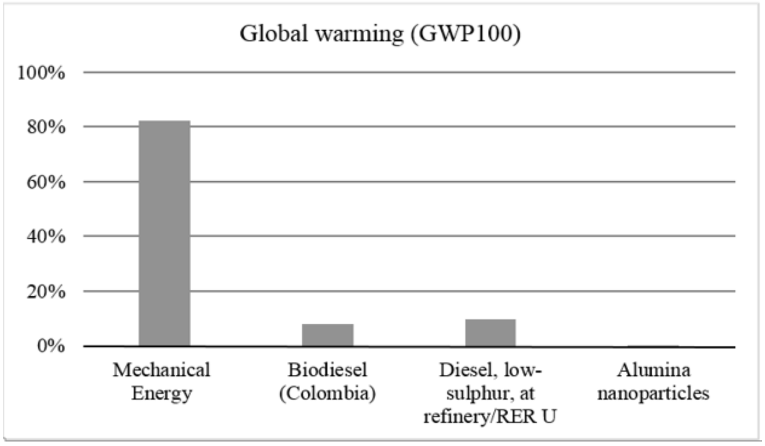

Figure 5. Total Global warming impact for the processes.

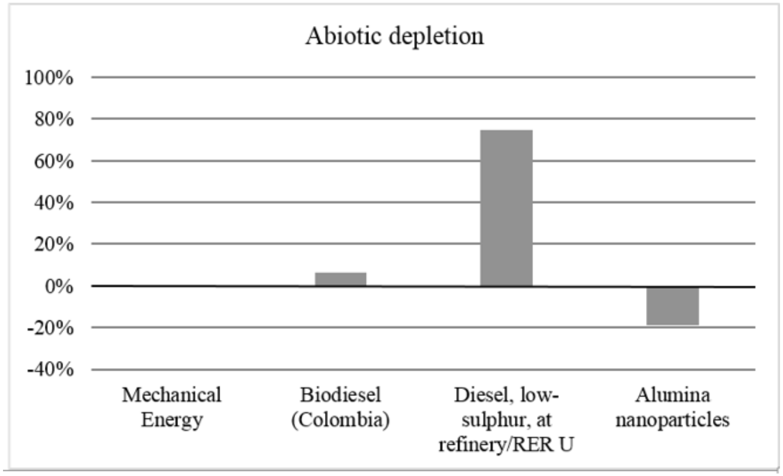

Figure 6. Total abiotic depletion impact for the processes.

The environmental assessment of the synthesis of alumina nanoparticles considered the use of the sol-gel method. Aluminium nitrate from the reaction between nitric acid and aluminium hydroxide, along with citric acid from the submerged fermentation process of *Aspergillus niger* were the reactants used for this stage. A negative impact was observed in the abiotic depletion category in the form of a beneficial contribution to the environment. This was achieved by the use of a microorganism to produce the organic acid.

High proportions of fossil fuel that have been used in B10 blends lead to environmental consequences that are influenced by oil refining and crude extraction processes for the production of diesel. These stages somewhat overshadow the advantages of using nanoparticles and their additive role.

4. Conclusions

LCA methodology allowed the analysis of the case study by establishing the potential impacts of each process. The use of agrochemicals and fertilizers in the palm oil crops represents a major influence in eutrophication category. By considering that one of the reactants that is used to synthesize the additive derives from an organic source, a positive footprint for the environment could be evidenced regarding the category of abiotic resources. This is because the synthesis reflects a reduction in resource consumption. However, consequences were also generated towards ecosystems and human health.

Further research needs to be carried out to prove the contributions that could be achieved by using nanoparticles and higher concentrations of biodiesel.

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Received: March 2, 2018; Published: March 26, 2018