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# Direct use of waste vegetable oil in internal combustion engines

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ABSTRACT

Direct use of Waste Vegetable Oil (WVO) as fuel is very attractive to reduce fossil fuels utilization and increase sustainability. WVO incorrect disposal causes serious damages to sewage systems and wastewater treatment plants. Moreover, if WVO reaches natural ecosystems, such as rivers, aquifers or subsoil, the environmental consequences can be severe. In recent years, the main reuse of WVO has been in biodiesel production, which is remunerative under current tax allowance policies. However, biodiesel production requires complex physical–chemical treatments, while direct use of WVO just needs mechanical treatment. As a consequence, WVO direct use in energy conversion systems lower the impact, from the economic, energetic and environmental points of view, with respect to biodiesel production. Moreover, as concerns the environmental impact, it should be considered that the direct use of WVO as fuel produces less polluting emissions when considering the whole life cycle: carbon dioxide produced during combustion, in fact, can be partially absorbed by crops used for oil production.

This paper presents a comprehensive review of the work done to evaluate the effects of direct use of WVO in internal combustion engines. Many authors have shown the advantages of using straight vegetable oils or biodiesel produced from WVO as fuel, while the benefits of WVO direct use have not yet been clearly presented. The available literature still presents few papers about this topic, therefore also the use of vegetable oil, that presents physical chemical characteristics very similar to those of WVO, has been taken into account. After a brief introduction, the characteristics of WVO most affecting its use as fuel have been studied. Then several applications of WVO direct use in internal combustion engines and the available fuel supply technologies have been considered. Finally, the energetic performance and the pollutant emissions reported in literature have been deeply analyzed.

## 1. Introduction

In the last decades, the high rate of depletion of conventional fossil fuels and the growing concern about the environmental impact of energy conversion systems, have encouraged research towards the exploitation of alternative energy sources. Vegetable oil can be used in the stationary production of energy. It is well known that compression ignition engines were tested by their inventor, Rudolf Diesel, with peanut oil as fuel [1], and in his patent he wrote that the "*use of vegetable oil for engine fuel may seem insignificant today but such oil may become in the course of time, as important as petroleum*" [2].

The use of pure oils as fuel has involved several controversies in the literature in recent years: the main ethical issue concerns the question "food vs fuel". The growing fuel demand in developed countries risks to reduce food availability and increase crops price, especially in poor countries. Waste Vegetable Oil (WVO) reduces this problem and promotes a virtuous circle, decreasing environmental impact and enhancing material recovery. The use of WVO, as alternative source to fossil fuels for combined heat and power production (CHP), represents a smart way for waste valorization and circular economy promotion. WVO potential amount in Europe has been assessed between 700 and 1000 ktons per year [3]; in China the production has been estimated equal to 5.09 million tons in 2015 with an expected increase by roughly 3.7% in 2030 [4]. A large part of WVO is discharged into the environment [5], with a significant impact for natural ecosystems [6]. WVO can reach:

- the ground, where it deposits as a thin film around the soil particles. Here it forms a barrier layer between the particles, the water and the capillary roots of plants, reducing the absorption of nutrients from the soil;
- the aquifers, where it forms a lentiform layer that can reach potable water wells, making them unusable. It has been estimated that a liter of oil mixed with one million liters of water is enough to alter the

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taste of potable water and make it non-potable [6];
- water surfaces, where it may form a thin impermeable film that prevents oxygenation and penetration of sunlight, affecting the aquatic ecosystems.

WVO can also damage sewage systems and wastewater treatment plants: pipes clogging and problems to the biological treatment phases can cause undesired stops for maintenance, with relative increase of the management costs.

Therefore, there is a growing effort to avoid WVO disposal by increasing collection and its recovery as a fuel. Its direct use as fuel presents some technical problems. For this reason, the main current reuse is conversion into biodiesel through the processes of transesterification, neutralization, washing and distillation [7-9]. These processes are needed to improve the fuel chemical-physical characteristics, especially to decrease viscosity [10]. WVO high viscosity, in fact, creates problems in compression ignition engines, such as effort in starting, poor atomization during injection, carbon deposition in the combustion chamber, higher requirement of energy to pump the fuel, filter plugging [11,12].

Conversion of WVO into biodiesel has high economic and environmental costs that are not yet enough competitive to consider a substantial replacement of traditional fossil fuels [13,14]. Direct use of WVO in engines may avoid the above mentioned treatments for biodiesel production and, as a consequence, reduce the environmental impact. As an example, Esteban et al. [15] compared the entire life cycle of pure vegetable oil and biodiesel produced from it, in order to understand which is the most environmentally friendly option. Based on the Life Cycle Impact Assessment (LCIA) and on the Energy Return On Investment (EROI), authors concluded that pure vegetable oils produce a lower amount of emissions compared to biodiesel during the entire life cycle and a better ratio of produced to consumed energy. Also Ortner et al. [16], through a consequential Life Cycle Assessment (LCA) modelling approach, found that esterification plants for biodiesel production from WVO generate higher Green House Gas (GHG) emissions than direct use of WVO in CHP plant. They assessed the energetic performance of different utilization paths of WVO, comparing the aforementioned solutions and biogas production from WVO anaerobically digested as a co-substrate. All the scenarios were found to save GHG emissions: the first two showed a significant ecological benefit in a very close range, while biogas production resulted to have lower potential because of the low efficiency of WVO fermentation. WVO esterification performed a little better of CHP because of the high conversion efficiency of WVO to biodiesel and the high environmental impact due to the substitution of conventional diesel fuel. In the case of CHP plant heat utilization was underestimated. Based on the consequential LCA modelling approach, if real substitution potential was considered, WVO utilization in CHP systems would reduce GHG emissions more than in case of biodiesel production.

This review describes the state of the art concerning the direct use of WVO in compression ignition engines in order to demonstrate its feasibility and competitiveness with respect to biodiesel.

The work available on WVO is limited; moreover, the results reported are not coherent since experimental setup and engine used are quite heterogeneous [17]. It is worth to notice that concerning the use of vegetable oils as fuel, pure or after physical-chemical treatments, several reviews have been presented. Ramadhas et al. [18] investigated the production and characterization of vegetable oil and the experimental works concerning the use of vegetable oils as internal combustion engine fuel. He concluded that they can be used as fuel in diesel engine with some minor modifications. Several advantages of vegetable oil were highlighted, among which the renewability, biodegradability and low environmental impact, but also the technical problems and challenges to be faced, such as availability and reliability of the raw material. Similar conclusions were achieved by Misra and Murthy [19], who underlined the potential of using vegetable oil as fuel in tropical developing countries. One of the most comprehensive work on vegetable oil use as fuel was presented by Sidibè et al. [20], who discussed the impact of its physico-chemical characteristics, the influence of production parameters on its quality, and reported the two main strategies of operation, duel fueling and blending. Soo-Young No [21] focused on the use of inedible oil as alternative fuel for diesel engine, describing the treatments needed to reduce the difference in terms of properties and performance between vegetable oils and petroleum based diesel fuels.

In literature there are also several studies about the conversion of vegetable oil and WVO in biodiesel. de Araújo et al. [22] pointed out the advantages of using WVO for biodiesel production, due to the economic and environmental convenience. He described the available processes for biodiesel production from WVO and stated the need for additional pretreatments, aimed to the removal of impurities deriving from cooking process. Several pretreatments can be used, such as steam injection, neutralization, vacuum evaporation and vacuum filtration. Fernandes et al. [23] assessed the best method for biodiesel production from WVO: they highlighted the importance to use a waste instead of raw material that can be useful for other applications. Issariyakul and Dalai [1] analyzed biodiesel from both pure vegetable oil and WVO, in terms of material properties, production processes and the influence on the fuel quality. They underlined the importance of raw material properties on the final quality of the fuel. Again, it was claimed that further pretreatments prior to conventional transesterification are needed when WVO are used as raw material. The use of biodiesel from WVO has been reported as a viable alternative to fuel compression ignition engines also by Kathirvel et al. [24], who investigated performance, combustion and emission parameters of CI engines. The advantages of WVO biodiesel use are the low cost, nontoxicity, biodegradability and renewability, beyond the reduction of net greenhouse gases emission.

What is missing in literature is a comprehensive work that highlights the benefits of direct use of WVO as fuel. As mentioned before, studies concerning WVO are few and sometimes contradicting. For this reason, in this work the authors aim to collect for the first time the available results concerning direct use of WVO in internal combustion engines. Based on the evidence that chemical-physical characteristics and performance as fuel of pure vegetable oil and WVO is very similar [17,22], also the data concerning straight vegetable oil have been reported, presenting the differences between them and WVO.

The paper is organized as follows: initially, physical and chemical characteristics that define the quality of WVO have been described, then the current applications have been analyzed, illustrating the employed supply systems. The energetic performance of various engines, as reported in several works of the literature, has been studied in terms of combustion process, specific fuel consumption, generated power and torque, head loss in the filter and exhaust gas temperature. Environmental impact of WVO direct use is presented by analyzing the pollutant emissions at different operating conditions.

## 2. Chemical-physical characteristics

WVO can be a blend of several vegetable oils that have undergone different physical and chemical processes which affect its chemical-physical characteristics. Therefore, if WVO is directly used as a biofuel, it is important to analyze its characteristics in terms of fuel quality. Sidibè et al. [20] have listed several features that have to be considered when pure vegetable oils are used as fuels in internal combustion engines. The examined characteristics are described below also in comparison with those of petrol-diesel.

### 2.1. Chemical characteristics

#### 2.1.1. Fatty acids

Vegetable oils contain fatty acids, whose nature depends on the type