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Hydrotreated vegetable oil fuel within the Fit for 55 package

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On March 28, 2023, the EU Council adopted a regulation setting stringent carbon dioxide emission standards for new cars and vans. Under the new law, new vehicles with a 100 per cent reduction in carbon dioxide emissions will be able to be registered after 2035. The new EU legislation sets the following targets: a 55 per cent reduction in CO_2 emissions for new cars and 50 per cent for new vans between 2030 and 2034 compared to 2021 levels; a 100 per cent reduction in CO_2 emissions for both new cars and vans from 2035. This will result in only electric or hydrogen-powered cars and vans being able to be registered after 2035. The fuel omitted from the Fit for 55 packages within cars and vans is hydrotreated vegetable oil. According to the research carried out so far, it is possible to replace diesel with HVO fuel even without interference with the fuel injection control system. If an internal combustion engine is fuelled with HVO fuel instead of diesel, the greenhouse gas emissions can be reduced by up to 90 per cent. What is more, the technology for using HVO fuel has many more possibilities for reducing CO_2 emissions, if only by refining the exhaust after-treatment process. The exclusion of this fuel from the Fit for 55 package raises serious doubts about the quality of the analyses based on which HVO fuel was not included in the Fit for 55 packages.

Key words: *HVO fuel, biofuel of the second generation, Fit for 55 packages, emission of toxic exhaust gas components*

1. Introduction

Internal combustion engines are a main source of CO_2 emissions. Greenhouse gases such as CO_2 are responsible for climate change. Reducing CO_2 emissions from internal combustion engines is therefore crucial to reducing global warming and its effects, including rising temperatures, changing precipitation, melting glaciers, and rising sea levels. Given these risks from CO_2 emissions from internal combustion engines, the Council of the European Union is introducing the 'Fit for 55' package. This is a set of reforms introduced in 2021 to accelerate action to reduce greenhouse gas emissions and achieve the Paris Agreement targets [11]. From the legislature's perspective, the Fit for 55 package aims to modernize existing legislation in line with the EU's 2030 climate target, a prerequisite for the transformative changes needed in the economy to achieve climate neutrality by 2050. However, there is concern among biofuel market experts that the new legislation will ruin the internal combustion engine market. Due to EU regulations and emission standards, the automotive market will be forced to undergo a decarbonization process. The time horizon outlined by EU regulations seems very short and will force companies to implement organizational changes quickly. Unfortunately, if budgeting, purchasing, training, testing, and implementation issues are to be carried out diligently this process takes years. A great many companies with entire fleets of vehicles are now looking for solutions that quantifiably reduce the CO_2 emissions of the company's cars and at the same time do not force the company to change the composition of its fleet from combustion cars to all-electric ones. One such solution is to fuel internal combustion engines with fuels with similar physical and chemical properties to diesel. Such fuels include those derived from biomass. Vegetable oils, animal fats and waste oils can be used as raw materials for alternative fuels [14]. Such fuels include higher fatty acid methyl esters (FAME). These are fuels produced from oilseed crops such as rapeseed or soybeans by transesterification. FAME fuels have several advantages over diesel fuel such as better ignition and reduced carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) emissions [27]. However, FAME fuel applications come with some limitations. FAME fuel can corrode storage tanks and has a higher viscosity which negatively affects fuel injection. A promising alternative to FAME may be hydrotreated vegetable oil (HVO). It is a synthetic liquid biofuel free of aromatics, oxygen and sulfur. In terms of chemical structure, it consists of straight-chain paraffinic hydrocarbons. The fuel is produced by hydrotreating vegetable oils, animal fats or waste oils [33]. Advantages of HVO fuel over FAME fuel include high heating value and cetane value, lower turbidity temperature, lower viscosity. With fewer unsaturated compounds in its chemical composition, HVO shows better oxidation stability than FAME. HVO fuel consists of straight-chain alkanes, which have a lower activation energy than the aromatic ring-shaped hydrocarbons of which diesel fuel is composed. Therefore, the ignition delay for HVO fuel is shorter than for diesel fuel. This results in an earlier onset of combustion and reduced CO, HC and PM emissions compared to diesel. This shows that hydrotreated vegetable oil can be the fuel that can allow you to professionally plan and manage the reduction of carbon footprint and toxic emissions in your fleet. The subject matter of the article is up to date, as it systematizes information on the emission of toxic exhaust components when using HVO fuel in the engine, and the article also refers to the latest legal regulations introduced by EU institutions.

2. Fit for 55

In line with a communication from the Council of the European Union on 28 March 2023, the Council adopted a regulation setting stricter CO_2 emission standards for new cars and vans. The new rules aim to reduce emissions from road transport, which accounts for the largest share of CO_2 emissions from transport [11]. They also serve to provide the right impetus for the automotive industry to move towards zero-emission mobility, while ensuring continued innovation in the sector. The new legislation sets the following targets [11]:

1. A target reduction in CO_2 emissions of 55% for new cars and 50% for new vans between 2030 and 2034 compared to 2021 levels.
2. A target of a 100% reduction in CO_2 emissions for both new cars and new vans from 2035.

The regulation amends existing legislation, last revised in 2019. Under the regulation, each manufacturer must ensure that the average CO_2 emissions of its fleet of newly registered vehicles in a given calendar year do not exceed its specific annual emissions target. If this is not the case, the manufacturer must pay a charge of €95 per gram of CO_2/km above the target per registered vehicle [31]. As a result, the newly agreed targets will ultimately make zero-emission cars cheaper than those powered by fossil fuels. The European Commission's proposal is to tighten carbon dioxide emission standards for passenger cars: by 2030 by 55 percent (compared to the status quo), and from 2035 by 100 percent. This means that in a few years it will not be possible to register a car with an internal combustion engine in the EU. This refers to newly manufactured cars. The European Commission also recommends improving the infrastructure: charging points for electric cars on main roads are to be spaced every 60 kilometers, and for hydrogen cars every 150. This could lead to a lack of profitability in the production of combustion cars. One solution that will take into account the goal of environmental protection and at the same time will not make it necessary to reorganise the operations of companies and ordinary households very quickly is to use biofuel as a substitute for diesel. Such a fuel is hydrotreated vegetable oil.

3. Review of HVO fuel properties

HVO (Hydrogenated Vegetable Oil), or hydrogenated vegetable oil, is a high-quality diesel product made entirely from renewable raw materials, i.e. vegetable oils and fat waste. HVO is a second-generation biofuel (the first was FAME or rapeseed oil methyl ester). HVO emits 90 per cent less carbon dioxide, 30 per cent less particulates and 9 per cent less nitrogen oxide, compared to regular diesel [9, 10, 25, 29]. Its production is based on vegetable waste, such as vegetable and fruit residues or even out-of-date margarine. The transport and manufacturing industries calculate that the use of pure biodiesel will help them meet the EU's stringent targets for reducing pollution and using green energy sources [5, 32, 33]. Hydrogenated vegetable oil is a high-quality product made from renewable raw materials, i.e. vegetable oils and fatty waste. According to the literature available today, it is the most environmentally friendly fuel for diesel vehicles. Companies associated with the transport industry as a whole estimate that the use of hydrotreated vegetable oil will help the entire transport industry to meet the EU's stringent pollution reduction standards. This includes meeting EU targets for the use of clean energy as widely as possible, in all sectors of the economy. It is estimated that reducing emissions of toxic exhaust components by replacing diesel with hydrotreated vegetable oil could have a real impact on improving the health of our society. The entire transportation industry knows that the cost of fuel is not the only determinant of its popularity. The price of one liter of HVO fuel is about €0.6 higher than the price of one liter of diesel fuel. However, if you look at the total costs that transport companies have to bear due to the need to meet the European Union's requirements for emissions of toxic components of exhaust gases, transport companies are showing interest in hydrotreated vegetable oil and are willing to decide to fuel their fleet of vehicles with this fuel. What's more, this also applies to manufacturing plants and factories, which are also required to report on the use of renewable energy and biofuels throughout the product manufacturing process. HVO production technology has been known for several years. Its forerunner was the Finnish station brand Neste, which launched pure biodiesel stations in Finland, Sweden and Lithuania and Latvia. Western European networks such as Total and Eni are now following in their footsteps. In Poland, ORLEN has also conducted research into HVO fuel, which has shown that HVO fuel is of similar or even higher quality than standard diesel [25, 28]. It is worth emphasizing that filling up with HVO fuel does not exclude the use of traditional diesel fuel. HVO fuel can act as a substitute fuel for diesel [2, 19, 29]. This expands the possibilities of powering internal combustion engines traditionally powered by diesel. Studies are confirming that HVO (including HVO100) is well-suited for diesel engines without any modifications [6, 22, 24]. This is why leading truck manufacturers are supporting the popularization of this fuel. Compliance with the standard for their entire fleet was recently announced by DAF and has been declared by Scania, MAN, Volvo, Mercedes-Benz, Renault Trucks or Iveco for several years. In particular, HVO fuel can be used by owners of Euro V and VI class trucks, i.e. virtually the entire Polish fleet serving international traffic, as well as the majority of vehicles in local traffic [14, 30]. Vehicles with engines meeting Euro III and IV standards can also be fueled with HVO fuel, but this requires interference with the fuel dosage control system [23].

Hydrotreated vegetable oils are mixtures of paraffin hydrocarbons. These fuels are free of any sulfur and aromatic compounds. The cetane number of Hydrotreated vegetable oils is extremely high and their other properties are comparable to fuels currently used to power compression-ignition engines. Table 1 provides a comparison of the physicochemical properties of the three fuels: HVO, FAME and diesel.

The physics-chemical properties of HVO and FAME fuels are determined by which vegetable oil they are produced from. For this reason, in Table 1 some parameters are reported in ranges.

HVO fuel can be used for powering CI engines in three options. The first alternative is to add only a small percentage of the biocomponent to the diesel fuel [28]. This is very common with ester-type biodiesel (FAME). Now, we can most often find diesel at gas stations with a 7% content of methyl ester of higher fatty acids of rapeseed oil. This amount takes into account the results of research on fuel stability and sediment formation in diesel engine power systems.

Table 1. Physical and chemical properties of the three fuels HVO, FAME, and diesel fuel [2, 6, 16, 22, 23]

Parameter	Unit	HVO	FAME	Diesel fuel
Density at 15°C	kg/m^3	780	885	835
Viscosity at 40°C	mm^2/s	2.5–3.5	4.5	3.5
Cetane number	–	60–98	52	54.6
Distillation range	°C	170–310	340–360	170–350
Cloud point	°C	−5... −25	−5	−5
Calorific value	MJ/kg	44	37.5	42.7
Calorific value	MJ/ dm^3	34.2	33.1	36.4
Sulphur content	%	0	0	30
Oxygen content	%	0	10	0
Storage stability	–	good	poor	good

The second option is to blend a few tens of per cent of HVO fuel with diesel fuel [28]. This is possible with hydrotreated vegetable oils (HVO) without any deterioration in fuel quality, adverse changes in exhaust emissions and degradation in engine performance. The fuel mixture will be of good quality, as the cetane number will be increased and the aromatic content will be reduced, resulting in lower emissions of selected exhaust components and better performance during cold start.

A final, third alternative is to take advantage of HVO as a clean fuel [28]. It is being considered primarily for public transportation, generators, and trucking companies.

Based on the available literature, a comparative analysis of the elemental and chemical composition of diesel fuel, HVO fuel and a mixture of diesel fuel and HVO fuel was analyzed. The performance of this study is shown in Table 2.

Table 2. Chemical composition of diesel fuel, HVO fuel and the mixture of diesel fuel and HVO fuel [9, 13, 35]

Name	Unit	Diesel fuel	HVO	HVO-30
Diesel fuel	%	100	0	70
HVO	%	0	100	30
Coal	%	85.9	84.8	85.8
Hydrogen	%	13.5	15.2	14
C/H ratio	–	6.4	5.6	6.1
Sulphur	mg/kg	5	2.5	3
Nitrogen	mg/kg	28	1.5	20
Aromatic compounds in total	%	18.9	0.2	13.6
Water	mg/kg	20	7	18

In the next step of the study, an analysis of the physics-chemical features of diesel, HVO fuel and a blend of diesel and HVO fuel was made. The results of the comparative study are shown in Table 3.

Table 2 and Table 3 show the physical and chemical properties of HVO fuel produced from rapeseed vegetable oil.

Special focus should be placed on the different density values of HVO fuel relative to diesel and the higher cetane number value of HVO fuel compared to conventional diesel. The major benefits of HVO fuel are its high cetane number, high energy density and the freedom from oxygen in the molecule of the resulting fuel. An important advantage of HVO fuel is its cold point level, which can be as low as –25°C. This in turn renders HVO suited for use in very cold winters. Importantly, the production and use of HVO is largely climate-neutral if only renewable energy sources are used. HVO is obtained from waste cooking oils, fats and fat residues, waste fats and vegetable oil [33]. It is then converted into hydrocarbons by catalytic hydrogenation, which is the addition of hydrogen at intense heating. This, in turn, is an energy carrier and thus a potential fuel. To what extent HVO will also establish itself in the market in the long term depends primarily on how global fuel production volumes and associated availability develop. Despite significant growth in production, HVO is widely available in only a few countries in Europe.

Table 3. Physicochemical properties of diesel, HVO fuel and the mixture of diesel and HVO fuel [11, 16, 38]

Parameter	Unit	Diesel fuel	HVO	HVO-30
Density at 15°C	kg/m^3	835	780	824
Cloud point	°C	–5	–7	–6
Flash point	°C	67	98	73
Viscosity at 40°C	mm^2/s	3.5	3.1	3.2
Calorific value	MJ/kg	42.7	44	43.4
	MJ/ dm^3	36.4	34.2	35.8
Cetane number	–	54.6	70	65
Boiling point	°C	363	313	358
Lubricity (HFRR)	µm	323	361	300
Heat of combustion	MJ/kg	45.98	47.28	46.34

4. Emissions of toxic components

Toxic components in the exhaust gas can make up several per cent of the volume of the exhaust gas. The emission of toxic components depends on the type of fuel and the way it is burned in the engine [1, 18]. For compression-ignition engines, the primary concern is the emission of carbon oxides, hydrocarbons, nitrogen oxides, particulates and carbon dioxide [4, 20, 28, 34]. The use of biofuel has an impact on the emission of these toxic exhaust components. Such test results are presented in Fig. 1 for three mixtures of HVO and diesel showing the percentage difference between the emissions of selected toxic components of the exhaust gas when the engine is fueled with these fuels compared to being fueled with pure diesel. Simulation studies were carried out using AVL BOOST software. AVL BOOST is software with which you can model the operating conditions of an engine and then simulate the varying operating conditions of the engine. AVL BOOST is a calculation system with real-time capability. It contains basic engine components for the greatest possible flexibility in engine design. Modelling takes place in the following stages. First, the gas stream, i.e. the gas properties, intake manifold, air filter, compressor and cylinder must be modeled. This requires the input of data such as the geometrical parameters of the engine, the timing phases, etc. The next stage is to model the heat transfer through the cylinder walls, engine cooling. This boils down to defining the heat transfer model and the combustion process model. The next step is to model the mechanical load of the engine and the engine control, and to enter the fuel data. The volume proportions of HVO fuel and diesel were chosen to compare the results with the available literature [10].

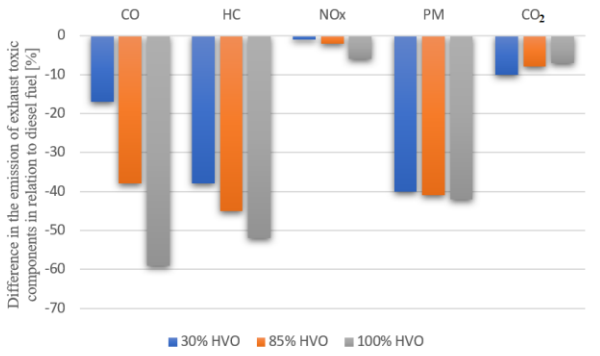

Fig. 1. Difference in emissions of toxic exhaust constituents about pure diesel

The results in Fig. 1 show that HVO biofuel significantly reduces carbon monoxide, particulate matter, and hydrocarbon emissions compared to a diesel-fueled engine. This is true for both HVO biofuel and a blend in a volume ratio of 85% HVO and 15% diesel fuel 30% HVO and 70% diesel. The emissions of nitrogen oxides when using HVO biofuel and a mixture of 15% diesel fuel and 85% HVO fuel and also 30% HVO and 70% diesel are comparable to the emissions of nitrogen oxides when using diesel. This is the main advantage of this fuel, given the comparison between HVO biofuel and FAME biofuel. The use of FAME typically increases NO_x emissions due to its elemental composition, which contains oxygen [18]. The simulation results obtained are consistent with those described by other researchers and available in the literature.

5. HVO vs. the Fit for 55 package

The transport and logistics industry is facing new challenges with the Fit for 55 packages adopted by the European Union. The new EU legislation sets the following targets [11]:

- 55 per cent reduction in CO_2 emissions for new cars and 50 per cent for new vans between 2030 and 2034 compared to 2021 levels [11]
- a 100 per cent reduction in CO_2 emissions for both new cars and vans from 2035 [11].

More precisely, such targets will force the market to replace internal combustion vehicles, with electric and hydrogen vehicles. A similar solution is to apply to heavy vehicles used in road transport, as 90% of them are to be zero-emission from 2040. However, it seems that the deadlines proposed under the Fit for 55 package are virtually unrealistic to meet! No company can make such significant changes overnight. Truck manufacturers, already have an electric truck on sale. However, the charger to charge such an electric vehicle, which will travel up to 400 km, must have a power output of 750 kW. Today, the available capacities of chargers are 20 kW, with a maximum of 50 kW. Therefore, an expansion of the electrical grid infrastructure is necessary. With hydrogen, the situation seems even more difficult. At the moment, there is not a single hydrogen-powered truck on the market for sale. Extensive research into hydrogen fuel was carried out by Lotos at one time, and it turned out that transporting this fuel was a problem. A hydrogen tanker weighs 23 tonnes and is capable of carrying about 300 kg of hydrogen at a time. It follows that hydrogen needs to be produced on-site, and hydrogen stations need to be built with small installations ready to produce this fuel on-site. Importantly, back in the second decade of the 21st century, it was estimated that with the projected increase in biodiesel demand, HVO fuel production would double on a European scale and triple globally. The entire biofuels market segment was expecting a steady increase in the share of biofuels in the fuel market and was therefore increasing its investments in this direction in order to cope with the expected increase in demand for biofuels [12]. Polish corporation PKN ORLEN is in the process of building a unit to hydrogenate vegetable oil. The investment is being built in Plock. The company estimates that it will be able to produce 300,000 tons of HVO fuel per year. The cost of this investment is estimated at €150 million. Production is scheduled to begin in 2024.

The solution to the problems described above for electric and hydrogen propulsion in heavy transport is HVO fuel, which reduces greenhouse gas emissions by 90 per cent [13]. Preliminary simulation studies carried out by the authors of this article using AVL BOOST software confirm this. A Perkins 3.4 854 E-E34TA engine equipped with a classic common rail fuel injection system was used as the test subject. As part of the simulation studies carried out by the authors, the test object was modelled by entering the geometric parameters of the engine and modelling the heat transfer process through the cylinder walls. Subsequently, the gas properties, intake manifold, air filter and HVO fuel data were modelled. Importantly, the introduction of such fuel does not require any investment in the vehicle, as the fuel simply replaces diesel. Research on this HVO fuel was conducted by ORLEN. These studies show that HVO fuel has comparable parameters to diesel. Hydrotreated vegetable oil is a very high-quality diesel fuel with an excellent cetane number level. It has a high calorific value and is free of aromatics and heteroatoms (Sulphur) and heteroatoms (Sulphur, nitrogen, or oxygen). HVO fuel is also immiscible with water and completely compatible with diesel produced from crude oil. This makes HVO fuel an excellent alternative to diesel in terms of engine performance and environmental protection [12]. It is sufficient to extend the infrastructure of a diesel filling station with the possibility of filling up with HVO fuel. Such a solution will make it possible to travel freely throughout Europe with a combustion engine fueled by HVO fuel. The exclusion of HVO fuel from the Fit for 55 packages, therefore, raises serious doubts about the quality of the experts drafting the regulation!

Conclusions

Based on a comprehensive assessment of HVO fuel and an analysis of the proposals in the Fit for 55 package, the following conclusions can be drawn:

- Under the new law, new passenger vehicles and vans will be able to be registered after 2035 with a 100% reduction in carbon dioxide emissions
- From 2040 onwards, zero-emission is to apply to 90 per cent of heavy vehicles used in road transport
- Such stringent emissions standards will result in vehicles with internal combustion engines being replaced by electric or hydrogen power

- The deadlines proposed under the Fit for 55 package are virtually unrealistic to meet
- It is possible to replace diesel with HVO fuel even without interference with the fuel injection control system
- Most of the physicochemical parameters of diesel and HVO fuel are of similar value. The exception is the density of HVO fuel, which is about 7% lower than that of diesel. Furthermore, the cetane number of HVO fuel is approx. 30% higher than the cetane number of diesel fuel. HVO fuel contains negligible amounts of aromatic compounds in contrast to diesel fuel (Table 1–3)
- HVO fuel is a solution that will simultaneously reduce emissions of toxic exhaust components while not exposing the transport market (especially heavy transport) to problems with refueling infrastructure
- The entire biofuel market segment expected a steady increase in the share of biofuels in the fuel market and therefore increased investments in this direction to meet the anticipated increase in biofuel demand
- With AVL BOOST software, the authors performed simulation studies to assess that HVO fuel can successfully replace diesel fuel. By replacing diesel with HVO fuel, similar engine performance can be achieved while reducing toxic emissions
- There are more and more voices among biofuel experts that the Fit for 55 package will revolutionize the passenger car market in Europe. In just a few years, society will no longer be able to drive cars with passenger engines. The question arises whether this does not violate civil liberties. The more so that the regulations will apply to the European market, so Europeans will pay for the transformation. This transformation would really make sense, the whole world would have to be active in this matter, including China, India and the United States
- The exclusion of HVO fuel from the Fit for 55 package raises serious doubts about the quality of the experts drafting the regulation!

The authors' achievement in this article is to systematize the knowledge on HVO fueling of internal combustion engines and to compare the results from AVL Boost with those available in the literature. The simulation studies carried out so far are the first stage of HVO fuel testing carried out by the authors of the article. In the next stage, we will carry out an empirical study of HVO fuel feeding of an internal combustion engine and its actual impact on the emission of toxic components of the exhaust gas.

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The article uses the results obtained with the AVL software (available at the Faculty of Automotive and Construction Machinery Engineering of the Warsaw University of Technology under the Platinum Partnership license).

Nomenclature

AVL	simulation software in the field of internal combustion engines
FAME	fatty acid methyl esters
HVO	hydrogenated vegetable oil

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