Alcohol-based diesel fuel for conventional engines - it is a reality

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1. Introduction

Industry worldwide has a strong incentive to develop alternative motor fuels to protect the environment and adhere to tighter emissions requirements. In 1997 in Kyoto, representatives from 105 states signed the Kyoto Protocol [1], which is designed to reduce excess carbon dioxide emissions produced when burning oil, mineral gas, coal and related products. The combustion of motor fuels adds considerably to the imbalance of carbon dioxide in the atmosphere. The use of motor fuel components derived from renewable raw materials, so called biocomponents, enables a reduction of the harmful impact burning fuel has on the environment. Accordingly in 2003 the European Commission passed a directive [2] to member states promoting the use of biocomponents in motor fuel starting from 2005. So it is evident that in the years to come the role of mixed fuels produced partly from petroleum and partly from renewable raw materials will grow considerably. Gasoline-ethanol blends for spark ignition engines and diesel mixtures containing methyl ethers of higher fatty acids for use in diesel engines are examples of this type of fuel.

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The development and marketing of a diesel fuel containing biocomponents, a biodiesel, is complicated by the standards requirements [3] for diesel fuel which impose substantial restrictions on potential fuel additives. First, a high flash point is required, which according to the requirements of the EU standard should be not lower than 55°C. This immediately rules out a wide variety of potential biocomponents as they are too volatile. Second, the distillation properties and cloud point set by the standard similarly rule out quite a number of readily available products produced from renewable raw materials. Third, a marketable fuel must be stable especially in the presence of water. Fourth, the performance of biodiesels must be similar to standard diesel and the emissions properties of biodiesels must be significantly better than those of standard diesel.

It is well known that replacing part of the hydrocarbons in diesel fuel by oxygenates can provide satisfactory engine power and cleaner exhaust without modification of the existing diesel engines [4,5]. The feasibility and properties of mixtures of diesel fractions with pure ethanol was reported long ago [6]. However, the main problem of using lower alcohols is the tendency of the fuel mixtures to phase separate particularly in the presence of water and at temperatures below 0°C. The problem of water in diesel-alcohol mixtures is solved in a number of patents, which include the use of surfactants [7-11]. The problem of using lower alcohols in diesel fuel is solved by the creation of microemulsions stabilized by surfactants [12,13]. Also fatty acids and organic ethers have been added to mixtures of diesel and the lower alcohols [14].

Besides being used as a replacement of the petroleum component of a diesel fuel, oxygenates have been proposed for increasing the cetane number and reducing the harmful pollutants in the exhaust emissions produced during the combustion of diesel fuel [15-17]. Others report work on multi-component oxygen-containing diesel fuels. These works report improved performance properties of such fuels and reductions in the level of harmful substances in the exhaust. This is to be expected given that multi-component oxygen-containing diesel fuels ignite and combust better [18,19].

Reduction of particulates by 52% as compared to the base fuel is reported [20] when using a mixture of 15% dimethoxymethane and 85% low sulfur, low aromatics diesel. However, dimethoxymethane has a tendency to evaporate from the fuel if special handling measures are not taken. Moreover, the addition of 15% dimethoxymethane to the hydrocarbon base requires some modification of the fuel system of the engine.

The effect on regulated and unregulated exhaust emissions produced by the addition to a standard diesel fuel of 20% methyl esters of fatty acids was studied [21,22]. It is demonstrated that the use of the mixed fuel results in a reduction of HC, CO and particulates and in a lower emission of Poly Aromatic Hydrocarbons (PAH) and Nitro Poly Aromatic Hydrocarbons (NPAH) compounds compared with a standard diesel.

The objective of the studies [23,24] was to select oxygenates as blending components in diesel fuel. Based on the analysis of several dozens of oxygen-containing compounds it is demonstrated that only two can be used for formulating mixed diesel fuels.

Despite all these developments, currently there is no fuel on the market containing more than 6% oxygenates which is suitable for operation in conventional diesel engines.

Over the last ten years oxygen-containing diesels for conventional engines have been developed by the authors. A specific goal of the research was to obtain a fuel comprising at least 15% oxygenates. Such fuel was to have physical chemical properties and characteristics in use closely similar to the standards in force for diesel fuels. Moreover, the fuels developed should have the additional advantage of significantly lower exhaust emissions. We have earlier reported the research in this direction [25-27].

New, previously unknown combinations of hydrocarbons and oxygen-containing compounds have been determined providing the required diesel fuel performance properties and also less harmful emissions. The major principle for the selection of these combinations is that the oxygen-containing components to be mixed with the hydrocarbon base fuel should include at least two compounds having at least four different oxygen-containing functional groups.

Regarding the oxygen-containing components, higher alcohols and the corresponding ethers and acetals are recommended. For the esters one of the constituent compounds, that is either the alcohol or the fatty acid, can be of a lower molecular weight and the second compound higher. In addition to those already mentioned, organic nitrates, peroxide compounds and epoxides are recommended as oxygen-containing compounds. Such oxygenates in mixtures with hydrocarbon diesel fractions provide the alternative fuel with the required performance properties, compliance with the standards requirements and combustion emissions which contain fewer harmful pollutants.

In the light of current opinion on the nature of the combustion of oxygenated diesel fuels it can be supposed that the discovered combination of the oxygen-containing components and the hydrocarbon base fuel, which successfully combines a high content of bound oxygen and the necessary calorific value of hydrocarbons, provides favourable conditions in the combustion chamber of a diesel engine. The results of such combustion are the performance properties and the exhaust emissions of the new alternative fuel as reported here. A European patent [28] and patents in some other countries have already been granted.

The approach taken allows the oxygen-containing diesel to be used by the existing vehicle fleet without modification or adjustment. The advantage of this approach is that vehicle users will not have to make additional investments in expensive engine modifications nor, in fact, new engines. In addition, the use of the oxygen-containing compounds obtained from biomass meets all the requirements of the directive [2] especially as regards the four difficulties already mentioned.

To understand the nature of the influence of the oxygen-containing compounds on diesel fuel properties we started by studying the stability of model mixtures containing alcohols, ethers and individual hydrocarbons. Figure 1 demonstrates the experimental data obtained on the stability of multi-component mixtures consisting of oxygen-containing compounds and hydrocarbon. Analysis of the experimental data demonstrates that ethers increase the stability of alcohol-hydrocarbon mixtures even in the presence of some water. Research of the stability of multi-component mixtures continues. In addition to the hydrocarbon, alcohol and ether mixtures, compositions containing hydrocarbons, alcohols, esters and acetals will be studied. We consider that the homogeneity of the mixed fuel affects its combustion and, as a result, its performance properties and exhaust emissions composition.

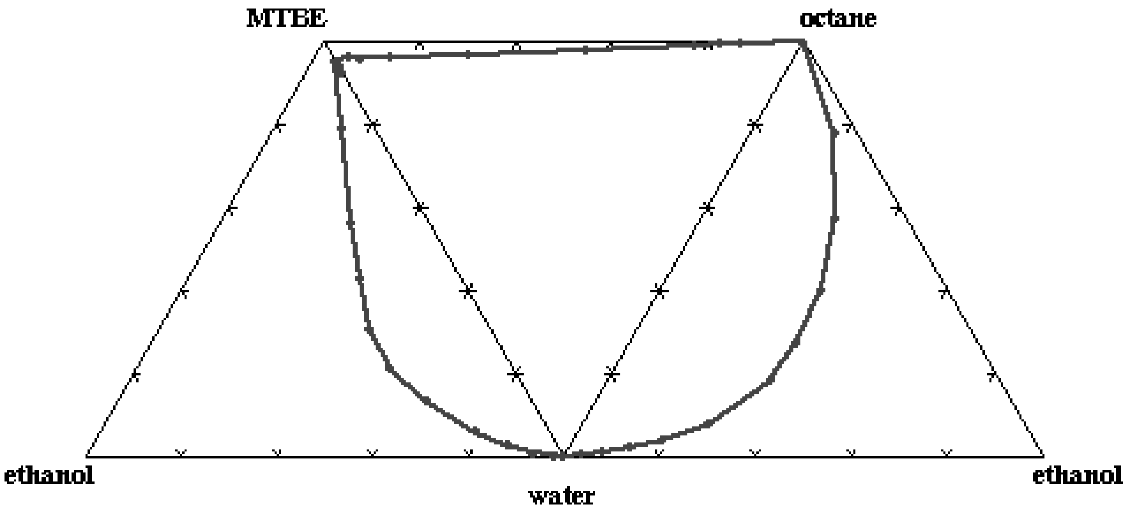

Figure 1. Phase diagram of the liquid liquid equilibrium of three component mixtures of octane, MTBE, ethanol and water.

Obtaining mixtures resistant to reduced temperatures and comprising higher hydrocarbons and oxygen-containing compounds is a considerable step towards the creation of an alternative diesel fuel. However these mixtures can become a fuel only when it is proved that they provide the performance of conventional engines and are within the limits of the characteristics set by the standards for diesel fuel.

The alternative fuel Biodiesel 15, which we have developed, was tested on a four cylinder engine VALMET 420 DSG with a nominal power of 46 kW mounted on a test bench at the research institute VTT, Finland. The test was carried out over a prolonged period of operation of 500 hours. Additionally, at the Statoil research centre in Norway the performance of a fuel pump was checked in a test bench study lasting 1000 hours. Both the Valmet 420 DSG engine and the fuel pump, mounted on test benches, were disassembled and inspected by engine specialists before and after the tests of the new fuel. An analysis of the data obtained [30] showed that the new fuel does not have any negative effects on the performance of the engine and the fuel pump.

The alternative fuel Biodiesel 15 developed has also been tested in winter conditions in the northern part of Sweden with ambient temperatures below -20°C. Two forest machines Valmet, harvester VALMET 901 (ID2350) equipped with a standard four cylinder engine VALMET 420 DWRE with a nominal power of 84 kW and forwarder VALMET 860 (ID4673) equipped with a standard six cylinder engine Valmet 620 DS with a nominal power of 118 kW were operated on the new fuel. The operation of the machines on the alternative fuel Biodiesel 15 during more than two months did not cause any difficulties and according to the drivers and operators was in no way different from the operation of the machines on standard diesel fuel.

According to the opinion of the specialists inspecting the internal condition of the engines of the Valmet forest machines before and after operating on Biodiesel 15 there was no change in the engine conditions [31].

Positive results from the various tests of Biodiesel 15 enabled the start of fleet testing in municipality buses in Sala, Sweden. The fleet test lasted for a period of more than one year. There were 16 buses comprising 15 commuter buses and one service bus running on Biodiesel 15. The 16 buses included four SCANIA L94UB model year 2001 buses, two SCANIA CN113 CITY model year 1997 buses, three SCANIA CN113 FÖRORT model years 1994 and 1995 buses, one VOLVO D10LE CITY model year 2001 buses, three VOLVO B10M FÖRORT model year 1999 buses, two VOLVO B10M FÖRORT model year 1993 buses and one service bus model year 1996. The mileage of all 16 buses during the entire period of the fleet test amounted to 772,750 km. The operation of these 16 buses on the new alternative fuel was controlled throughout the whole fleet test in accordance with the program *Fälttest av Agrodiesel 15* [32] developed by the Institute för Jordbruks – och miljöteknik and coordinated with the oil company Statoil and the engine producers Volvo and Scania. During the whole test period there were no negative remarks from the drivers, service personnel or passengers regarding the operation of Biodiesel 15. In addition, the exhaust emissions composition of two of the buses were regularly tested in the specialist centre AVL MTC AB [33]. These two buses were a VOLVO B10M FÖRORT EURO 2 model year 1999 with an engine VOLVO DH10A285EC96, and a SCANIA L94UB EURO 3 model year 2001 with an engine SCANIA DC 902 Variant BO1.

The exhaust emissions tests demonstrated a reduction of particulates content during the operation of the new fuel. This is particularly marked for the EURO 2 type of engine, see figures 2 and 3. Other regulated exhaust emissions from the VOLVO and SCANIA bus engines during the operation on Biodiesel 15 were on the same level as the exhaust emissions from the same engines operating on a standard Swedish Mk1 diesel fuel.

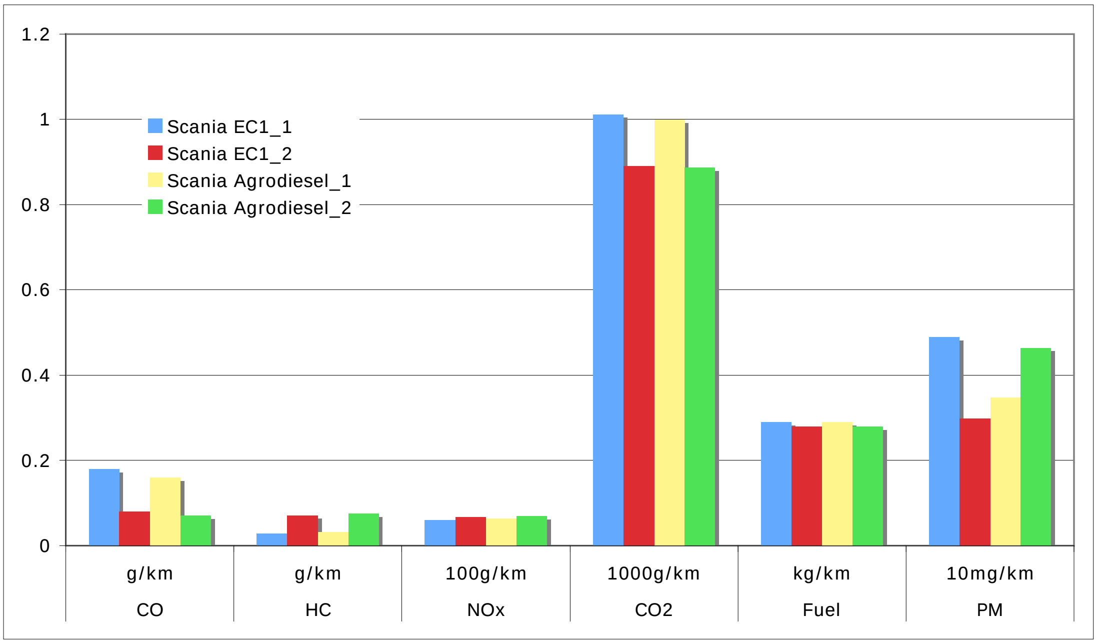

Figure 2 Emissions of measured components for the Scania vehicle

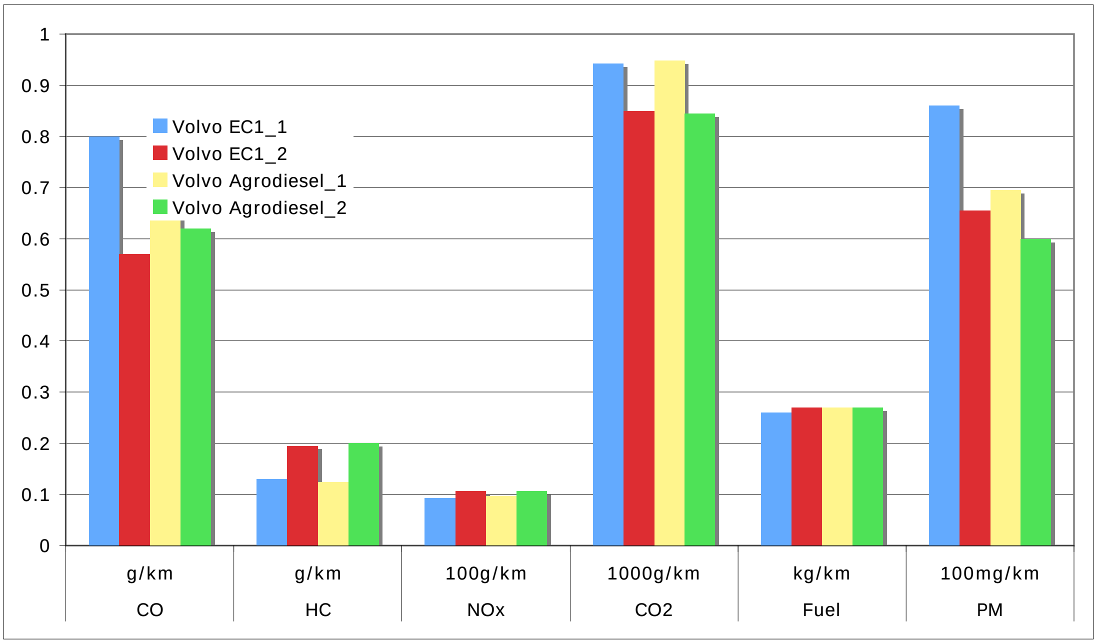

Figure 3 Emissions of measured components for the Volvo vehicle

We also observed for engines of type EURO 3 a reduction in the proportion of small particles in particulate distribution, see figures 4 and 5.

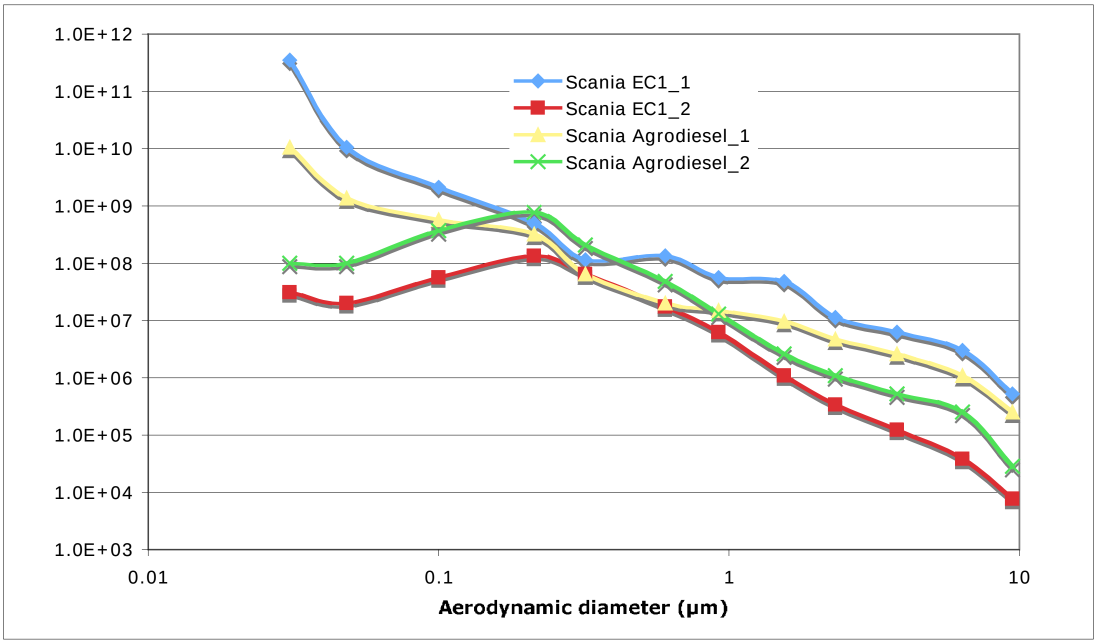

Figure 4 Particle size distribution, comparison between the fuels and test runs for the Scania vehicle(logarithmic scales).

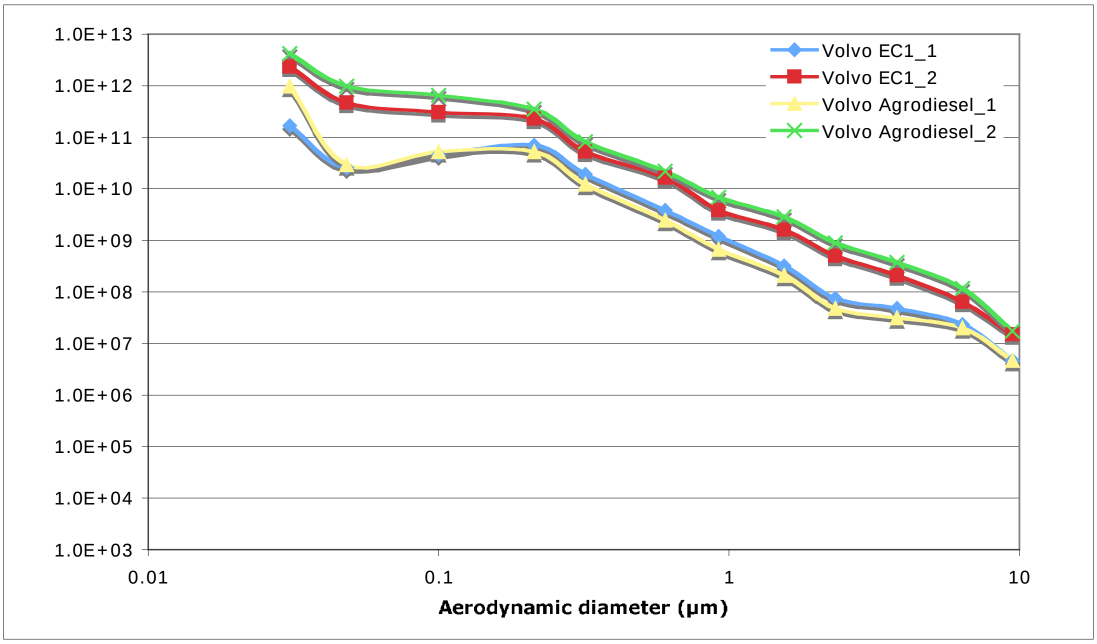

Figure 5 Particle size distribution, comparison between the fuels and test runs for the Volvo vehicle(logarithmic scales).

The VOLVO DH10A285EC96 and SCANIA DC 902 Variant BO1 engines installed on the buses were inspected with endoscopes before and after the tests. The engine specialists did not make any remarks during any of the inspections.

Measurements of the fuel consumption of all 16 buses during the whole period of the fleet test in 2003-2004 showed that the consumption of Biodiesel 15 was 2% lower than the consumption of standard Swedish Mk1 diesel by the same 16 buses during the identical period in 2002-2003 prior to the fleet test as shown in table 1.

Table 1 Comsumption of diesel Mk1 and Agrodiesel 15 and mileage during test and reference periods.

	Mk1 diesel 2002-2003	Agrodiesel 15 2003-2004
Amount of fuel (liter)	244358	226164
Mileage (km)	817464	772750
Fuel consumption (liter/100km)	29.9	29.3

Conclusion

A systematic approach to the problem of developing alternative fuels for standard diesel products has been used. This has enabled the successful introduction of oxygenates in the fuel composition. The objectives were broadly based to meet all the existing standards in force for diesel fuel, to be suitable for the existing inventory of diesel engines and to extend the use of alternative oxygen-containing biodiesel fuels in diesel engines. These objectives have been met in all details. The new alternative fuel contains 15% of oxygenates, which can be produced both from petroleum and biomass. They can be recommended for operation in conventional diesel engines.

Use of the alternative fuel containing 15% oxygen-containing hydrocarbons obtained from biomass for operation in the existing inventory of conventional diesel engines would help to reduce considerably, by more than 15%, the net emission of carbon dioxide to the atmosphere compared with operating the same engines on mineral sourced fuel.

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