# Dimethyl Ether Fuel

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Dimethyl ether (DME), like hydrogen, can be used as an activator in the combustion process, affecting its course. A higher rate of hydrogen and DME combustion accelerates the natural gas combustion initiation process, and should also have an effect on liquid petroleum gas (LPG) combustion. Both these gaseous fuels are currently used extensively to power motor vehicles.

Keywords: internal combustion engine ; indicator diagram ; dynamics ; DME ; alternative fuel ; in-cylinder pressure

## 1. Introduction

Recent years have seen extensive progress in the electrification of automotive drive systems. This trend is understandable given the environmental goal to reduce $CO_2$ emissions, and the growing use of renewable fuels such as dimethyl ether (DME) and biomethane, to power generators. By coupling electricity generators with internal combustion engines powered by renewable fuels, one can increase energy production without causing negative environmental impact. Using biomass-derived renewable fuels can even reduce the carbon footprint of such energy sources. Therefore, it seems reasonable to conduct research aimed at determining the suitability of selected renewable fuels for powering such internal combustion engines.

One of the known alternative fuels considered as a second-generation renewable fuel is DME. Given the extensive options for obtaining this fuel, it may be possible to increase general interest in this energy source and the potential for diversification of conventional fossil fuels. DME can be obtained by recycling waste from the wood and pulp industries. There are other sources from which DME can be sourced, but if they were utilized, the fuel would lose its renewable status.

## 2. Fuel Properties

Engine fuels currently in use are mixtures of hydrocarbons characterized by a very wide range of boiling points. **Table 1** provides information on the physicochemical parameters of fossil fuels and alternative fuels. A characteristic property of these fuels, that must be taken into consideration, is a low boiling point, especially when compared to methane and liquid petroleum gas (LPG). In a free state, these fuels exist as gases, and under certain conditions (e.g., overpressure or low temperature), it is possible to condense them, which increases the density of the energy stored. Both methane ($CH_4$) and LPG are commonly used in various European countries to power internal combustion engines. Their physicochemical properties, especially their explosive limits, are similar to those of hydrogen and dimethyl ether (DME). Methane and LPG are often used to power spark ignition engines, while hydrogen is rarely used as a fuel in internal combustion engines, although this option is currently being researched by the Toyota Corporation. The properties of DME make this fuel suitable for powering CI engines [1].

**Table 1.** Physicochemical properties of chosen fuels [1][2].

| Parameter | Methane | LPG | Dimethyl Ether (DME) | Petrol | Diesel |
|---|---|---|---|---|---|
| Formula | $CH_4$ | $C_3H_8$-$C_4H_{10}$ | $CH_3OCH_3$ | $C_7H_{16}$ | $C_{14}H_{30}$ |
| Molecular weight (g/mol) | 16.4 | 44.1 | 46.07 | 100.2 | 198.4 |
| Density (g/cm$^3$) | 0.720 | 0.2 | 0.661 (liquid)<br>2.057 (vapor) | 0.737 | 0.856 |
| Boiling temperature (°C) | −162 | ~22 | −24.9 | 17–220 | 140–380 |

| Parameter | Methane | LPG | Dimethyl Ether (DME) | Petrol | Diesel |
|---|---|---|---|---|---|
| Formula | $CH_4$ | $C_3H_8$-$C_4H_{10}$ | $CH_3OCH_3$ | $C_7H_{16}$ | $C_{14}H_{30}$ |
| Octane number | 130 | ~105 | | 80–100 | |
| Cetane number | | | 55–60 | | 40–55 |
| Lower calorific value (MJ/kg) | 50.2 | 46 | 28.8 | 43.47 | 41.66 |
| Stoichiometric air/fuel ratio (kg/kg) | 17.2 | 15.5 | 9.0 | 14.7 | 14.6 |
| Self-ignition temperature (°C) | 540–650 | 540 | 350 | 228–300 | 150–250 |
| Burning velocity (cm/s) | 30–33.8 | 38 | 42.9–61 | 30–60 | |
| Sulfur (ppm) | 7–25 | 10 | 0 | ~200 | ~250 |

Because the physicochemical properties of DME are similar to liquefied gas, DME can be used as an additive to LPG. It is also possible to use such a mixture as a gaseous fuel for domestic appliances, which is the case, for instance, in regions such as the Middle East (Iran) and Asia (Korea, Japan, and China). In many sectors of the economy (both in industry and institutions), the LPG-DME mixture can be used as a fuel to power engines [3][4], coupled with an electricity generator, or as an energy carrier in heat pumps. The use of the LPG-DME mixture will make it possible, to some extent, to achieve independence from fossil fuels and to reduce their extraction. By that means, energy security will increase and the impact of the unstable prices of fossil energy carriers on national economies will be curbed [1][2].

## 3. State of Knowledge

DME fuel was often addressed in the literature as early as the end of the 20th century. There were high hopes regarding this energy carrier, but unfortunately that did not translate into large-scale utilization of the fuel for powering internal combustion engines. However, the concept of using DME as an engine fuel is gaining popularity. Selected studies on the problems of fuel combustion and associated emissions are discussed below.

There are studies [5][6][7][8][9][10][11] which address the possibilities for using DME as a fuel to power internal combustion engines. They present the current state of knowledge on the use of renewable and alternative fuels with regard to the problem of internal combustion engine powering in vehicles.

In a study by Kwak J., et al., road tests of emissions in ppm were carried out for four vehicles [5]. Two of the vehicles were powered by CI engines, the other two by SI engines. Four types of fuel were included in the assessment: diesel fuel, LPG, CNG, and DME. Each of the vehicles tested was powered by a different fuel, and the speeds at which exhaust gases were sampled were as follows: 50 km/h, 80 km/h, and 100 km/h. The size of the nanoparticles emitted, and their quantity as a function of vehicle speed, were adopted as the basic emission parameter. The study concluded that the size of the nanoparticles emitted was largest in the case of DME. Moreover, the nucleation mode particle concentration in the DME feed was proportional to the $NO_x$ emission.

Lee S., Oh S., Choi Y., and Kang K. attempted to determine the emissions from a 2.7 $dm^3$ engine fueled with a mixture of LPG and DME [6]. The fuel was fed indirectly to the intake manifold in a liquid phase. The parameters measured were torque, exhaust gas temperature, and combustion process stability. Furthermore, the emission of basic exhaust gas components (CO, THC, and $NO_x$) was also verified at the rotational speed of 1800 rpm. The torque values measured for the throttle wide open were recorded within the rotational speed range of 1800–5200 rpm. The highest torque values within the entire range of rotational speeds were obtained for the LPG fuel (70% butane and 30% propane), while the lowest value was recorded for n-butane with a 20% fraction of DME. Exhaust gas temperature measurements revealed the highest temperature values for the n-butane and DME mixture fuel. The temperature difference between the highest and the lowest point was approximately 80 °C, a relatively large value. The authors also determined the effect of the DME share in the mixture on the combustion process. Their research made it possible to determine the dynamics of the combustion process by establishing the pressure increases in the cylinder. Their results showed that the addition of DME accelerated the combustion process. Moreover, the authors found that once the excess air ratio was modified it was possible to use the DME additive without any further modifications.

The impact of a DME additive on LPG was assessed by Pathak S.K., Sood V., Singh Y., Gupta S., and Channiwala S.A. [7]. The authors examined the behavior of a vehicle powered by an SI engine fed with LPG-DME fuel against the EURO IV exhaust gas purity standard. The engine of the test vehicle was equipped with an adaptive gas fueling system, where the gas was delivered to the engine in the indirect evaporation phase (to the intake manifold). The test program included an assessment of the changes to the exhaust gas emissions against various fuels (gasoline, LPG, and an 80/20% mixture of LPG and DME). The researchers were mainly focused on the high $NO_x$ emissions attributable to the DME fuel. The reason for its increased emission of nitrogen oxides was the higher temperature in the combustion process due to a slight depletion of the mixture, and the factor responsible for the mixture depletion was the small amount of oxygen carried by DME. The study also presented the results of an analysis of carbon dioxide emissions and fuel consumption. Attention was paid to a slightly higher fuel consumption with DME, which was caused by the fuel's lower energy value. The $CO_2$ emission results discussed in the study confirm the possibility of reducing the volume of particles introduced into the environment. Carbon dioxide emissions from a fuel containing 20% of DME are lower by approximately 10% than the emissions attributable to gasoline. The authors advocated using the DME additive with LPG, without the need to make any technical modifications to the injection system.

Other studies [12][13][14][15] of LPG-DME fuels have focused on determination of the effect of the ignition advance angle, the composition of the fuel-air mixture on the operational parameters of engines, and analysis of the potential for knocking combustion. A study by Chen Y., Zhang Q., Li M., Yuan M., Wu D., Qian X. [14] presented the results of research on wave propagation in the LPG-DME fuel combustion process. The authors established the velocity and value of the shock wave pressure in a closed tank filled with fuel comprising an LPG and DME mixture.

An important aspect of this problem was describing and testing the process of the LPG and DME mixture combustion. Knowledge of the combustion process would make it possible to adapt engines to meet the combustion requirements of a specific fuel [16][17][18]. The authors of the study attempted to determine the time delay in the initiation of ignition of a stoichiometric mixture of methane and DME. Their tests involved using a pipe in which the shockwave propagation velocity resulting from the ignition of gaseous fuels was controlled. The test results thus obtained were compared with data retrieved from the literature on the subject. The study also addressed the possibility of using DME to power HCCI, SEHCCI or PCCI engines. Computer calculations were carried out to estimate engine operation indicators in the event that DME fuel was used to power the engine.

DME is not the only fuel currently being considered to power IC engines. Some studies [19][20][21][22] have discussed the possibilities of using renewable plant-derived fuels. These fuels were fed into diesel engines, where the combustion process and the potential for changing the EGR valve settings were examined. Other studies have discussed the possibility of using ethanol to power IC engines. Manufacturers offering vehicles with engines adapted for ethanol fuel are featured in another study, which also analyses options for running on CNG, biodiesel, and electricity [21]. The most recent study [13][23][24][25] presents numerical simulations of a four-cylinder IC engine simulated in an AVL Boost environment. These simulations made it possible to establish the relevant CO, HC, and NOx emissions, as well as to determine engine operating parameters such as power, cylinder pressure, and temperature in the combustion chamber. LPG, ethanol, and gasoline were used as fuels in this case.

In light of the above, efforts to establish if DME is suitable for powering SI engines seem justified.

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