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A comparison of diesel engine car performance using H_2O-CH technology

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Abstract. One of the ways to reduce the use of fossil fuels in transport is to use alkane gases in diesel engines. However, as the direct application of gaseous fuels in diesel engines presents technical challenges. A dual-fuel system integrating H_2O-CH technology offers an effective solution to facilitate the use of alkane gases in internal combustion diesel engines. By partially substituting diesel fuel in the combustion chamber with a mixture of alkane gas and water vapour, a more uniform and complete combustion process can be achieved, thereby reducing diesel consumption and greenhouse gas emissions.

The aim of this study is to compare the performance (power, torque, fuel, gas and water consumption) of a passenger car with a diesel engine when running on pure diesel fuel and when running on a combination of diesel and gaseous fuel using H_2O-CH technology equipment. The performance indicators were compared in different driving modes using the chassis dynamometer Mustang MD1750, while simultaneously measuring fossil diesel, LPG (Liquefied Petroleum Gas), and water consumption.

The results demonstrate that a properly integrated and calibrated dual-fuel system equipped with H_2O-CH technology can, under certain operating conditions, achieve higher engine performance while partially replacing diesel fuel with a mixture of alkane gas and water vapour. The presence of water vapour in the fuel mixture reduces the risk of detonation in the combustion chamber and contributes to smoother and more stable engine operation.

Keywords: alkane gases, dual fuelling diesel engine, water vapour injection, ArtuPower system.

Introduction

The idea of using liquefied gas in diesel engines is not new. However, due to the differences in design solutions compared with the use of LPG (liquefied petroleum gas) in Otto engines, dual-fuel systems are not popular. The number of electric cars has increased rapidly in the last 15 years. There is also a trend towards an increase in the proportion of new Otto engine in passenger cars compared with the number of diesel cars. In 2023, 35.3% of new cars in the EU were petrol-powered, 13.6% diesel-powered, 14.6% battery-electric, 7.7% plug-in electric, 25.8% hybrid-electric and 3% alternative fuel cars (ACEA, 2024). This distribution shows a decrease in the number of new diesel-powered cars, however, the trends in the registered car sector are different from those in the new car sector. For this reason, there is also a need to make existing cars more environmentally friendly, for example, by converting and adapting them to other, more environmentally friendly fuels. The situation for trucks is different from that of passenger cars, 97.7% of new trucks are diesel-powered.

Diesel engines do not have a spark plug to ignite the fuel mixture. Therefore, the engine cannot run on pure LPG alone; diesel fuel is required to ignite the fuel mixture. There is another problem; engines with a dual fuel system have a tendency to detonate due to the high compression ratio. Researchers are trying to eliminate these shortcomings by using water vapour injection into the intake manifold.

Ashok *et al.* have found in their studies that gas-diesel engines reduce PM and NO_x components, but power decreases in part-load mode (Ashok *et al.*, 2015). In experiments with a 2 l Perkins diesel engine and additional water injection, it is possible to reduce the specific fuel consumption from 226.8 g $(kWh)^{-1}$ to

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189.5 g (kWh)$^{-1}$ (16.4% fuel saving) when using 27% LPG from the fuel mixture mass (Ortega *et al*., 2023). Xiaokang Ma *et al*. have studied the effect of water injection on the exhaust gas composition of a diesel engine. Water injection reduces soot formation and the formation of the NO_x component, as the combustion temperature decreases (Ma *et al*., 2014).

Dittrich *et al*. have studied the operation of a dual-fuel diesel engine with LPG. When comparing the operation of the engine with LPG and with pure diesel fuel, the engine produced 4% less torque, but CO_2 emissions and particulate matter decreased. In the experiments, the maximum gas content used was up to 60%. The engine had two gas injectors installed in the intake manifold, which ensured accurate gas supply. It is also noted that as the gas content in the fuel mixture increases, the possibility of detonation increases (Dittrich *et al*., 2018).

Al-kaabi *et al*. studied a gas-diesel engine on an engine test bench with two different diesel high-pressure injectors. One injector had 100% efficiency; this part of the experiment was conducted with pure diesel fuel. The other injectors had 50% efficiency; this part of the experiment was conducted with an additional 50% LPG. The experiments showed fuel savings in the engine speed range from 1000-2000 min^{-1} from 14.4% to 15.3% (Al-kaabi, Balla, & Mudhaffar, 2020).

A gas-diesel engine provides both fuel economy due to a better combustion process and also reduces CO_2 emissions. The fuel consumption is also reduced proportionally (Molnar *et al*., 2024).

The parameters of a gas-diesel fuel engine can be improved using computer modelling of the nozzle injection angle (Renald *et al*., 2021). The angle of the gas nozzles in the intake manifold is also very important in the gas-diesel injection system. According to studies, the best nozzle angle is a 45º angle to the intake manifold airflow. This improves gas mixing with the incoming air (Chau *et al*., 2024).

One of the options for improving the parameters of a gas-diesel engine is the additional injection of hydrogen. Adding hydrogen reduces the amount of soot and CO_2 emissions, but increases NO_x emissions, as the combustion temperature increases (Akal *et al*., 2020). In order to optimise gas injection for a gas-diesel engine in these studies, a special control unit has been developed that allowed precise adjustment of the gas injection time. When experimenting with a diesel engine on an engine test bench at different engine speeds, the best performance results were obtained at a fuel ratio of 50% diesel fuel and 50% liquefied gas (Al-kaabi, Balla, & Al-Zuhairy, 2020).

Using LPG in a diesel engine on an engine test bench resulted in a 4–6% reduction in specific fuel consumption (g kWh^{-1}) (Aydin *et al*., 2018). Studies conducted on a single-cylinder engine indicate that adjusting the injection parameters can yield a 1–3% reduction in specific fuel consumption (Ianniello *et al*., 2020). In engine test bench experiments focused on reducing fine particulate emissions, an optimal LPG substitution ratio of 53–59% was identified within an engine speed range of 2200 to 3200 min^{-1}, resulting in fuel economy improvements of up to 11.9%. During these experiments, diesel fuel consumption was reduced by as much as 50% compared with operation on conventional diesel alone (Toledo *et al*., 2022). Substituting diesel with LPG can also provide an economic benefit, as the price of LPG is typically lower than that of diesel fuel.

Nemoianu's test bench investigations showed that the use of LPG in diesel engines at 3900 min^{-1} and with a 40% LPG injection ratio resulted in a 3.5% reduction in specific fuel consumption (Nemoianu, 2022).

Polish researchers Paczuski *et al*. carried out studies involving water injection into the intake system of an LPG-fuelled Otto engine. Several water injection strategies were analysed, including the introduction of water vapour into the intake manifold. Such water supplementation was found to reduce the risk of knock, a phenomenon also relevant when modifying a diesel engine's fuel supply system to operate with LPG (Paczuski *et al*., 2016).

Most available studies have been performed in laboratory settings using engine test benches, whereas relatively few investigations have been conducted with vehicles on chassis dynamometers or under real driving conditions. Therefore, the aim of the present study is to perform passenger car tests on a chassis dynamometer to determine the effects of using an LPG-water vapour mixture in diesel engine operation with respect to fuel economy, engine power and torque characteristics.

Materials and Methods

The experiments were carried out in 2025 at the Alternative Fuels Research Laboratory of the Latvia University of Life Sciences and Technologies. The test vehicle used for the study was 2014 Peugeot 308 equipped with a 1.6-litre diesel engine. The main technical parameters of the vehicle include a compression ratio of 16:1, a rated power output of 68 kW at 4000 min^{-1} according to the manufacturer's specifications, a Common Rail fuel system, and a 5-speed manual transmission. The vehicle was fitted with a liquefied petroleum gas (LPG) system consisting of a gas reducer and LPG supply to the engine intake manifold, as well as the ArtuPower system developed and patented by "ABLabs". The

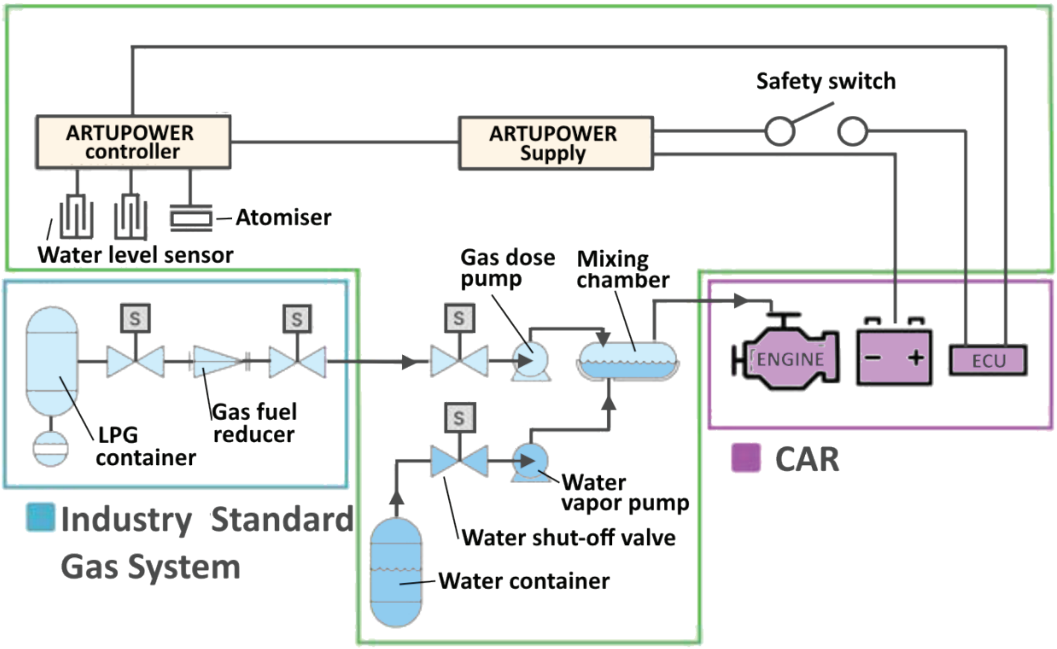

Figure 1. ArtuPower and dual fuel system components.

ArtuPower system mixes LPG with water vapour and doses the mixture according to the engine operating conditions. A schematic representation of the installed ArtuPower system is shown in Figure 1.

The tests were performed on a Mustang MD-1750 chassis dynamometer. The dynamometer is equipped with an eddy-current load unit that enables simulation of road load and aerodynamic resistance, allowing vehicle testing under both steady-state load conditions and driving cycles. The maximum measurable power on the dynamometer is 1285 kW, with a maximum absorption power of 295 kW and a maximum permissible test speed of up to 300 km h^{-1}.

Diesel fuel consumption was measured using an AVL KMA Mobile fuel consumption meter. The device operates on a high-precision PLU-121 flow meter, which employs the widely recognised PLU measurement principle. The fuel consumption measurement system is equipped with a conditioning module that enables instantaneous fuel flow measurement in vehicles with both supply and return lines.

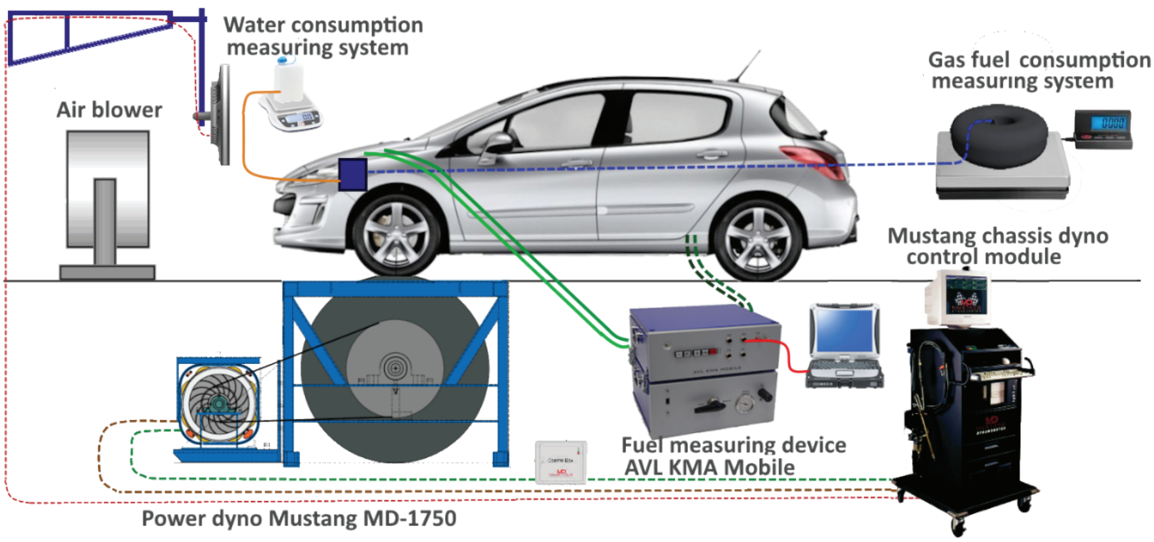

Figure 2. Schematic view of the experimental setup.

To determine the LPG consumption, a gravimetric method was used. For accurate measurement, an additional LPG tank was connected to the system via a three-way switching valve, enabling the flow to be alternated between the vehicle's main tank and the auxiliary tank.

The mass of consumed LPG was determined using electronic scales with a measurement range of up to 40 kg and a resolution of 2 g. Although this equipment is not suitable for determining instantaneous gas consumption, it provides sufficient accuracy for determining the total mass of LPG consumed during a defined test interval.

A schematic diagram of the experimental vehicle and measurement equipment is shown in Figure 2.

Standard commercial diesel fuel and automotive LPG were used as test fuels. The LPG consisted of a propane–butane mixture with a propane-to-butane ratio of 4:1.

The effect of using an LPG-water vapour mixture in diesel engine operation was evaluated in two stages. First, a test series was carried out using conventional fossil diesel fuel; subsequently, with the dual-fuel system activated, an analogous test series was performed using a mixture of diesel fuel, LPG and water vapour. The list and logical sequence of the tests are shown in Figure 3. Each test series consisted of 3-5 repeated measurements, from which the average values were calculated. Steady-state operating points at 1500 rpm and 1800 rpm were chosen based on the specific characteristics of the vehicle, as these engine speeds correspond to the typical operating conditions at maximum allowable urban and inter-urban driving speeds.

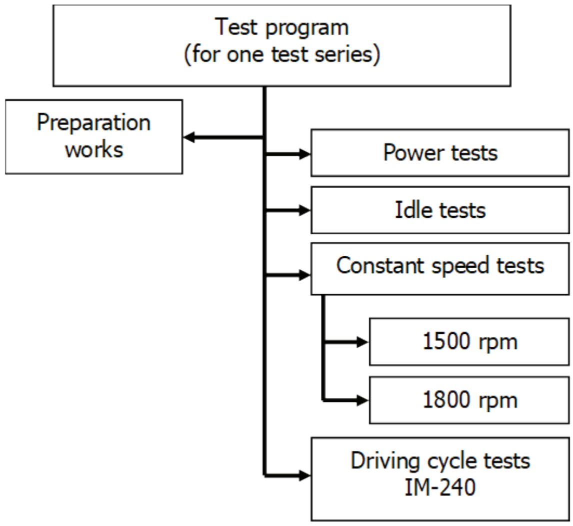

Figure 3. The schematic of experimental methodology.

Results and Discussion

In this study, the injection of a liquefied petroleum gas (LPG) and water-vapour mixture into the diesel engine was controlled and ensured by the ArtuPower system installed on the test vehicle. The system utilises a range of vehicle parameters, including engine load and temperature, engine speed, vehicle speed, intake air temperature, intake air mass flow, and lambda value, as well as information on gas and water levels in the respective tanks. Based on these input parameters and the programmed control algorithms, the system automatically calculates the required amount of LPG, mixes it with water vapour, and supplies the mixture

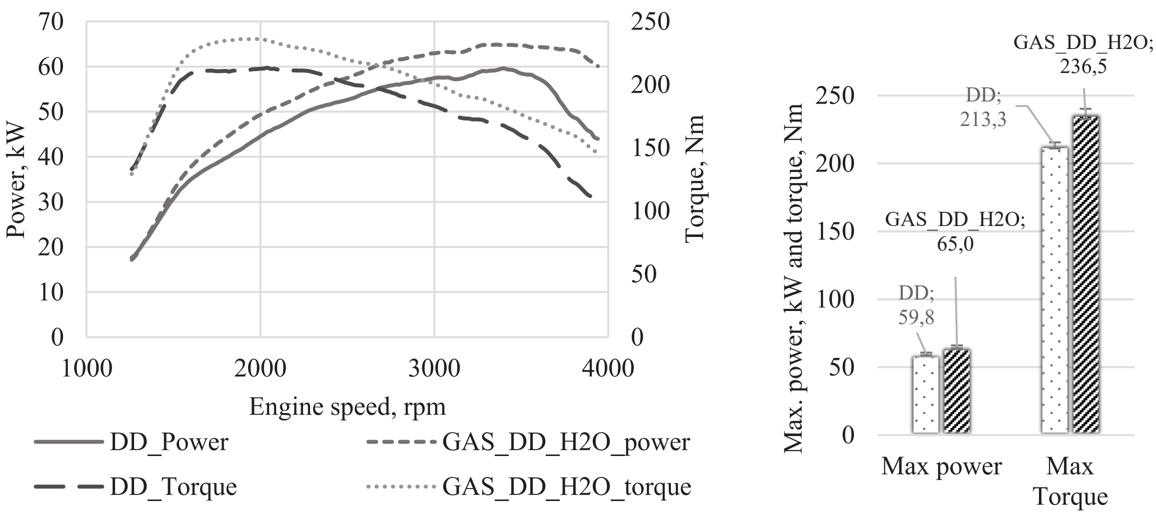

Figure 4. The effect of additional injection of a gas-water mixture on the diesel engine power and torque.

into the engine intake manifold. The reduction in diesel fuel supply is achieved because the driver needs to apply less throttle to maintain the required driving mode.

The experimental results demonstrate that equipping a conventional diesel-powered vehicle with an LPG system, complemented by equipment capable of mixing the gas with water vapour and dosing it according to engine operating conditions, allows for a significant increase in both engine power and torque. As shown in Fig. 4, the increase in maximum engine power and torque is observed across almost the entire engine speed range. The maximum wheel power of the vehicle increases from 59.8 ± 1 kW at 3400 min^{-1} when operating on fossil diesel fuel to 65.0 ± 1.1 kW at 3360 min^{-1} when operating on the diesel-LPG-water vapour mixture. The torque increases from 213.3 ± 2.3 Nm at 2040 min^{-1} to 236.5 ± 3.8 Nm at 1980 min^{-1}. As a result, partial substitution of diesel fuel with an LPG-water vapour mixture yields an 8.8% increase in maximum power and a 10.9% increase in maximum torque.

This increase in power and torque is provided by the installed ArtuPower system control unit programming, which does not interfere with the existing engine control unit (ECU) of the diesel fuel system. No signs of engine knock were observed during the power measurements, contrary to what has been reported in several studies involving dual-fuel operation in spark-ignition engines using LPG without water injection. For example, Toledo *et al*. reported that knock-free operation is achievable only under low and medium loads, while knock is present in other operating conditions, caused by the low cetane number of LPG and the high compression ratio of the engine, which increases in-cylinder temperature during the compression stroke (Toledo *et al*., 2022).

The observed improvements in engine power and torque are difficult to directly compare with other

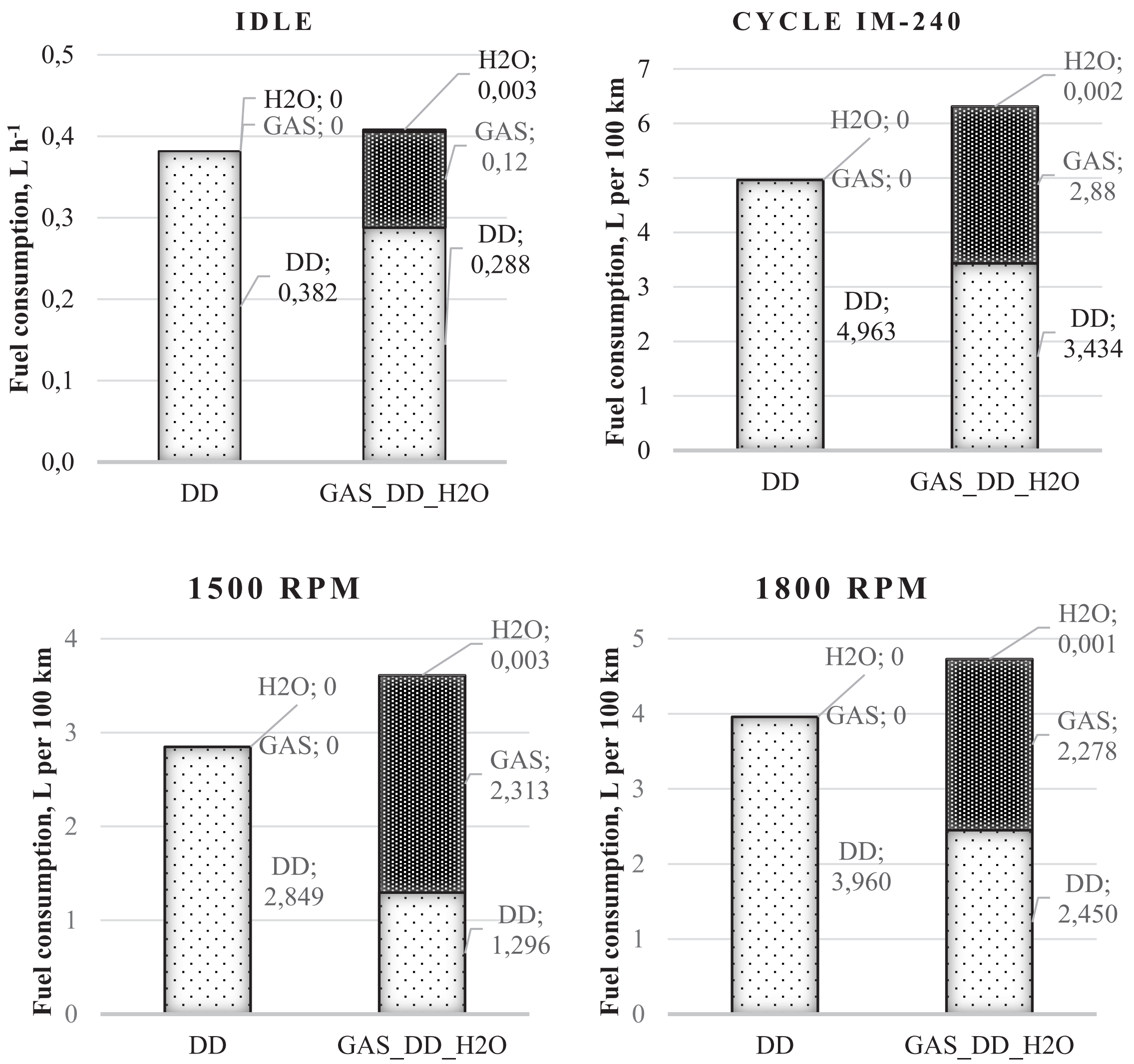

Figure 5. The effect of additional injection of a gas-water mixture on the diesel engine fuel consumption.

published studies, where diesel engine efficiency typically remains unchanged or even slightly decreases, such as in the studies of Molnar *et al*. (Molnar *et al*., 2024), mainly because the present study used a chassis dynamometer rather than an engine test bench.

According to the approved testing programme, fuel consumption was measured in the following modes: idling, constant engine speed at 1500 min^{-1}, constant engine speed at 1800 min^{-1}, and the IM-240 driving cycle. Since the vehicle does not move during idling, fuel consumption for this mode is expressed in litres per hour, whereas in the other modes, the fuel consumption is expressed in litres per 100 km.

In the constant-speed tests at 1500 and 1800 min^{-1}, the vehicle was driven on the chassis dynamometer under load conditions corresponding to the vehicle mass and target speed, as controlled by the dynamometer software based on the specified vehicle parameters.

The fuel-consumption results (Fig. 5) show that under dual-fuel operation, fossil diesel consumption decreases in all tested modes. In idling, diesel consumption decreases from 0.382 ± 0.007 L h^{-1} to 0.288 ± 0.015 l h^{-1}, representing a 25% reduction, with the required energy replaced by the LPG-water vapour mixture. The additional LPG consumption in idling, recalculated as liquid volume, is 0.12 L h^{-1}.

In the constant-speed regimes, a greater proportion of diesel fuel can be replaced by LPG compared with idling. At 1500 rpm, diesel consumption decreases from 2.849 ± 0.140 L 100 km^{-1} to 1.296 ± 0.062 L 100 km^{-1}, with an additional 2.313 L of LPG per 100 km of distance. This corresponds to a 54.5% reduction in diesel consumption. At 1800 rpm, diesel consumption decreases from 3.960 ± 0.116 L 100 km^{-1} to 2.450 ± 0.131 L 100 km^{-1}, with 2.278 L of LPG added per 100 km of distance, resulting in a 38% reduction.

In the IM-240 cycle, which most realistically represents real-world vehicle operation under dynamic driving conditions, diesel consumption decreases from 4.963 L 100 km^{-1} to 3.434 L 100 km^{-1}, with an additional 2.88 L of LPG supplied. This corresponds to a 31% reduction in diesel fuel consumption.

Summarising the fuel-consumption results, it is evident that equipping a diesel vehicle with a basic LPG system and an additional device that mixes LPG with water vapour and doses it proportionally to engine load allows diesel fuel savings of 25-54%, depending on the operating mode. However, it must be understood that any driving mode requires a certain amount of energy. The energy saved from the reduced diesel use must be replaced by energy from another fuel, in this case, from LPG. Although the lower heating value (LHV) of LPG per unit mass (45.908 MJ kg^{-1}) is higher than that of diesel fuel (42.5 MJ kg^{-1}), when taking into account fuel densities (LPG: 0.56 kg L^{-1}; diesel: 0.83 kg L^{-1} at 15 °C) (Aydin *et al*., 2018), the volumetric LHV of LPG is lower. This is also reflected in Fig. 5, where the total combined consumption of diesel and LPG, expressed in litres, exceeds the volumetric consumption of diesel fuel alone.

Water consumption was not analysed separately, as it accounted for less than 1% of diesel consumption. Its precise determination over the short test duration was not feasible due to the characteristics of the installed auxiliary fuel system, which draws water from the tank intermittently and independently of the specific driving mode.

The amount of LPG consumed in the tests may be influenced by several factors, including LPG composition, engine operating conditions, control-software settings that determine gas supply at a given load, and other engine-specific parameters. Depending on the balance between LPG supply, engine speed and load, engine operation may become more or less economical. Since the dosing of LPG and water vapour is automatically calculated by the control system, the results vary between operating regimes and depend on the specific settings.

An equally important, but not extensively addressed aspect in this study, concerns the environmental and economic implications of such a dual-fuel system. The results show that a significant share of diesel fuel can be replaced with LPG. Because LPG prices in fuel markets are generally considerably lower than diesel prices, it is important to evaluate whether the cost savings from reduced diesel consumption can offset the additional costs of the LPG system, auxiliary equipment, maintenance, and the LPG itself. A financial assessment should be performed taking into account regional fuel prices, installation and maintenance costs of the equipment, and the expected annual mileage. The environmental aspect likewise warrants a dedicated study. Since the tested system incorporates additional water-vapour mixing and dosing, conclusions drawn from other studies on emissions changes may not be directly applicable to this configuration.

Conclusions

The use of LPG in the test vehicle equipped with a dual-fuel system and an auxiliary device that mixes LPG with water vapour ensured stable engine operation across all operating regimes, with no signs of knock observed.

Operation in the dual-fuel mode, enabled by the installed equipment, resulted in an 8.8% increase in maximum engine power and a 10.9% increase in maximum torque compared with operation on conventional fossil diesel fuel. These improvements were achieved without any modification to the original engine control unit, and increases in power and torque were observed over a wide engine-speed range.

During idling, the use of LPG reduced diesel consumption from 0.382 ± 0.007 L h^{-1} to 0.288 ± 0.015 L h^{-1}, corresponding to a 25% reduction. The additional LPG supplied amounted to 0.12 L h^{-1} (recalculated as liquid volume).

At a constant-speed mode of 1500 rpm, diesel consumption decreased from 2.849 ± 0.140 L 100 km^{-1} to 1.296 ± 0.062 L 100 km^{-1}, with an additional 2.313 L 100 km^{-1} of LPG introduced. This corresponds to a 54.5% reduction in diesel fuel consumption compared with operation on fossil diesel alone.

At a constant-speed mode of 1800 rpm, diesel consumption decreased from 3.960 ± 0.116 L 100 km^{-1} to 2.450 ± 0.131 L 100 km^{-1}, with an additional 2.278 L 100 km^{-1} of LPG supplied. This represents a 38% reduction in diesel consumption relative to pure fossil diesel operation.

In the IM-240 cycle, diesel consumption decreased from 4.963 L 100 km^{-1} to 3.434 L 100 km^{-1}, with 2.88 L of LPG added. The resulting 31% reduction in diesel consumption is primarily attributable to the increased proportion of LPG injected into the intake system.

Studies on the LPG use in compression-ignition engines would benefit from a comprehensive analysis involving engine performance, fuel consumption, emissions, and potentially economic aspects, as changes in individual parameters may be closely interrelated.

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