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EFFECT OF FUEL ADDITIVE ON EMISSIONS, POWER, AND TORQUE IN DIESEL INTERNAL COMBUSTION ENGINE

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The paper deals with the effects of fuel additive on the performance parameters and emissions of a diesel engine. Experimental measurements were carried out on a Renault Alaskan 2.3 dCi vehicle with 96,500 km mileage, using a MAHA MSR500/3 dynamometer and a MAHA MET MGT 6.3 exhaust gas analyser. The tests compared power, torque, and emissions (CO, CO_2, HC, NO_2, smoke opacity) when using pure diesel fuel and diesel with additive in a 1 : 1000 ratio. The results showed a statistically significant improvement in performance characteristics: average power increased by 11.4% (from 87.41 kW to 97.34 kW) and torque by 14.2% (from 315.30 Nm to 360.19 Nm), with the maximum difference in the mid-range rpm (2000–3000 min^{-1}). Emissions showed a reduction in CO_2 (by 6.6%) and NO_2 (by 10.3%), but the HC content increased almost threefold. Differences in CO and smoke opacity were at the measurement error threshold. The statistical analysis (two-sample *t*-test) confirmed the high significance of the results (*p*-values <0.05). The conclusions point to a complex effect of the additive, including an influence on the fuel system and turbocharger, which led to more efficient combustion manifested by higher performance and an altered emission profile.

Keywords: diesel engine; fuel additive; emissions; performance parameters; turbocharger; fuel system

When operating machines with diesel combustion engines, the activity ensuring the proper function of the fuel system is one of the most important tasks in machine care. The operation of the fuel system, in fact, is directly reflected in the main engine indicators. These are performance, consumption, and the environmental impact of operation (Rievaj et al., 2019; Markov et al., 2019). Research in recent years shows that fuel additives can significantly improve the performance characteristics and emissions of diesel engines, with demonstrated improvements in performance or reductions in emissions (Daud et al., 2022; Synák et al., 2019; Janoško and Krasňanský, 2025). Incorrect function leads to either a decrease in performance or an increase in specific fuel consumption, so operating costs rise, and operation becomes uneconomical. This is caused by an incorrect fuel combustion process, which simultaneously leads to exceeding emission limits. A comprehensive review of the impact of fuel additives on combustion characteristics shows that additives improve the combustion properties of diesel and biodiesel blends, while simultaneously reducing exhaust gas emissions (Kristyadi et al., 2022). It has been verified in practice that a malfunctioning fuel system has a greater impact on proper engine function than significant leakage in the combustion chamber (Rosa et al., 2024). Through machine use and storage, gradual or abrupt changes occur in the materials of individual fuel system components and the connections between them. Research in the field of additives demonstrates that their addition can improve engine thermal efficiency and reduce fuel consumption and emissions of carbon monoxide, unburned hydrocarbons, and nitrogen oxides due to a catalytic effect. Current fuel additives contain detergents for cleaning injectors, lubricants to reduce friction, cetane number boosters to optimise combustion, and fuel stabilisers to prevent degradation (Čedík et al., 2018; Naife, 2022; Imdadul et al., 2015).

Based on these facts, our work deals with experimental confirmation that the addition of a commercial additive to diesel fuel led to a statistically significant increase in engine power and torque, while at the same time reducing CO_2 and NO_2 emissions, but increasing unburned hydrocarbons. The contribution of the paper lies in the comprehensive analysis of the simultaneous effect of the additive on power and emissions during vehicle driving tests. Experimental measurements were performed in accordance with standard procedures for testing diesel engine performance and emissions using a dynamometer in conjunction with a certified exhaust gas analyser, ensuring comparability with other studies (Čedík et al., 2018; Kristyadi et al., 2022).

Material and methods

Formulation of hypotheses

When evaluating the effects of fuel additives, it is important to consider their potential impact on various aspects of engine performance and emissions. Additives are designed to improve the combustion process, which should lead to a more efficient use of the energy contained in the fuel. This can be manifested as increased engine power, reduced fuel consumption, and reduced harmful emissions. The aim of the experiment was to verify these assumptions and to determine whether adding an additive to the fuel brings measurable improvements in these areas. Based on these considerations, the following hypotheses were formulated:

- Does the selected fuel additive affect the Renault Alaskan engine's performance characteristics?
- Does the selected fuel additive affect the Renault Anaskan emissions?

These hypotheses provide a framework for analysing the experimental results and allow for a systematic assessment of the effectiveness of the additive used.

Material

Measurements were carried out on a Renault Alaskan 2.3 dCi vehicle with approximately 96,500 km mileage. The vehicle has a switchable 4 × 4 drive and permanent rear-wheel drive. The vehicle is equipped with a turbocharged diesel engine with a power of 140 kW and a displacement of 2.3 dm^3 and also has ADBLUE. Further specifications can be found in Table 1. First, measurements were carried out on the vehicle without the use of an additive in both a continuous and discrete manner, then the substance was added, the vehicle travelled a distance of 1000 km, and the measurements were repeated.

Table 1 Parameters of the measured vehicle

Manufacturer	**Renault**
Model	Alaskan
Fuel	diesel
Engine	2.3 dCi
Number of cylinders	4
Power	140 kW
Torque	450 Nm
Emission class	Euro 6 + ADBLUE
Gearbox	7-speed automatic
Drive	4×4 / rear-wheel

Characteristics of the additive used

Measurements were carried out on the Millers oils diesel power Ecomax additive for diesel fuel, which the manufacturer recommends dosing at a ratio of 1 : 1000. The manufacturer declares an increase in cetane number by 4 units, a reduction in fuel consumption, an increase in engine power and torque, and a reduction in emissions. The additive is also intended to clean the engine's combustion chamber as well as the injectors. The manufacturer informs about the possibility of increasing the dose up to double. The manufacturer also declares compatibility with vehicles equipped with a DPF filter, expecting the additive to provide:

- efficient combustion of the fuel dose;
- consumption reduction of up to 7%;
- cleanliness of the combustion chamber and injector;
- increased engine power;
- reduced emissions and smoke opacity;
- smoother engine operation and less noise.

Characteristics:

- density at 15 °C: 0.953;
- flash point: 60 °C;
- colour: light yellow.

MAHA MSR500/3 Dynamometer

The vehicle parameters were measured on a MAHA MSR500/3 dynamometer, which can also measure all-wheel drive vehicles thanks to variable wheelbase adjustment and electronic synchronisation of the front and rear roller speed. This dynamometer works with the MCD2000 communication port (MAHA, 2024b). The measurement results were corrected according to Council Directive 80/1269/EEC. The technical parameters of the dynamometer are shown in Table 2.

Table 2 Parameters of MAHA MSR500/3

Dimensions (H×W×L or H×W×D)	1560 × 860 × 420 mm
Maximum axle load	2500 kg
Wheel track/track width	700–2200 mm
Wheelbase	2200–3200 mm
Maximum speed	300 $km \cdot h^{-1}$
Maximum power/output on individual axles, static/dynamic	260 kW/1000 kW
Measurement accuracy	±2%

MAHA MET MGT 6.3 exhaust gas analyser

The vehicle's exhaust gases were analysed using a MAHA MET MGT 6.3 analyser, and values were evaluated using MAHA emission software. The device obtains values from the exhaust pipe using a probe. The analyser is capable of evaluating emissions from both diesel and petrol engines (MAHA, 2024a). The technical parameters of the gas analyser are shown in Table 3.

Table 3 Parameters of the MAHA MET MGT 6.3 exhaust gas analyser

Measurable gases	**Measurement range**	**Measurement error**
CO	0–15%	0.01%
CO_2	0–20%	0.01%
HC	0–30,000 ppm	1 ppm
O_2	0–25%	0.01%
Lambda	0–9.99	0.01
Absorption coefficient	0–9.99 m^{-1}	0.01 m^{-1}

Statistical evaluation

The *t*-test is a statistical method used to compare the means of two groups of data and determines whether the differences between them are statistically significant. In our experiment, a two-sample *t*-test was used to compare the engine parameters (power, torque) and emissions (CO, CO_2, HC, O_2, NO_2, lambda, *k*-value) when using fuel with and without additive. The *t*-test is based on the null hypothesis, which assumes that there is no difference between the means of the two groups. The alternative hypothesis, on the other hand, claims that the differences between the groups are statistically significant. The result of the *t*-test is a *p*-value, which determines the probability that the observed differences between the groups occurred by chance if the null hypothesis is true. If the *p*-value is lower than the chosen significance level (0.05), the null hypothesis is rejected and the alternative hypothesis that the differences between the groups are statistically significant is accepted.

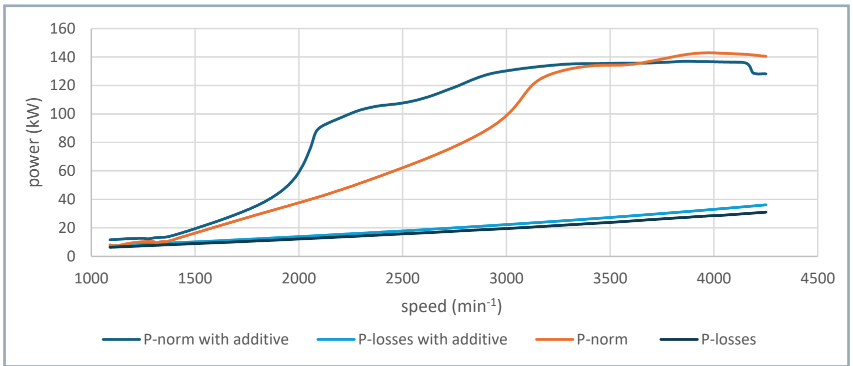

Fig. 1 Comparison of power with and without additive by continuous method

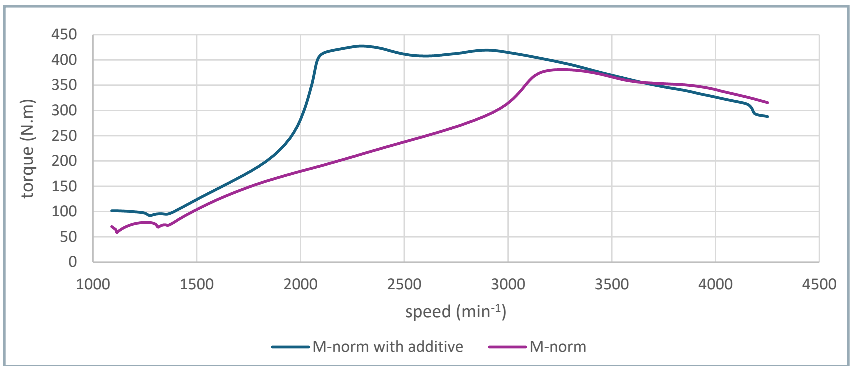

Fig. 2 Comparison of torque with and without additive by continuous method

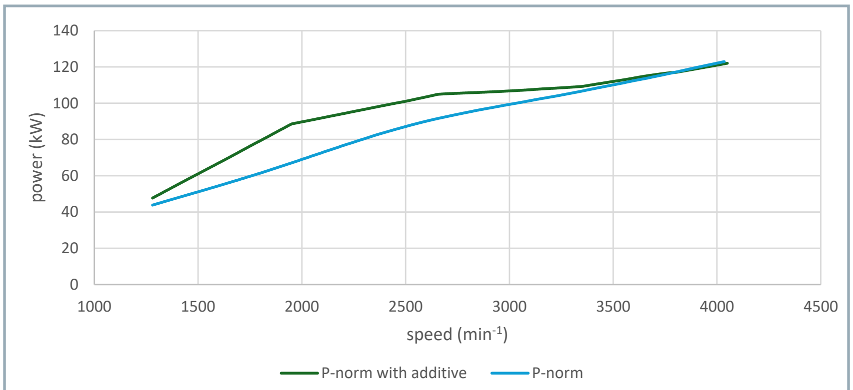

Fig. 3 Comparison of power with and without additive by discrete method

Results and discussion

The first measurement performed was a continuous measurement of power and torque.

In Fig. 1, the differences in engine power and losses when using the fuel with and without additive can be clearly seen. The power curve shows that the engine with additive achieves higher power already from low rpm. This difference is most pronounced in the mid-range rpm, specifically between 2000 and 3000 min^{-1}, where the power of the fuel with additive exceeds the power without additive by up to approximately 30–40 kW, peaking at up to 50 kW at 2300 min^{-1}.

Figure 2 shows the engine torque curves when using the fuel with and without additive. In the low rpm range (up to 1500 min^{-1}), the differences are minimal, but the engine with additive exhibits slightly higher torque, indicating that the engine achieves better response at low rpm when using the additive. The most significant improvement is visible in the mid-range rpm (2000–3000 min^{-1}), where the engine with additive achieves up to 47 Nm higher torque (427.5 Nm at 2295 min^{-1} vs 380.8 Nm at 3260 min^{-1}) while reaching its maximum.

Discrete measurement

In experimental measurements, discrete power measurement is often used, which allows recording power values at specific points (speed) instead of continuously monitoring the curve. Discrete power measurement is particularly practical in cases where it is necessary to analyse the engine in precisely defined modes, for example, at certain speed.

Figure 3 shows the engine power curve as a function of rpm, with power values recorded using discrete measurement. In the low rpm range, the differences between the two curves are minimal. The engine power with additive is only slightly higher, indicating that the additive does not have a significant effect on the combustion process in this rpm range. The engine exhibits similar characteristics with both types of fuel. In the mid-range (1500–3000 min^{-1}), the difference between the two curves is most pronounced. The engine

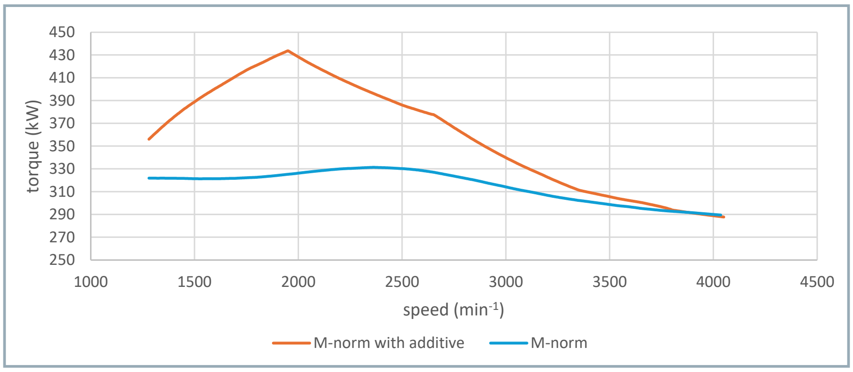

Fig. 4 Comparison of torque with and without additive by discrete method

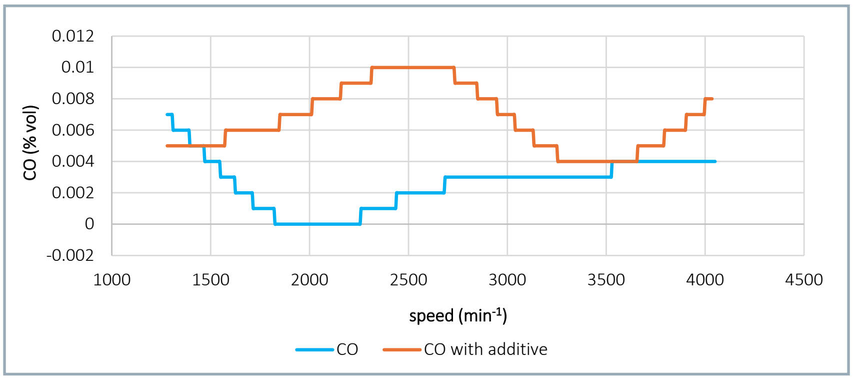

Fig. 5 Comparison of CO with and without additive by discrete method

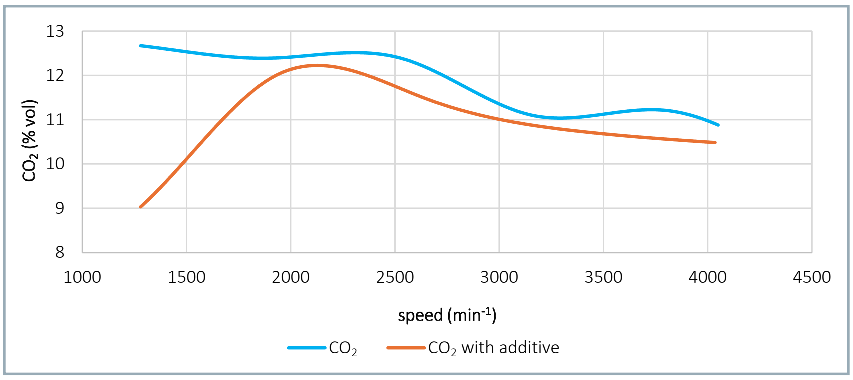

Fig. 6 Comparison of CO_2 with and without additive by discrete method

with additive achieves higher power, with the maximum difference being approximately 20 kW at 2000 min^{-1}.

Figure 4 shows the engine torque curve as a function of rpm, obtained by discrete measurement. In the low rpm range, a visible difference between the two curves is apparent. At 1350 min^{-1}, the engine achieves a torque of approximately 367 Nm when using the additive, while without the additive, the values are around 321 Nm. As the rpm increases, this difference significantly enlarges. The most pronounced difference is recorded in the mid-range rpm, where the engine with additive reaches its maximum torque of 433 Nm at 1950 min^{-1}. In contrast, the engine without additive reaches a maximum of only 330 Nm at 2500 min^{-1}. This represents a difference of more than 100 Nm in favour of the fuel with additive, which is an extremely significant improvement. At rpm around 4000 min^{-1}, the two curves almost meet, indicating that the effect of the additive is minimised at high rpm.

Based on Fig. 5, it is evident that the carbon monoxide (CO) content in exhaust gases when using the additive is higher in some rpm ranges than without the additive. This effect is most pronounced in the mid-range rpm (around 2000–3000 min^{-1}), where CO values with the additive reach higher levels. However, the precision of the measuring device, which is 0.01 ppm for CO, must be taken into account. It can therefore be stated that the difference in CO emissions before and after using the additive is not greater than the measurement error.

Figure 6 shows the carbon dioxide content in exhaust gases as a function of engine rpm. At low rpm, up to 2000 min^{-1}, the CO_2 content when using the additive is significantly lower than without it. At 1500 min^{-1}, the difference is 10 vs 12.5% vol., which represents a 20% difference. As the rpm increases, the CO_2 content when using the additive gradually increases and approaches the values without the additive. At higher rpm (3000–4000 min^{-1}), both curves show a slight decrease in CO_2 values, remaining relatively close to each other at approximately 10.5–11.5% vol. In this

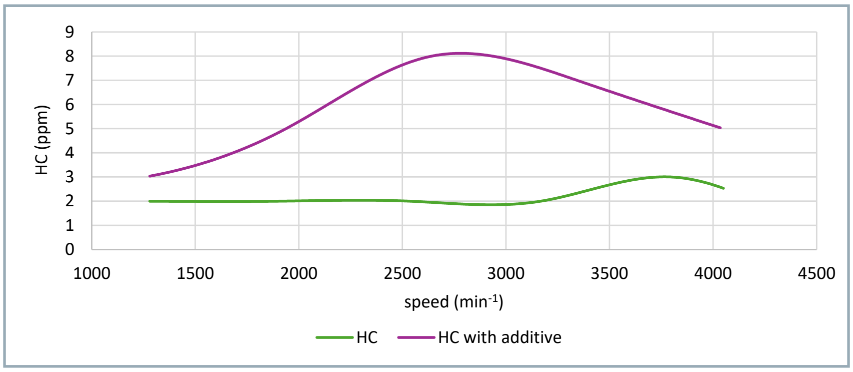

Fig. 7 Comparison of HC with and without additive by discrete method

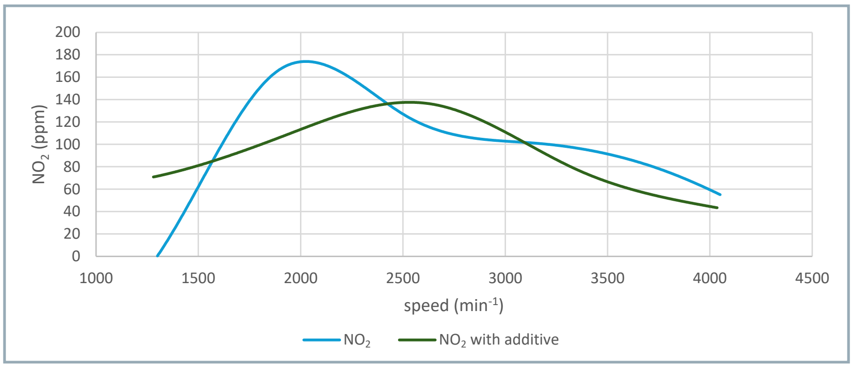

Fig. 8 Comparison of NO_2 with and without additive by discrete method

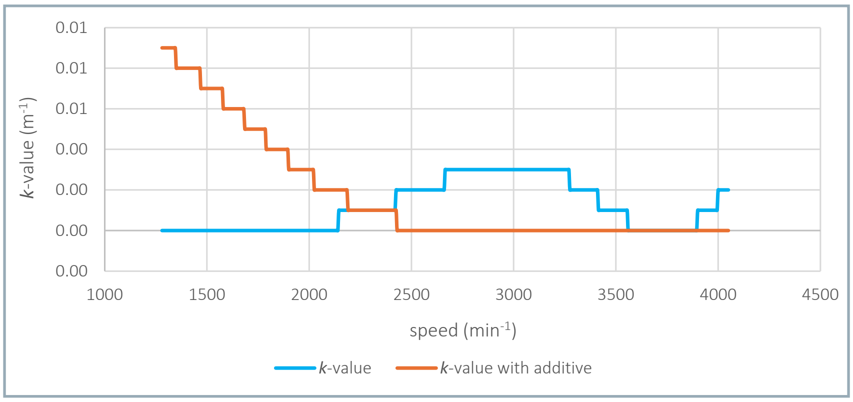

Fig. 9 Comparison of smoke with and without additive by discrete method

mode, the effect of the additive on CO_2 production is relatively small.

Figure 7 shows the hydrocarbon (HC) content in exhaust gases as a function of engine rpm. At low rpm (around 1000–1500 min^{-1}), the HC content when using the additive is slightly higher than without it. This difference indicates that fuel combustion is less efficient, leading to increased production of unburned hydrocarbons. As the rpm increases between 2000 and 3000 min^{-1}, the HC content when using the additive significantly rises, reaching a maximum of around 8 ppm. Without the additive, the HC content remains relatively stable at approximately 3 ppm.

Figure 8 shows the nitrogen dioxide (NO_2) content in exhaust gases as a function of engine rpm. At low rpm up to 1500 min^{-1}, the NO_2 content when using the additive is higher than without it. This increase can be due to a lean mixture (higher lambda), which leads to higher combustion temperatures and thus increased NO_2 formation. At mid-range rpm, the NO_2 content reaches its maximum for both modes. Without the additive, the maximum is higher (approximately 174 ppm at 2000 min^{-1}), while with the additive it reaches lower values (around 137 ppm at 2550 min^{-1}).

Figure 9 shows the *k*-value. The *k*-value is a quantity that expresses the degree of smoke opacity of exhaust gases, i.e., the concentration of solid particles in exhaust gases. It is given in the unit of m^{-1} and is an important indicator of combustion quality and engine condition, especially for vehicles with diesel engines. In the lower rpm spectrum, the smoke opacity value for fuel with additive is higher, at the level of 0.01 m^{-1}, and subsequently decreases. The smoke opacity values for fuel without additive are below the level of 0.01 m^{-1}. However, the measurement precision of the MAHA MET 6.3 instrument is 0.01m^{-1}, so it can be stated that the difference in smoke opacity between the fuels is at the level of measurement error. Overall, the figure shows that the engine's smoke opacity is very low in all modes, which is typical for modern diesel engines with a functional particulate filter.

Statistical evaluation of measured data

Tables 4 to 6 show the basic statistical indicators for the individual measured engine variables under two alternatives – without additive and with additive in the fuel. From the comparison of average values, it is evident that after adding the additive to the fuel, the average values of CO, HC, O_2, lambda, and *k*-value increased, while the average values of CO_2 and NO_2 decreased. This indicates that the additive caused a richer mixture and an increase in the production of some pollutants, but at the same time reduced the production of carbon dioxide and nitrogen oxides.

The *T*-test results show all differences between the variables without additive and with additive. *P*-values below 0.05 mean that they are statistically highly significant. As the *p*-values are extremely low, the statistical significance of the differences is proven. This means that the effect of the additive on all the monitored parameters is demonstrable and not caused by chance. Overall, it can be stated that adding the additive to the fuel has a significant impact on all the monitored emission and operational parameters of the engine. The results show not only changes in average values, but also in the variance and stability of individual variables, which points to a complex intervention in the combustion process and engine operation.

Fuel additives have various effects on the functioning of the internal combustion engine, improving combustion itself as well as the function of engine accessories by removing deposits. Therefore, we can divide these effects into the following categories:

Influence on the fuel system

The additive cleans the critical fuel system components, as supported by scientific studies. Injector cleaning dissolves deposits, improving fuel atomisation and combustion efficiency, which correlates with increased mid-range torque. Deposit removal ensures consistent fuel flow, enhancing low-rpm engine responsiveness. Paradoxically, temporary CO emission increases during mid-rpm operation can stem from dislodged deposits altering transient combustion dynamics.

Influence on the turbocharger

Performance gains at lower and mid-rpm suggest turbocharger optimisation. Carbon deposit removal from turbine blades improves air compression efficiency, boosting torque and throttle response. Concurrently, optimised turbocharger function enhances air-fuel ratio control, aligning with observed CO_2 reduction and O_2 level changes.

Table 4 Statistical evaluation of power and torque values

Measured value	P (kW)		Mk (Nm)	
Alternative	**with additive**	**without additive**	**with additive**	**without additive**
Average with measurement tolerance	97.34 ±1.95	87.41 ±1.75	360.19 ±7.20	315.32 ±6.31
Standard deviation	18.95	22.86	46.65	13.40
Coefficient of variation	0.19	0.26	0.13	0.04
***T*-test**	1.4E-136		2.1E-1180	

Table 5 Statistical evaluation of CO, CO_2, and HC emission

Measured value	CO (% vol)		CO_2 (% vol)		HC (ppm)	
Alternative	**with additive**	**without additive**	**with additive**	**without additive**	**with additive**	**without additive**
Average	0.00	0.01	11.86	11.08	2.19	6.11
Standard deviation	0.00	0.00	0.63	0.76	0.37	1.57
Coefficient of variation	0.62	0.30	0.05	0.07	0.17	0.26
***T*-test**	2.6E-125		4.25E-84		2.8E-231	

Table 6 Statistical evaluation of O_2, NO_2, lambda, and *k*-value emission values

Measured value	O_2 (% vol)		NO_2 (ppm)		lambda		*k*-value (m^{-1})	
Alternative	**with additive**	**without additive**	**with additive**	**without additive**	**with additive**	**without additive**	**with additive**	**without additive**
Average	3.96	4.82	107.41	96.32	1.24	1.31	0.00	0.00
Standard deviation	0.94	1.04	38.94	29.26	0.07	0.10	0.00	0.00
Coefficient of variation	0.24	0.22	0.36	0.30	0.06	0.07	1.03	1.58
***T*-test**	1.19E-54		4.9E-18		2.28E-52		0.000323	

Complex effect

The additive exerts systemic improvements: mid-rpm CO increases indicate a richer mixture for higher torque output, while cleaner injectors enable efficient fuel atomisation and energy release. Synergistically, enhanced fuel system cleanliness and turbocharger performance enable optimal low-rpm operation, demonstrating holistic combustion process optimisation (Woldetensy et al., 2025).

Fuel additives influence the cleanliness of the combustion process and engine accessories by removing and preventing deposits, as additives contain detergent components that dissolve carbon deposits on injectors, intake valves, and piston rings, prevent the adhesion of impurities to critical components of the fuel system, thereby maintaining optimal fuel flow, and remove existing deposits during combustion (Daud et al., 2022; Huo et al., 2022; Pielecha et al., 2023).

Another study by Zerda et al. (2001) examined the effect of additives on the microstructure of deposits, thereby reducing their adhesion to engine surfaces. Deposits formed when using additives have a smaller internal pore area, which indicates their lower resistance.

Pach (2024) deals with the effect of the additive on the formation of soft particles, which are the main cause of deposits in high-pressure injectors. Tests with biodiesel blends have shown that additives stabilise the fuel and reduce the risk of inorganic deposit formation.

Xu et al. (2015) also monitored the effect of fuel additives on spark-ignition engines. They concluded that additives create a protective film on the surface of injectors, which prevents the adhesion of deposits. Optimised additive chemistry increases their effectiveness in removing deposits.

Other publications deal with the influence of additives on combustion itself in the internal combustion engine. The authors state that there is an improvement and stabilisation of combustion, an increase in the octane/cetane number, an increase in the heating value of the fuel and thus an improvement in the thermal efficiency of the engine. The authors also state that some elements in additives can improve the thermal conductivity of the fuel, thereby accelerating and improving fuel burnout (Daud et al., 2022; Latiff et al., 2013).

In other studies, the influence of additives on exhaust emissions is investigated. The results show that adding an additive to the fuel increased the thermal efficiency of the engine and reduced the specific fuel consumption. The emissions of CO, hydrocarbons, and particulate matter were reduced. The added additive thus improved the combustion process and reduced the production of pollutants. Adding a nitro-additive to diesel fuel reduced exhaust smoke opacity, reduced NO_x emissions, and improved combustion efficiency. The additive prolonged the ignition delay period, increased the proportion of premixed combustion, and improved the overall engine efficiency (Yin et al., 2022; Ergin et al., 2019).

Conclusion

The evaluation of the formulated hypotheses:

Hypothesis 1

Does the selected fuel additive affect the engine's performance characteristics?

The data show that the use of the additive has a statistically significant impact on the engine's performance characteristics:

- Average engine power increased from 87.41 kW to 97.34 kW, representing an increase of approximately 11.4%.
- Average torque increased from 315.30 Nm to 360.19 Nm, representing an increase of approximately 14.2%.
- Low *p*-values of the *T*-test (1.4E-136 for power and 2.1E-118 for torque) confirm that these differences are highly statistically significant.

From the graphs, it is evident that the additive has the most significant impact in the mid-rpm range:

- For power, the most significant difference is in the 1500–3000 min^{-1} range.
- For torque, it reaches different maximums of 427.5 Nm at 2295 min^{-1} with the additive and 380.8 Nm at 3260 min^{-1} without the additive.

The results indicate that there is a significant, statistically confirmed difference in performance characteristics before and after using the additive.

Hypothesis 2

Does the selected fuel additive affect the vehicle's emissions?

The data show the following changes in average emission values:

- CO increased from 0.00 to 0.01% vol., which is, however, a difference at the level of measurement error.
- CO_2 decreased from 11.86 to 11.08% vol. (a reduction of approximately 6.6%).
- HC increased from 2.19 to 6.11 ppm (an almost threefold increase).
- O_2 increased from 3.96 to 4.82% vol. (an increase of approximately 21.7%).
- NO_2 decreased from 107.41 to 96.32 ppm (a reduction of approximately 10.3%).
- The lambda value increased from 1.24 to 1.31 (a shift towards a leaner mixture).
- The *k*-value (smoke opacity) increased from 0.00 to 0.01 m^{-1}, which is, however, again a difference at the level of measurement error.

Differences in the measured parameters before and after adding the additive to the fuel may have two causes. One of them is the chemical properties of the additive itself, which affect the combustion process, and the other is the chemical effects on the combustion chamber and engine accessories. It can be stated that the observed improvement in performance and changes in emissions are probably the result not so much of a direct effect on fuel combustion from the perspective of the cleaning effect of the additive on the fuel system and turbocharger components, which leads to more efficient combustion and better utilisation of energy from the fuel. Differences in the power and torque curves after adding the additive are significant, especially in the ramp-up at low and medium rpm. It is probable that for this reason, there was also an increase in exhaust gas emissions in this rpm spectrum, which are proportional to the amount of fuel and air supplied.

These conclusions can also be confirmed by the subjective feeling from driving, where even before the second measurement itself, the vehicle felt noticeably livelier with better throttle response and acceleration from low rpm.

During continuous and discrete measurement, a different maximum power was measured, with the one from discrete measurement being slightly lower. We attribute this to the fact that the continuous test is fast, while the discrete test takes a considerably longer period, where the vehicle is held at the preset measurement points. At the same time, a greater influence on the lower power could have been insufficient ram air cooling of the vehicle, as the vehicle has a higher ground clearance, which caused a larger part of the air from the radial fan to go under the car and not directly onto the charge air cooler.

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