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TESTING OF SELECTED FUEL ADDITIVE IN DIESEL ENGINE

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The aim of this paper was to evaluate the influence of the fuel additive „VIF Super diesel additive winter mixture“ on the observed parameters of a vehicle with a diesel engine. The effect of the additive was investigated on Citroën C4 with a 1.6 HDi engine with a mileage of over 159,000 km. The testing of the effect of the additive took place in laboratory conditions on a cylindrical stool. The test vehicle's exhaust gas treatment system included an exhaust gas recirculation, an oxidation catalyst, and a particulate filter. The power, energy (fuel consumption), and emission (NO_x , k -value, smokiness in %) parameters of the vehicle were monitored without the additive, after adding the additive to the fuel, and then after driving 3600 km with the additive. We found a small increase in vehicle power after driving 3600 km with the additive by 1.86%, a slight reduction in fuel consumption by 4.2%, and a significant decrease in emission parameters. The NO_x emissions were reduced by 9.96% after the first measurement with the additive and after the second measurement with the additive by 8.64%. The smokiness expressed by the absorption correction factor decreased after 3600 km with the additive by 35.48%, and the smokiness expressed as a percentage decreased by 33.8%. The overall impact of the additive on the power, energy, and emission parameters of the tested vehicle after analysis is evaluated as positive.

Keywords: consumption; engine power; emission limits; emissions; exhaust gas analyser; VIF

Motor vehicles, as we know them today, have been produced for over a century. Combustion engines go through various technological modifications either for the purpose of increasing energy efficiency, reducing fuel consumption and emissions from exhaust gases, or for the purpose of reducing production costs and thus also the final price of the product. Vehicles with combustion engines emit harmful substances contained in exhaust gases into the atmosphere. These harmful components are responsible for the formation of smog and acid rain. Pollutants in exhaust gases include CO , HC , NO_x , PM , and others (Matějovský, 2005; Müllerová et al., 2011; Skráčaný and Šarkan, 2017; Kalghatgi, 2019; Polerecký et al., 2019; Jing et al., 2020; Wen et al., 2022). Pollutants are formed primarily from the interruption of reactions due to short residence time in the combustion chamber, the inhomogeneity of the mixture due to different air-fuel ratios, the influence of the walls of the combustion chamber, etc. The introduction of ever new emission standards forces manufacturers to develop new systems to reduce the production of harmful components. There are two categories into which all technologies for the reduction of harmful components of exhaust gases from diesel engines can be classified. The first one is active emission control by which it refers to those technologies that improve the quality of the combustion process and thus reduce the production of pollutants (Lee et al., 2013; Polóni et al., 2017; Šmerda et al., 2013; Lendák et al., 2014; Ďurčanská et al., 2015; Rapp et al., 2016; Angelovič et al., 2020; Synák and Synák, 2022; Zhang et al., 2023). It can be exhaust gas recirculation (EGR), active modification of particulate matter and NO_x emissions. The second option is passive emission control technologies which have very little or no effect on engine power. Among the basic devices for additional treatment of exhaust gases

from diesel engines are diesel oxidation catalyst (DOC), particulate filter (DPF), tank catalyst (LNT), selective catalytic reduction (SCR), and various combinations of these systems. In addition to the technical condition of the engine, the production of pollutants is also significantly influenced by the quality of the fuel (Jaworski et al., 2015; Třebický, 2015; Basshuysen and Schaefer, 2016; Kozak, 2016; Sarkan et al., 2017; Janoško and Kuchar, 2018; Jablonický et al., 2022; Kristyadi et al., 2022; Tulik et al., 2024). The quality indicators of the fuel can also be increased additionally with various fuel additives. The aim of this paper is to evaluate the impact of the VIF Super diesel additive winter mixture on the power, emission, and energy parameters of the tested vehicle. The importance and benefit of this research is significant, as the possible path of decarbonisation and harmful impurities is preferred quite a bit. These ingredients bring an effective reduction of harmful substances; although these benefits are known, there is quite a bit of distrust and scepticism because few results or almost no credible results are published in this area. This research is currently of great importance also from the point of view of the European Commission's "Green Deal" plan for the green transformation of the European Union's economy for the sake of a sustainable future and effective reduction of emissions until transition to other alternative sources of energy (STN EN 590:2023; Slovak Republic Decree no. 228/2014; Regulation 2019/631 of the EU).

Material and Methods

Material used

To carry out the research, a Citroën model C4 vehicle (Fig. 1) was used. The vehicle was manufactured in 2013



Fig. 1 Measured vehicle Citroën C4



Fig. 2 The selected additive in a 500 ml package

and is powered by a 1.6 dm³ diesel engine. The reduction of harmful components of exhaust gases in the vehicle is ensured by the oxidation catalyst and the particulate filter, which form a single unit and are located in close proximity to the engine. The vehicle had travelled more than 159,000 km before the initial measurement. During the research, the vehicle was equipped with the Continental WinterContact TS 860 tires with a winter pattern of size 205/55 R16. Table 1 shows the basic technical parameters of the tested vehicle.

During the entire course of the research, propellants are replenished from SLOVNAFT gas stations. Classic diesel with the designation EVO Diesel B7 will be pumped, i.e. with a maximum of 7% biocomponent. The manufacturer declares that diesel fuel in all parameters meets

the requirements of the technical standard STN EN 590. For testing, an additive VIF labelled Super diesel additive winter mixture will be chosen. The additive is intended for all diesel engines, including modern ones with solid particle filters, Euro 5 and Euro 6. The manufacturer declares an increase in the lubricity of the fuel, an increase in the cetane number, an improvement in the cold start of the engine, the suppression of fuel foaming in the tank, an improvement in the filterability and fluidity of the fuel in winter, and corrosion protection. The additive contains 2-ethylhexyl-nitrate, aromatic hydrocarbons C10, naphthalene. The Austrian manufacturer LANG CHEMIE recommends choosing a mixing ratio with diesel of 1 : 1000 (Slovnaft, 2024). The selected additive is shown in Fig. 2.

Devices used

An external fuel flowmeter from AIC Systems AG with type designation AIC-5004 will be used to measure consumption. A flowmeter with an accuracy of $\pm 1\%$ in the entire measurement range will be used. The flowmeter connects to the vehicle's fuel system in the engine compartment. The composition of emissions in the exhaust gases will be measured using the MAHA MGT 5 exhaust gas analyser, the MAHA MDO 2 LON smoke meter, and the relevant MAHA emission software. MAHA MGT 5 is an exhaust gas analyser (HC, CO, CO₂,

Table 1 Technical parameters of the examined vehicle

Engine	Diesel, turbocharged, direct high-pressure injection
Designation/engine code	1.6 HDi/9HP (DV6DTED)
Cylinder displacement	1560 cm ³
Maximum power/at rpm	68 kW/4000 min ⁻¹
Maximum torque/at rpm	230 Nm/1750 min ⁻¹
Curb weight	1313 kg
Fuel tank volume	60 l
Emission class	EURO 5
The highest design speed	180 km·h ⁻¹
The number of kilometres driven	159,140 km



Fig. 3 MAHA MGT 5 exhaust gas analyser and MDO 2 LON smoke detector

O₂, NO_x) and also serves to calculate the lambda value. The accuracy of measurement is 32–120 ppm vol. MDO 2 LON is an opacimeter that serves for quick testing and diagnosis of smoke, both during free acceleration and during simulated vehicle load. Both devices are shown in Fig. 3.

A cylindrical stool of the German manufacturer MAHA with type designation MSR 500/3 4WD will be used to measure the performance parameters together with the MCD 2000 communication desk. The extensive range of operating modes includes static power measurement at constant revolutions, constant speed, constant tractive force, and dynamic power measurement with adjustable acceleration. The accuracy of the cylinder test facility specified by the manufacturer is $\pm 2\%$. In order to always ensure the same or approximately the same engine temperature as its cooling, the MAHA AIR 7 radial fan (MAHA, 2015) will be used.

Methodology of measurements

- Fixing the vehicle, preparing and placing the measuring devices in accordance with the applicable regulations and warming up the engine to operating temperature.
- Initial measurement of the power of the combustion engine (number of repetitions 3 times).
- Initial time measurement of emission parameters at a steady simulated engine load (number of repetitions 3 times). The monitored parameters were power (P), revolutions (nm), NO_x, absorption correction factor, smoke percentage, and fuel consumption. The emission limits that the vehicle must meet are as follows: NO_x 0.1580 g·km⁻¹; absorption correction factor 0.51 m⁻¹, and fuel consumption 4.1 l·100 km⁻¹.
- According to the manufacturer, choosing a mixing ratio with diesel in a ratio of 1 : 1000 and simulated driving on the cylinder test bench without load for 30 min, in order to mix the fuel with the additive.
- The calculation of the correction factor Ka according to the standards EWG 80/1269, SAE J1349, JIS D 1001:

$$K_a = \left[\left(\frac{990}{p} \right)^{0.7} \cdot \left(\frac{T}{298} \right)^{1.5} \right] fm \quad (1)$$

where: K_a – correction factor; p – the atmospheric pressure on the cylinder test bench (mbar); T – the air temperature in the cylinder test bench (K); fm – a characteristic parameter for each engine type (norm = 0.3)

- The measurement of engine power after adding the additive (number of repetitions min. 3 times).
- The time measurement of emission parameters at a steady simulated engine load after adding the additive (number of repetitions 3 times).
- The re-measurement of emission parameters at a steady simulated load and the measurement of engine power after driving 3600 km ± 50 km from the first application of the additive.
- Emissions measurements were carried out at the traction force $F = 700$ N, revolutions $n = 2730$ min⁻¹, and the fourth gear engaged. The speed of the vehicle varied between 101.5 km·h⁻¹ and 102.5 km·h⁻¹ with parameters set in this way. The time interval of steady driving was 90 seconds, from which the 30 seconds interval with the most uniform speed curve was selected when processing the results. The monitored parameters were power, NO_x, absorption correction factor, smoke percentage, and fuel consumption.

Result and Discussion

Initial vehicle power parameters

In the initial measurement, we obtained the starting values of the corrected engine power according to the EWG 80/1269 standard, the actual engine power and torque. The vehicle manufacturer declares a normalised engine power of 68 kW at 4000 min⁻¹; the values measured by us on the cylinder test bench were 71.4 kW at 3825 min⁻¹. The torque value given by the manufacturer is 230 Nm at a speed of 1750 min⁻¹; the value measured by us is 239 Nm at 2267 min⁻¹.

The power parameters of the vehicle after the addition of the additive

After mixing the additive into the fuel, we performed five measurements of power parameters. From the average values, it follows that the motor power has slightly increased after correction by the EWG 80/1269 standard, specifically by the value of 0.62 kW. In case of the actual power without correction, the increase is only 0.5 kW. A graphical representation that compares the values before and after the addition of the additive is in Fig. 4. In addition to the faster and slightly steeper onset of power, the graph also shows the onset of torque already at lower speeds.

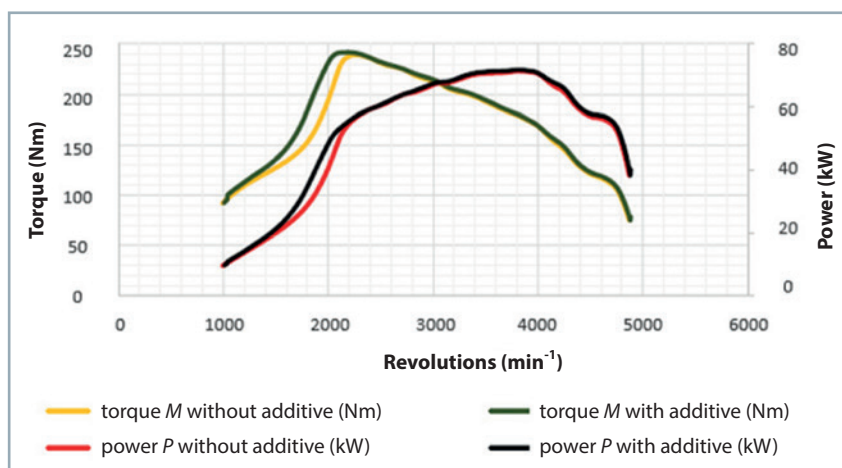
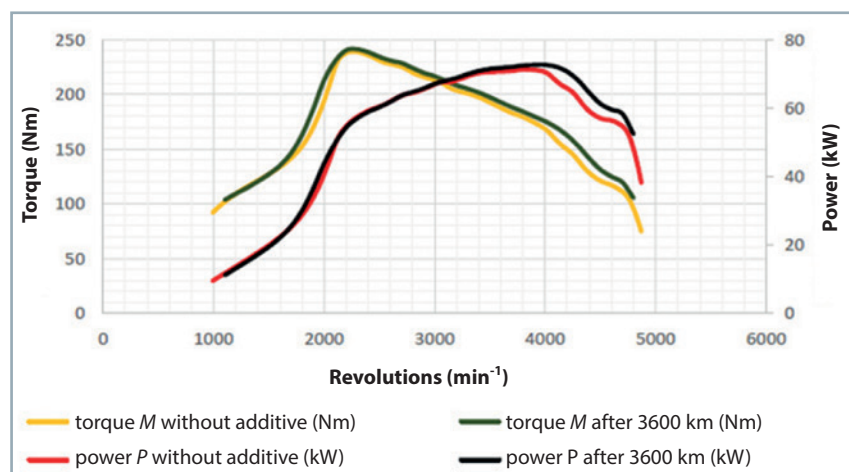


Fig. 4 Comparison of external speed characteristics of investigated vehicle before and after the addition of the additive

Table 2 Comparison of vehicle power parameters, without and with the additive

Performance information	Manufacturer	Without additive	With additive	After 3600 km with additive
Corrected engine power P_{norm} (kW)	68	71.4	72.02	72.73
Engine power P_{mot} (kW)	68	72	72.5	73.4
Maximum power at rpm (min^{-1})	4000	3825	3758	3981
Maximum torque M_{norm}/rpm (Nm)/(min^{-1})	230/1750	239/2267	242/2160	243/2175

**Fig. 5** Comparison of external speed characteristics of investigated vehicle before and after 3600 km with the additive

The power parameters of the vehicle after driving 3600 km with the additive

From the measured values of the last series of measurements, the corrected power increased by 1.33 kW (+1.86%) after driving 3600 km with the additive compared to the initial power measurement, and the real power without correction increased by 1.4 kW (+1.94%). In Fig. 5, it is possible to observe a slight increase in the power course in the range from 4000 to approximately 4700 revolutions per minute. The course of torque has also improved slightly.

Results from power and torque measurements are shown in Table 2.

The values of fuel consumption and emission parameters before the addition of the additive

The measurement was carried out during simulated driving with engine load. The interval in which the values were assessed was chosen with regard to the most even revolutions possible. The time dependence of measured data before the addition of the additive is shown in Fig. 6.

Fuel consumption and emission parameters after the addition of the additive

There was a decrease in values for almost all measured parameters, compared to the measurement without the additive. The NO_x emissions dropped by 9.96% immediately after the addition of the additive. The value of the absorption correction factor remained unchanged.

Fuel consumption and emission parameters after driving 3600 km with the additive

The measurement after driving 3600 km consisted of two phases of measurements. When measured in the first phase from the interval

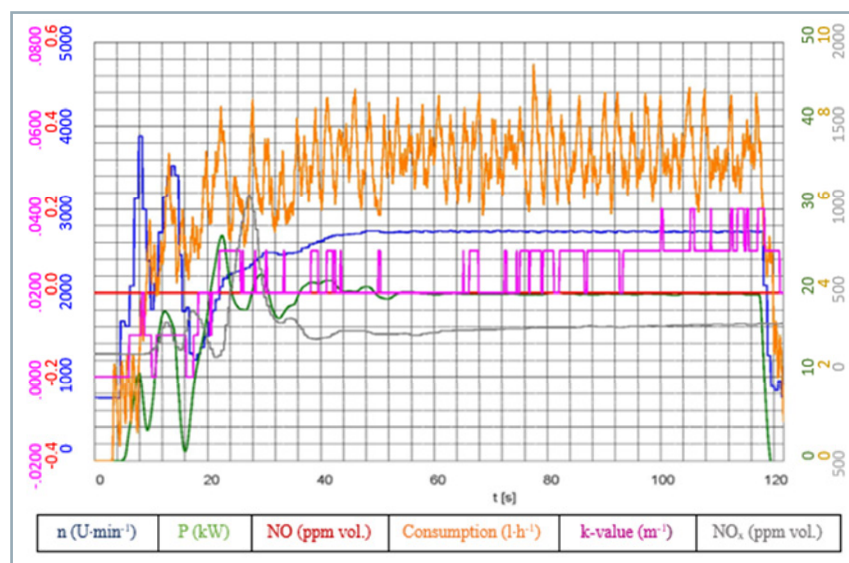
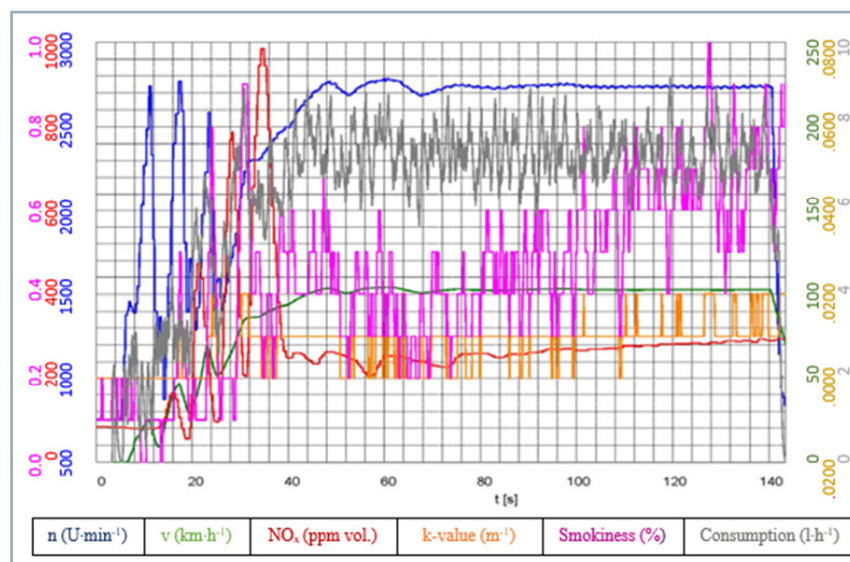
**Fig. 6** Time dependence of measured data before the addition of the additive

Table 3 Comparison of individual parameters without and with the additive

Measured parameters	Time of measurement	Values	Standard deviation	Variation coefficient
NO_x (ppm)	before the addition of the additive	311.20	14.79	0.047
	after the addition of the additive	280.19	4.79	0.017
	measurement with the additive after 3600 km (before DPF regulation)	287.90	18.21	0.063
	measurement with the additive after 3600 km (after DPF regulation)	284.32	4.80	0.017
Absorption correction factor (m⁻¹)	before the addition of the additive	0.03	0.00	0
	after the addition of the additive	0.03	0.02	0.666
	measurement with the additive after 3600 km (before DPF regulation)	0.02	0.01	0.5
	measurement with the additive after 3600 km (after DPF regulation)	0.02	0.01	0.5
Smokiness (%)	before the addition of the additive	1.56	0.17	0.109
	after the addition of the additive	1.04	0.05	0.048
	measurement with the additive after 3600 km (before DPF regulation)	1.03	0.36	0.349
	measurement with the additive after 3600 km (after DPF regulation)	1.03	0.49	0.476
Fuel consumption (l.h⁻¹)	before the addition of the additive	7.62	0.33	0.043
	after the addition of the additive	7.37	0.45	0.061
	measurement with the additive after 3600 km (before DPF regulation)	7.26	0.38	0.052
	measurement with the additive after 3600 km (after DPF regulation)	7.30	0.39	0.053

**Fig. 7** Time dependence of measured data after the addition of the additive and driving 3600 km

of 100 seconds, the values of smoke (purple curve) and absorption correction coefficient (orange curve) increased significantly. One of the possible causes could be the ongoing regeneration of the particulate filter. That's why we decided to perform its forced regeneration through self-diagnostics. Subsequently, in the second phase, we continued with five measurements of emission parameters and fuel consumption. The measured and calculated average values as well as the standard deviation and variation coefficient from both phases, i.e. before and after regeneration of the DPF filter, are shown in Table 3.

The measured values of emission parameters after the regeneration of the DPF filter clearly disprove that the reason for the abnormal increase in values in the first phase of measurements was the ongoing regeneration process of the DPF filter. It is obvious that during the measurement after filter regeneration, an unknown process took place in the combustion chamber,

which increased the values of smoke and the correction coefficient of absorption. However, despite this fact, the mentioned values are lower compared to the initial measurement, the value of the absorption correction factor dropped by 33.3% and the smoke level dropped by 33.97%. The measured values from the measurements of emission parameters and consumption under simulated engine load are shown in Table 3, and the time dependence of measured data after the addition of the additive and driving 3600 km is shown in Fig. 7.

It can be concluded that the fuel additive used has a positive effect on the power, emission, and energy parameters of the vehicle. The corrected performance of the vehicle after driving 3600 km with the additive increased by 1.86%. In terms of the emission characteristics of the vehicle, there was a decrease in all monitored parameters. In case of NO_x emissions, there was a 9.96% decrease immediately after the addition of the additive, and after driving 3600 km with the additive, NO_x emissions dropped by 8.64% compared to the measurement without the additive. This is a proportional reduction of particles compared to the original condition without the additive transposed to the EU Regulation 715/2007*630/2012J, which indicates the units $\text{g}\cdot\text{km}^{-1}$ for NO_x emissions. However, for this, it is necessary to capture the exhaust gases in special bag chambers, but such a test device was not available. The value of the absorption correction factor did not decrease immediately after mixing the additive, which means that the additive does not have an immediate effect on the values of the absorption correction factor. The smoke value expressed as a percentage immediately after mixing the additive decreased by 33.34%. Compared to measurements without the additive, after driving 3600 km with the additive, the smokiness expressed by the absorption correction factor decreased by up to 35.48%, and the smokiness value expressed as a percentage decreased by 33.8%. Fuel consumption dropped by 3.29% immediately after the addition of the additive and by 4.2% after driving 3600 km with the additive.

Balušík (2017) carried out similarly focused research with the same fuel additive. The mentioned author investigated the effect of the additive on the power, energy, and emission parameters of Škoda Octavia I with a 1.9 TDI engine. He states that by using the fuel additive, vehicle power increased by 10.25%, NO_x decreased by 29.2%, and fuel consumption decreased by 3.39%. In these values, a certain similarity can be seen with the results achieved by us in the presented work. However, it should be added that the mentioned author examined a vehicle manufactured in 2002 with more than twice the mileage (388,000 km).

A different conclusion was reached by Novosad (2019), who tested the same VIF Super diesel additive winter mixture. The author investigated the effect of the additive on the operating parameters of Volkswagen Passat with a 2.0 TDI engine and manufactured in 2011. After mixing the additive into the fuel, the power of the vehicle increased by 0.72% only. Compared to our results, Novosad (2019) reports the opposite effect of the additive on fuel consumption. In his case, fuel consumption increased by 1.86%.

Janoško and Feriancová (2019) assessed the impact of the VIF additive used in diesel fuel on improving the power and emission parameters of the vehicle and its consumption. The results of experimental measurements partially show the positive effect of the selected additive on the fuel consumption and emissions of the tested passenger car. The NO_x emissions decreased by 4%, but fuel consumption increased by 1%; therefore, the VIF manufacturer's claims of a 5% reduction in fuel consumption were not confirmed by these authors' measurements.

Podskalan (2021) carried out similar research, with the testing of the same VIF additive on a Škoda 100 vehicle. The author came to the same conclusion that the NO_x emissions were reduced by 11.71% with the fuel additive. When measuring fuel consumption, a reduction of 5.44% was recorded after adding the VIF additive.

Conclusion

The aim of this research was to assess the influence of the selected fuel additive on the power, energy, and emission characteristics of a vehicle with a diesel combustion engine. Experimental measurements were carried out on a Citroën C4 vehicle with a 1.6 dm^3 diesel engine by using the VIF Super diesel additive winter mixture. The experiments performed with the diesel engine showed the following findings:

- Based on the measured values of the power parameters, it can be concluded that the vehicle is in a good technical condition and the tested additive has a minimal effect on the performance of the vehicle.
- The power of the vehicle after driving 3600 km with the additive increased by only 1.86%. NO_x emissions were reduced by 9.96% after the first measurement with the additive and by 8.64% after 3600 km with the additive. The smokiness expressed by the absorption correction factor decreased after 3600 km with the additive by 35.48%, and the smokiness expressed as a percentage decreased by 33.8%. In terms of the vehicle's energy parameters, fuel consumption was reduced by 4.2% due to the additive.
- From the results achieved, the effect of the additive on the power, energy, and emission parameters of the tested vehicle can be evaluated as positive.

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