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Evaluation of the fuel commercial additives effect on exhaust gas emissions, fuel consumption and performance in diesel and petrol engine

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Abstract. The paper deals with the impact assessment of the additives used in diesel and petrol fuel to improve the power and emission parameters of the vehicle and its consumption. The usage of additives in engine fuels have an increasing tendency. The manufacturers claim that additives have positive impact on engine operating parameters, cleaning the fuel supply system and decreasing fuel consumption by improving the engine combustion process. Based on the above statements, measurements were performed to determine change in the engine parameters utilising additives. Measurements were performed under laboratory conditions on the MAHA MSR 500 test bench (dynamometer) to simulate free driving cycle selected by authors, which were carried out at constant engine speeds and constant load. Focus have been given on tracking of the vehicle's external speed characteristic and measurement of selected parameters: CO, HC, O_2, fuel consumption (petrol engine) and smoke, fuel consumption (diesel engine). Resulting values of the driving cycles measured before and after additives application have been then compared. The result of experiment confirmed that tested fuel additives improved performance and torque depending on engine mileage and fuel type. Tested diesel engine with the higher mileage (approx. 388 k km) showed significant increase in power (cca 3.57%) and torque while in newer petrol engine (approx. 73 k km) improvement has not been measured. Emissions were improved in both engines. Difference has been also measured in fuel economy as in petrol engine consumption insignificant increased while in the diesel engine it decreased. This paper brings new complex view on energetical and emission changes in internal combustion engines.

Key words: fuel additive, emission, fuel consumption, engine speed characteristic.

INTRODUCTION

The increase of road transport (especially the individual transport) is a worldwide problem in the major part of cities. The fast growth of the world population and industrial development is linked with an increasing consumption of fossil fuels. Fossil fuels, besides their benefits in terms of tradition and mastered processing technology, have many disadvantages (Jindra et al., 2016). The increasing traffic intensity brings many negative impacts. The most significant negative impacts of transport include the noise, vibration and production of harmful exhaust emissions as CO, CO_2, NOx, HC and particulate matters. The exhaust gases emitted from the engine often get into the human respiratory tract and may cause headaches, irritation of the mucous membranes in eyes and throat and cause cancer (Küüt et al., 2015). The oxides of nitrogen and sulfur which are emitted by internal combustion engines can result in acid rains (Fayyazbakhsh & Pirouzfar, 2017). Globally, the road transport sector is one of the main sources of carbon dioxide emissions and pollution. Therefore, the reduction of emissions from this sector is one of the key objectives in order to meet the Kyoto Protocol and create a sustainable transport system (Beleov et al., 2017).

The combustion of hydrocarbon fuels results in emissions of various kinds. The gaseous pollutants from diesel engines mainly contain carbon monoxide (CO), nitrogen oxides (NOx), sulphur oxides (SOx), hydrocarbons (HC) and small particles (Colbeck et al., 2011; Ma et al., 2011). Nitrogen oxides are usually generated during combustion at high temperature and its concentration increases with the engine combustion efficiency (Yanowitz et al., 2000; et al., 2012). Exhaust gases, thus products of combustion are one of the most serious shortcomings of internal combustion engine (Janoško 1994; Lenďák et al., 2014). To decrease negative impact of the emissions on the environment and mankind it is necessary to establish a regular inspection of the exhaust gases of diesel engines. When air is used as the oxidant, it is always the most significant component of the nitrogen N_2 content in the combustion process. The oxygen O_2 occurs in the exhaust gas, when the entire content does not apply to the fuel oxidation, because there was excess of the fresh air or it has not been used for other reasons (closing in fuel beam, etc.). Oxidation of NOx, which consists mainly of NO_x and a smaller amount of nitric oxide NO_2 is generated in the combustion chamber at high temperatures (Králik et al., 2016). The relationship between the quality of the mixture with the amount and composition of exhaust gases and technical condition of the engine has a great diagnostic meaning (Ogunmola et al., 2013; Jukl et al., 2014).

In order to meet the increasingly strengthened exhaust emissions regulations, much effort has been put into improving existing fuels or innovating novel fuels as well as developing new engine generations (Khalife et al., 2017).

The fuel adulteration method is widely accepted by many researchers, to achieve specific fuel properties to improve performance and achieve good emission control of diesel engine without any modification of the existing engine. There can be used various types of additives, based on different chemical principles such as alcohol, organometallic, nitrate etc. Each of these types has different effects on the parameters of combustion engines (Song et al., 2006; Gidney et al., 2010).

The basic requirements of all catalysts as fuel additives to conventional fuels are: The additive should decrease the exhaust emissions as well as increase the oxidation intensity in the engine. It is necessary to maintain the typical operational properties of engines. If catalytic additives are mixed with fuel, their chemical stability in the mixture must be retained under all conditions. Catalytic additives should not decrease the working effectiveness of the particulate filters and catalytic additives should not increase the emissions of environmentally harmful substances (Polonec & Janosko 2014; Shaafi et al., 2015).

The fuel type associated with a change in the combustion process results in the formation of particle shape and shows that the particle size and number distribution emitted is closely related to the physical and chemical properties of the fuel, suggesting that an increase in the proportion of oxygen in the air–fuel mixture due to the addition of an oxygenate, can lead to a significant change in size distribution and number of emitted particles with one or another fuel blend. Some experiments using combustion engines with oxygenated fuels have reported an emission reduction of total hydrocarbons, CO, and smoke, which means a reduction of PM (Gürü et al., 2002; Barrios et al., 2014).

Several additive manufactures such as: Castrol TDA, STP, Liqui Moly, Sheron, Ekolube, Valvoline, VIF and Tectane claim that their products improve technical state of fuel injection system by cleaning and improve cold engine starts, increase octane number. Some manufacturers guarantee decreases of fuel consumption in range of 2–7% and improvement in emissions. For testing, we chose an additive from company Lang Chemie whose name is VIF because it is one of the most commonly used in Central Europe.

MATERIALS AND METHODS

The aim of the contribution was to evaluate the effect of selected Super diesel and Super benzin additive from VIF manufacturer on the power and emission parameters along with the fuel consumption for the diesel and petrol engine with different mileage. The tested vehicles are Škoda Octavia (Fig. 1) category M1 with the 1.9 TDI diesel engine with a rotary injection pump and Renault Clio (Fig. 2) category M1 with 1.2 L petrol engine. The vehicle's main parameters are displayed in Table 1.

Figure 1. Tested vehicles Škoda Octavia 1.9 TDI (388 k km).

Figure 1. Tested vehicles Renault Clio 1.2 (73 k km).

Table 1. Main parameter of tested vehicle

Vehicle	Škoda Octavia	Renault Clio
Year of manufacture	2002	2008
Engine type	ASV	D7FG7
Cylinders capacity	1,896.0 cm^3	1,149.0 cm^3
Emission regulations	EURO 3	EURO 4
Post-treatment emission systems	NKAT, EGR	NKAT
Highest engine power/speed	81 kW / 4,150 min^{-1}	43 kW / 5,250 min^{-1}
Maximum vehicle design speed	191 km h^{-1}	158 km h^{-1}
Operating weight	1,275 kg	1,010 kg
Number of driven axles	1 / front	1 / front
Tires	195 / 65/ R15 – Barum Polaris 3	175 / 65 / R14
Number of driven kilometres	388,546	73,523

Characteristics of working mediums

Škoda Octavia car used fuel from brand Slovnaft. It was a basic range of fuel without the additive with the trade name Tempo plus winter diesel. Pumped diesel fuel met the requirements of standard EN 590 and also satisfies the conditions of the World Association of Automobile Manufacturers.

Renault Clio used Shell FuelSave Natural gasoline with 95 octane number and winter specification. The gasoline must meet the norm STN EN 228 and law number 725/2004 Z.z. In the both tank contained approximately 25 litres which was half the capacity of the tank.

VIF additives (Fig. 3) has been chosen as it is well known and often used in real world. It is sold in a plastic bottle with volume of 125 mL. In Škoda with diesel engine, Super diesel additive was used. It is a product constructed on the basis of 2-ethylhexyl nitrate ($C8H17NO3$), the manufacturer indicates improvement in the cetane number by 5 units, better combustion, reduced engine noise and lower fuel consumption by 5%.

Figure 3. Used additives by VIF.

In Renault, Super benzin additive was used which is constructed on the polyether basis. The additive should improve fuel consumption by 5 to 7%, keeps the engine and the fuel system clean, improves the lubrication properties of the fuel and protects the injection from wear.

The additives serve to improve 40 to 60 litres of fuel. In the tests, the entire volume of the additive was used, ensuring a dosing ratio of up to 1: 200 respectively 0.125 L additive: 25 L fuel.

Characteristics of the instruments

Due to inaccurate measuring of fuel consumption by a vehicle on-board computer, it was necessary to use a different, more accurate system. We used an AIC-5004 Fuel Flowmaster (Fig. 4) external fuel meter from AIC SYSTEMS AG (accurancy ± 1%, the uncertainties K = 2) which joined the car's fuel system in its engine compartment. Due to the fact that the device is connected to a performance dynamometer, it does not need a display unit, but the data is displayed along with the other measured variables on the roller dynamometer. This makes it possible to read the exact values of a specific amount of fuel in specific engine operating modes.

Figure 4. External fuel meter AIC-5004 Fuel Flowmaster by AIC SYSTEMS AG.

Performance dynamometer by the German manufacturer MAHA (Fig. 5) with the designation MSR 500 (accurancy ± 2%, the uncertainties K = 2) with the possibility of measuring 4-wheel drive have been used to measure the performance of the vehicles. Air temperature in laboratory was 21–24 °C, relative humidity 26.8–27.5% and air pressure 994.2–995.6 hPa. From this and other parameters MAHA calculated the corrected performance according reg. EWG 80/1269.

Figure 5. Performance roller dynamometer MAHA MSR 500.

Exhaust gas analyser, model MGT 5 / MDO2 – LON (Fig. 6) by brand MAHA have been used to detect quantity of emissions in the exhaust gas. It is a dual instrument to record the production of both petrol and diesel emissions. Accurancy and measurement uncertainties of analyser: accuracy CO = ± 0.06%, the uncertainties CO K = 0,012, accuracy HC = ± 12 ppm, uncertainties HC K = 1.2, accuracy smoke = ± 0.6%, uncertainties smoke K = 2.0).

During the measurement of the petrol engine emissions were measured carbon monoxide CO (% of vol.) and unburned hydrocarbons HC (ppm) and in diesel engine smoke was measured (m^{-1}).

Figure 6. Exhaust gas analyser – MGT 5 / MDO2 – LON by brand MAHA.

Similarly, as the fuel flow meter, the device is connected to a performance dynamometer, which allows recording and displaying, in addition to the normal emission tests, the quantity of emissions produced depending on the combustion engine operation mode.

Methology of measurement

Experimental measurements of a vehicle with a gasoline and diesel engine were divided into two levels:

At the first level, the engine speed during the entire operating speed range as well as the maximum power and torque values through the MAHA MSR500 cylindrical test were measured and rated. This is a standardized test of measurement.

At the second level, fuel consumption and exhaust emissions were measured and monitored. Focus has been given on the tracking of selected parameters during the selected free driven cycle proposed by the authors, which were performed at constant engine speeds and constant load. The operating engine speed was set at 3,500 rpm and the brake bench load set to 150 N in constant setting. The CO_2, HC, O_2 and fuel consumption were measured with the gasoline engine. The smoke and fuel consumption were measured with the diesel engine.

The process of measurement lasted 150 seconds, from which a 30 second steady state was subsequently selected. These measurements were repeated 5 times prior and 5 times after adding the additive to the fuel for all parameters of the engines, which together is 20 measurements.

The measurement process itself consisted of several important steps: fixing the car on the roller, connection of the flowmeter, exhaust gas analyser, oil temperature probe and pairing the vehicle via OBD diagnostics with a computer to record all values from the control unit and the devices to the computer. After completion of the initial steps, the engine had to be warmed to the operating temperature to ensure the most accurate and trusted results.

It was necessary to calculate and analyse measured parameters using the basic following relationships:

Calculation of performance

$$P = M_k . \omega = M_k . 2 . \pi . n \text{ (kW)} \quad (1)$$

Calculation of torque

$$M_k = \frac{P}{2.\pi.n} \text{ (Nm)} \quad (2)$$

The quantity of fuel consumed for the selected period of time

$$V' = V_{x1} - V_{x2} \text{ (dm}^3 \text{ 30 s}^{-1}) \quad (3)$$

Hourly fuel consumption

$$V = \frac{V' . \rho_{fuel}}{t} \cdot 3{,}600 \text{ (kg hod}^{-1}) \quad (4)$$

RESULTS AND DISCUSSION

Based on the external engine speed characteristics obtained from the MAHA performance dynamometer, it was possible to assess and compare the performance parameters of the vehicles. As can be seen in Table 2, after comparing the results, it was concluded that the diesel power increased by 4.4 kW and torque by 5.97 Nm. Increase in power by 0.5 kW and torque by 0.55 Nm for petrol engine was in range of dynamometer measurement inaccuracy. Therefore, we do not consider measured values for petrol engine as significant in terms of performance improvement.

Table 2. Comparison of average performance parameters before and after adding additive to diesel

Vehicle	Parameter	Before using the additive	After using the additive
Renault Clio	Corrected performance [P_{norm}]	47.75 kW	48.25 kW
	Torque [M_{norm}]	93.2 N m^{-1}	93.75 N m^{-1}
Škoda Octavia	Corrected performance [P_{norm}]	83.80 kW	88.2 kW
	Torque [M_{norm}]	240.2 N m^{-1}	246.17 N m^{-1}

For a more complex assessment, not only the highest values are important, but also the overall performance of the speed characteristic. Figs 7 and 8 presents the overlap of the power curves before and after the addition of the additive. Significant difference can be seen mainly in speed characteristic of diesel engine. Speed characeristic after application of additive approximated factory set speed charateristic.

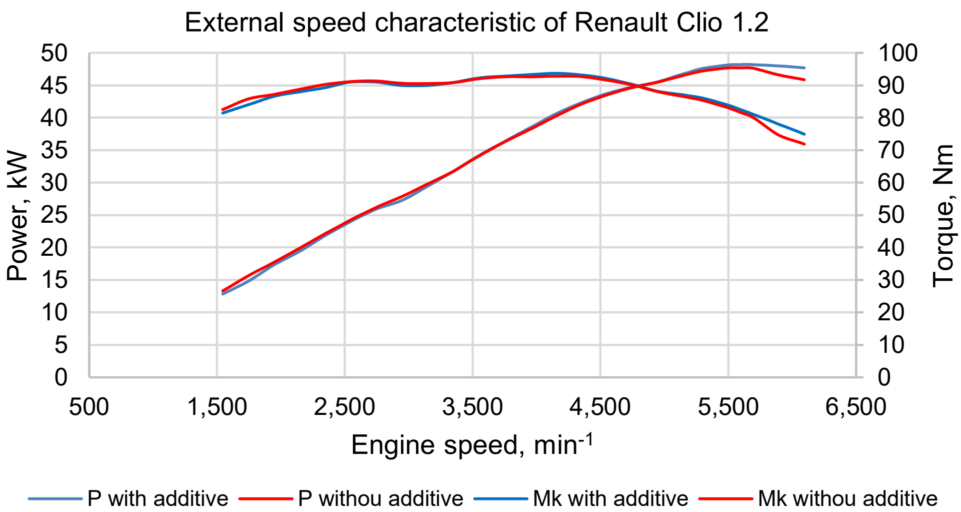

Figure 7. Comparison of average performance and torque curves before and after adding additive to gasoline.

For the Renault Clio 1.2, the manufacturer states a max. power of 45 kW at 5,250 rpm. During the experiments, the power output at these revolutions was measured at 47.2 kW prior additive usage and 47.6 kW after additive usage, which statistically does not represent a fundamental difference. For the Škoda Octavia 1.9 TDI, the manufacturer states max. power 81kw at 4,200 rpm. At these revolutions, the power of 80.87 kW was measured prior additive usage and 83.76 kW after the additive usage which represents a draw of 3.57%.

Another examined parameter was the influence of fuel additive on engine emissions. This was performed as a sequence of 5 consecutive measurements before and 5 measurements after addition within the specified time range.

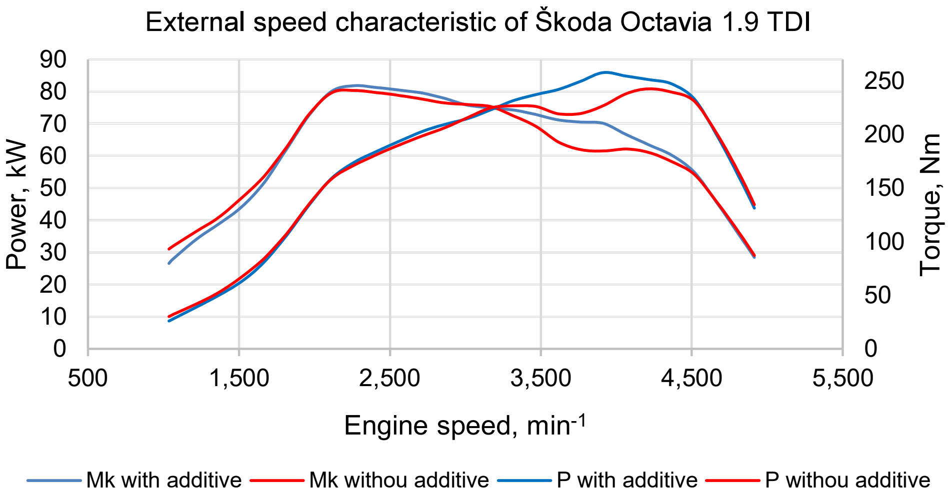

Figure 8. Comparison of average performance and torque curves before and after adding additive to diesel.

Similarly, to the measurement of emissions (Figs 9–12), we measured the fuel consumption by using a flow meter that was connected to the fuel system of the car. The values of these measurements were averaged and statistically analysed. The results are shown in Tables 3 and 4.

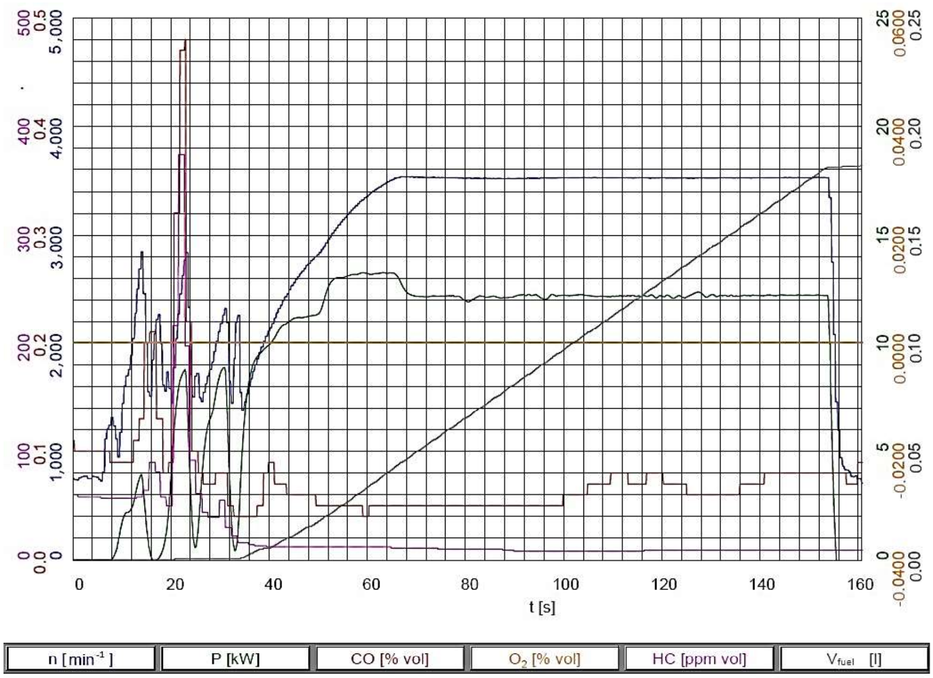

Figure 9. Sample of Renault Clio 1.2 time dependencies of measured parameters: power, speed CO, O_2, HC, fuel consumption before adding additive.

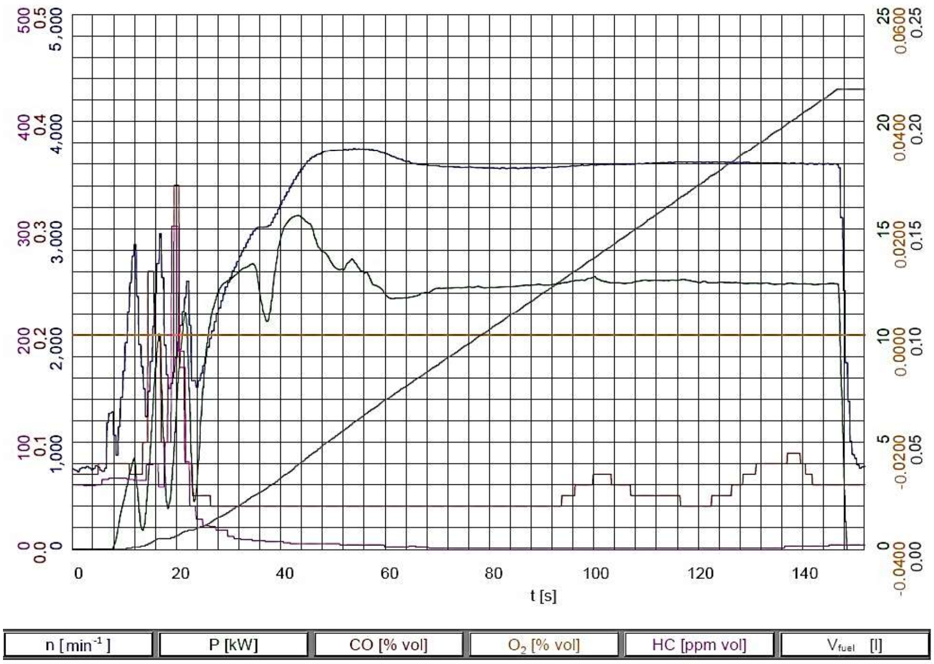

Figure 10. Sample of Renault Clio 1.2 time dependencies of measured parameters: power, speed CO, O_2, HC, fuel consumption after adding additive.

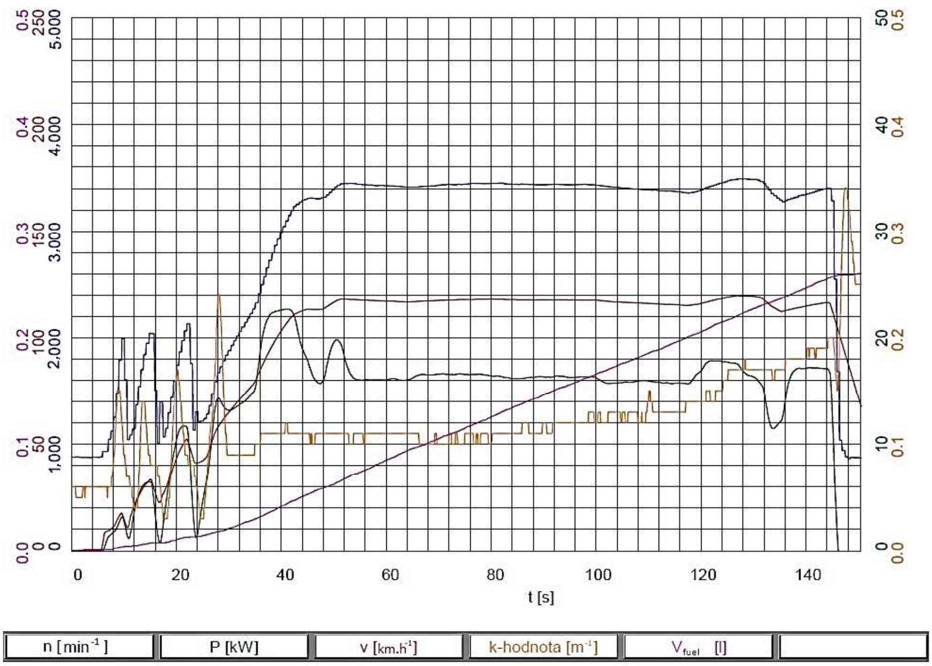

Figure 11. Sample of Škoda Octavia 1.9 TDI time dependencies of measured parameters power, speed, k-value, fuel consumption before adding additive.

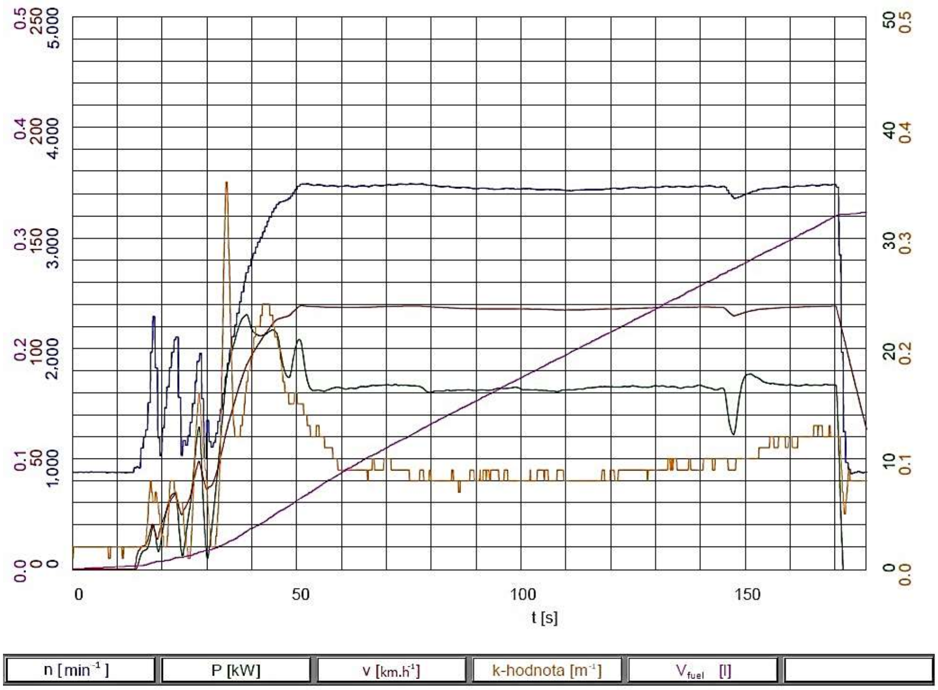

Figure 12. Sample of Škoda Octavia 1.9 TDI time dependencies of measured parameters power, speed, k-value, fuel consumption after adding additive.

Table 3. The results of measuring emissions and fuel consumption on the Renault Clio

Renault Clio	Time of measurement	Value	Different	Standard deviation	Variation coefficient
Carbon monoxide	before addition	0.083	- 0.033	0.025	0.303
CO (% of vol.)	after addition	0.050		0.043	0.865
Unburned	before addition	11.930	- 7.19	4.344	0.364
hydrocarbons HC (ppmo)	after addition	4.740		8.790	1.855
Fuel consumption	before addition	3.940	+ 0.29	0.185	0.047
(kg hod^{-1})	after addition	4.230		0.076	0.018

Table 4. The results of measuring emissions and fuel consumption on the Škoda Octavia

Škoda Octavia	Time of measurement	Value	Different	Standard deviation	Variation coefficient
K-value (m^{-1})	before addition	0.137	- 0.04	0.022	0.163
	after addition	0.097		0,014	0.014
Fuel consumption	before addition	5.432	- 0.184	0.174	0.092
(kg hod^{-1})	after addition	5.248		0.047	0.009

The results of the experimental measurements show partially the positive effect of the selected additive on the fuel consumption and the emissions of the tested passenger cars.

Measurement in Renault Clio showed that CO emission decreased by 39.76%, HC decreased by 60.27%. However, fuel consumption increased by 7.36% therefore claimed statements by VIF producer to decrease fuel consumption in range of 5–7% for petrol engine has not been confirmed by our measurements.

Measured parameters in Škoda Octavia 1.9 TDI showed that smoke (K-value) decreased by 29.20% and fuel consumption decreased too by 3.39% while VIF producer claims decrease by 5%.

CONCLUSIONS

The aim of the paper was to evaluate the impact of the additives on the vehicle's power and emission parameters along with fuel consumption. This complex approach of additives testing brings more precise answers on energetical and emission changes in petrol and diesel engines.

Experimental measurements were performed in a test laboratory on preselected vehicles. For testing purpose, vehicle Skoda Octavia with engine volume of 1,896 cm^3, 81 kW, 388 k km mileage and Renault Clio with engine volume 1,149.0 cm^3, 43 kW, 73 k km mileage were chosen. Both vehicles were equipped with manual transmission and front-wheel drive. The measurements partiality confirmed the additive manufacturer's claims about emissions improvement, fuel consumption and performance parameters. Upon using the diesel additive, a rather significant difference was noticed for torque and engine power. In the case of a petrol engine, the difference was minor in range of dynamometer inaccuracy. We assume that the gasoline additive does not have a significant effect on the engine's performance parameter, but it has a positive cleaning impact on the combustion chamber.

In conclusion it can be stated that tested diesel engine with the higher mileage (approx. 388 k km) showed significant increase in power and torque while in newer petrol engine (approx. 73 k km) improvement has not been measured. Emissions were improved in both engines. Difference has been also measured in fuel economy as in petrol engine consumption increased while in the diesel engine it decreased.

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