IMPACT OF USING DIFFERENT TYPES OF GASOLINE ON SELECTED VEHICLE PROPERTIES

UDC:662.75
Original scientific paper https://doi.org/10.18485/aeletters.2020.5.4.5

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Abstract:
The article focuses on determining the impact of using different types of gasoline on selected vehicle properties. To perform the measurements, there were six types of gasoline chosen from different gas stations and they differed in price, octane rating, and in an amount of additives and biocomponents. The immediate effect of petrol on engine performance and torque, exhaust gas composition and fuel purchase costs was examined. The results have shown a relatively low impact of gasoline on a vehicle's dynamic properties. The most visible change was measured when comparing the most expensive fuel to the cheapest one. There was an increase in the engine torque from 156 Nm to 160 Nm measured. Such a difference is lower than the deviation of measuring. The differences measured in the composition of the exhaust gases are low. However, there is a significant impact in choice of gasoline on the costs of fuel purchase.

ARTICLE HISTORY
Received: 26.11.2020.
Accepted: 23.12.2020.
Available: 31.12.2020.

KEYWORDS
Acceleration, emissions, fuel, gasoline, power, torque

1. INTRODUCTION

A vehicle can be fuelled by gasoline with different octane rating, content of additives, and different biocomponents [1-3].

An octane rating is a measure of fuel's ability to withstand knocking when ignited in a mixture with air in the engine's cylinder [4]. The engine control unit receives a signal from a knock sensor about the engine knocking [5]. If there is a knock detected, it adjusts the parameters via actuators in order to prevent the engine from knocking since it is a negative phenomenon. If the control unit's activities needed for knocking to be eliminated are considerable, such as adjustment of ignition timing, setting of valve timing and so on, they can affect the engine power and composition of the exhaust gases as well [6]. Gasoline with octane rating from 95 up to 101 is the most commonly available fuel used in most EU countries [7,8]. As seen from [9,10], due to change in gasoline with other octane ratings, actions that could lead to change in the engine power and torque, or in the composition of exhaust gases are usually not required.

There are various amounts of additives added into the gasoline. It is in order to increase the gasoline resilience against freezing or degradations caused by aging and alike [11]. Some distributors indicate that additives in the gasolines with higher price are those which aim to increase the engine power and reduce the amount of harmful emissions in the exhaust gases [12,13]. Despite this fact, the majority of the research results point out to low or almost no effect of gasoline additives supplementation [14]. The publication [15] has shown a significant increase in the engine power by 20%. However, in this case, the amount of additives was substantially higher since they were refilled before measuring.

From January 1st, 2020, the share of biocomponent in the gasoline has increased from 5% up to 10% in the Slovak Republic [16]. The distributors applied this in the gasoline with octane rating of 95. Concerning the gasoline with octane rating of 100 and more as well as premium gasoline,

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there was no increase in the share of biocomponent [7,8,17]. Increase in the share of biocomponent has been achieved by increase in ethanol and ETBE content [18]. ETBE - Ethyl tert-butyl ether production is both financially and technologically demanding, resulting in an additive that eliminates numerous disadvantages of ethanol [19]. According to distributors, gasoline with higher share of biocomponent entails no change in fuel consumption, same engine power and considerably lower CO_2 content in the exhaust gases [20]. However, the research results have not proved a significant impact of ETBE on reducing the CO_2 emissions [21]. Reduction of CO_2 content in the exhaust gases has been done by multiply higher ETBE concentration in gasoline [22].

The purpose of the measurements from this article is to determine the impact of choice of commonly available gasoline on immediate change in dynamic properties of a vehicle, and in the composition of exhaust gases as well. In order to provide better information of the gasoline's impact on dynamic properties of a vehicle, there is a calculation of theoretical vehicle acceleration value given, on the basis of the data measured. The article also contains a calculation of the costs of gasoline purchase depending on kilometres driven and price of gasoline.

For the measurements, a regular naturally aspirated vehicle was chosen. The measurements comprised six different gasolines with different price, octane ratings and biocomponent content. Relating to this, an impact of gasoline on course of the engine power and torque's curves, and on a vehicle's ability to meet legislative requirements in relation to composition of the exhaust gases has been assessed. All the measurements were performed under laboratory conditions.

2. MEASUREMENT METHODOLOGY

The purpose of the measurements was to determine the impact of gasoline on selected vehicle features. These include the course of the engine power and torque's curves and a vehicle's ability to meet legislative requirements in relation to concentration of particular components in the exhaust gases.

The measurements were done with six different gasolines. Their basic data are given in Table 1.

Table 1. Gasolines used during measurement

Gasoline	Octane rating	Price per litre [€/l]
A95	95	1.039
B95	95	1.209
C95 E10	95	1.110
D95 E5	95	1.30
E100	100	1.309
F101	101	1.226

The fuel price per 1 litre belongs to the date of purchasing, i.e. April 23rd, 2020. Concerning gasoline D95 E5, the price corresponds to the date of December 29th, 2019. And consequently, there has been an increase in biocomponent content in the gasoline from 5% up to 10%. Gasolines C95 E10 and D95 E5 are from the same gas station. According to the distributor, gasoline B95 in comparison with A95 is being supplemented by additives in order to increase the vehicle's performance and to reduce the fuel consumption and emissions. The gasoline A95 was from the gas station offering the cheapest gasolines all around.

During the measurements, a vehicle tank was replaced by another tank in order to avoid gasoline to be mixed. Thus, after measuring with one type of gasoline, the external tank was emptied and further replenished by new gasoline. After adding new gasoline into the tank with a fuel pump, a vehicle drove about 20km, and then the tank with new gasoline was emptied and further replenished by the same one. This avoided new gasoline to be mixed with the previous one in the vehicle fuel system. And, the control unit was able to adapt to other types of fuel [23].

Table 2 shows the technical data on the vehicle used in the measurements.

Table 2. Vehicle used for measuring [24]

Name	Kia Ceed 1.6 CVVT
Engine	Spark-ignition
Engine code	G4FC
Engine power/speed	92 kW/6,300 rpm
Engine torque/speed	154 Nm/4,200 rpm
Average fuel consumption	7.2 $l.100km.h^{-1}$
Weight at the time of measuring	1,230 kg
Tyre size	225/45 R 17
Tyre energy class	C
Gear ratio at 1st gear	3.52
Gear ratio in the transfer case	3.65
Coefficient of rotational mass resistance at 1st gear	1.35

Measuring of the engine power and torque was done by cylinder test station MAHA MSR 1050. The measurement accuracy is ±2% from the overall value of power measured [25]. While measuring the course of the engine power and torque's curves, a vehicle gradually reaches the maximum engine speed when having the penultimate gear used and acceleration pedal fully applied, and thus, it can be the course of cylinder power's curve determined. After the maximum engine speed is reached, a driver applies the clutch pedal and leaves the penultimate gear engaged. In this way, through vehicle coasting, the difference between the value of power delivered onto the wheels, respectively onto the dynamometer's cylinders, and the value of the engine flywheel is determined. The value of difference between the value of power delivered onto the dynamometer's cylinders and the value of the engine flywheel represents a power dissipation caused by mechanical losses [26].

Vehicle's ability to meet legislative requirements in relation to concentration of particular components in the exhaust gases has been measured by MAHA MGT 5 device. The composition of exhaust gases was determined at both idling speed and increased speed according to [27] Table 3 shows the legislative requirements for the vehicle used in the measurements.

Table 3. Legislative requirements in relation to concentration of exhaust gas components [27]

Parameter	Engine speed [rpm]	CO [%]	HC [ppm]	λ [-]
Idle speed	510 – 810	0.40	100	-
Increased speed	2,500 – 3,000	0.30	100	0.97 – 1.03

Besides the components from Table 3, CO_2 and O_2 concentrations were determined as well.

The costs of fuel purchasing after driving from 10 000km up to 80 000km per year were also being compared. For the comparison, the fuel consumption of 7.2 l.100 km^{-1}, and the price of litre of gasoline which is the same as in Table 1, were both taken into consideration. Gasoline D95 E5 was not considered in the calculations since it had been bought before a pandemic situation appeared and the costs had been considerably higher.

The impact of gasoline on a vehicle's ability to accelerate was determined by theoretical calculation based on the data measured during the engine power and torque's measurement. Theoretical difference in vehicle acceleration was calculated for those gasolines and engine speed at which the difference measured was the highest one.

The value of engine torque, vehicle mass, overall gear ratio, coefficient of rotational mass resistance, wheel radius, and vehicle rolling resistance are all important for vehicle acceleration [28].

The rolling resistance is calculated according to relation (1):

$$O_v = m \,.\, g \,.\, f \quad (1)$$

O_v is the rolling resistance N],
m is the vehicle mass [kg],
f is the coefficient of rolling resistance [-][29].

The second step of calculation is to determine the force on the wheels according to relation (2):

$$F_{k=} \frac{M_t . i_c . \eta_m}{r} \quad (2)$$

F_k is the force on the wheels [N],
M_t is the engine torque [Nm],
η_m is the mechanical efficiency of the gear,
r is the wheel radius [m] [30].

The value of M_t is being substituted by the values from measurements at which the biggest difference was measured as a result of different gasoline.

Overall gear ratio at 1st gear is given by relation (3):

$$i_c = i_I . i_r \quad (3)$$

i_c is the overall gear ratio [-],
i_I is the gear ratio at 1st gear [-] ,
i_r is the gear ratio in the transfer case [-].

The highest possible value of acceleration resistance can be calculated via relation (4):

$$O_a = F_k - O_v \quad (4)$$

O_a is the acceleration resistance [N],
F_k is the force on the wheels [N],
O_v is the rolling resistance [N].

Then, the maximum vehicle acceleration can be calculated:

$$a = \frac{O_a}{m \,.\, \delta} \quad (5)$$

a is the vehicle acceleration [m.s^{-2}],
O_a is the highest possible value of acceleration resistance,
m is the vehicle mass [kg],
δ is the coefficient of rotational mass resistance [31].

3. RESULTS

3.1. The cheapest gasoline and the most expensive gasoline

Figure 1 shows the results of measuring the course of engine power and torque's curves when using both the cheapest gasoline A 95 and the most expensive gasoline E100. Left vertical axis shows the engine power in kW, the horizontal axis shows the engine speed in revolutions per minute (rpm), and the right vertical axis represents the engine torque in Nm. Red curve corresponds to the course of engine power on its flywheel, and the orange curve represents the course of engine torque. Thick curves are the values measured with the most expensive gasoline E100, and thin dashed curves are with the cheapest gasoline A95.

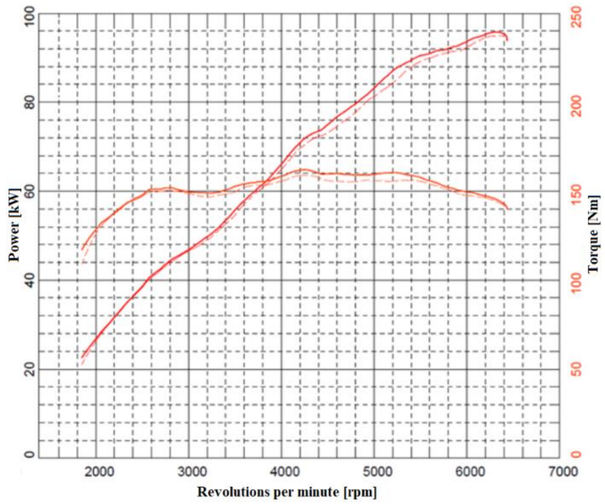

Fig.1. Comparison of the cheapest and most expensive gasoline

As seen from Figure 1, the biggest difference in the engine torque – 4 Nm – has been measured at the engine speed of about 5,200 rpm, and in the engine power – 3 kW – at the same engine speed.

3.2. The gasolines with different octane rating

Figure 2 shows the measurement results where the thick line represents measuring with gasoline A 95 with its octane rating 95, and the dashed thin line represents measuring with gasoline F101 with its octane rating 101.

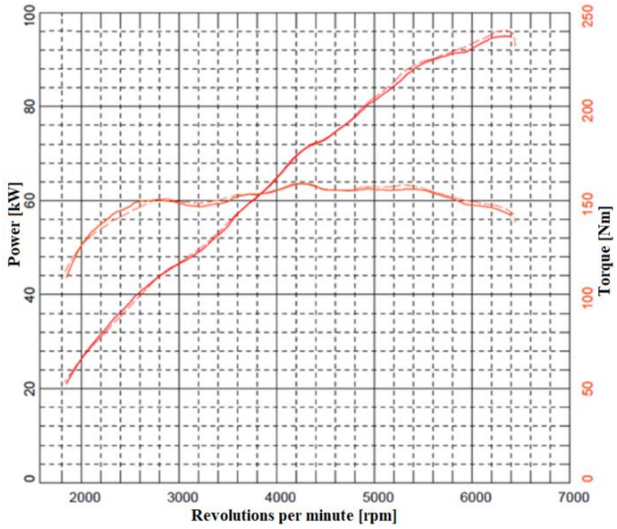

Fig.2. Comparison of gasolines with different octane rating

Concerning the engine torque, the biggest difference – 3 Nm – has been seen at the area of engine speed of 2,770 rpm, and, concerning the engine power, the difference – 1.2 kW – has been seen at the engine speed of 6,287 rpm.

3.3. The gasolines with different biocomponent content

Comparison of gasoline C95E10 with biocomponent content up to 10% - the thin dashed curve, to the gasoline D95E5 with biocomponent content up to 5% - the thick curve, is shown in Figure 3.

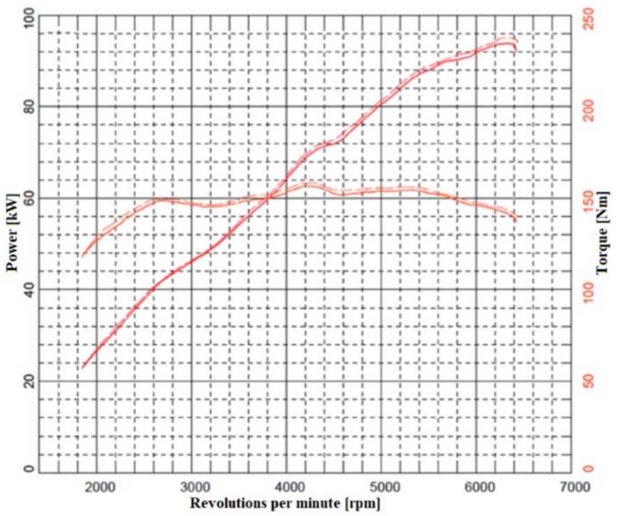

Fig.3. Comparison of gasolines with different biocomponent content

When comparing the gasolines from the same gas station but with different biocomponent content, there were both maximum differences in the engine torque – 2.5 Nm – and in the engine power – 1.2 kW – measured at the engine speed of 4,600 rpm.

3.4. Maximum values measured with particular gasolines

For better transparency, the results of impact of gasoline on the engine power and torque are also given in Table 4. Table 4 shows the maximum values of engine torque in Nm, and maximum values of engine power in kW. Besides these, there is also the engine speed at which the values were measured given in rpm.

Table 4. Maximum values measured with particular gasolines

Gasoline	Highest engine torque [Nm]/Engine speed [rpm]	Highest engine power [kW]/ Engine speed [rpm]
A95	158.0/4,221	94.9/6,284
B95	159.8/4,260	95.6/6,295
C95E10	159.1/4,290	95.0/6,300
D95 E5	156.6/4,195	93,8/6,320
E100	162.0/4,220	95.7/6,285
F101	158.8/4,240	96.1/6,290

As seen from Table 4, change in gasoline has only led to minimum differences in the engine power and torque.

3.5. The impact of gasoline on acceleration

The impact of gasoline on acceleration was calculated for the situation, at which the highest difference in the engine torque due to change in the gasoline, was measured. That situation occurred while measuring with gasoline A95 and E100 (Figure 1). The biggest difference measured was 4 Nm at the engine speed of 5,200 rpm. When using gasoline A95, the engine reached 156 Nm and when using the gasoline E100, the engine reached 160 Nm. After substituting the values from Table 2 and Figure 1 into formulas 1 and 2, the force delivered onto the wheels has been calculated for the gasoline A95 as 5,944 N and for E100 as 6,099 N. After the substitution into formulas 3 and 4, it has been calculated that when using the gasoline A95, it is possible to reach the maximum theoretical acceleration of 3.58 $m.s^{-2}$, and 3.73 $m.s^{-2}$ when using E100, all two at first gear used.

3.6. Impact of gasoline on composition of the exhaust gases

The impact of gasoline on a vehicle's ability to meet legislative requirements in relation to composition of the exhaust gases is evident from Table 5 and Table 6.

Table 5. Impact of gasoline on composition of the exhaust gases – idle speed

Gasoline	CO [%]	HC [ppm]	λ [-]	CO_2 [%]	O_2 [%]
A95	0.00	7	1.003	15.42	0.08
B95	0.00	5	1.002	15.43	0.07
C95E10	0.01	8	1.003	15.50	0.07
D95 E5	0.01	10	1.002	15.42	0.08
E100	0.00	7	1.003	15.44	0.09
F101	0.01	9	1.003	15.39	0.08

Table 6. Impact of gasoline on composition of the exhaust gases – increased speed

Gasoline	CO [%]	HC [ppm]	λ [-]	CO_2 [%]	O_2 [%]
A95	0.07	9	1.000	15.33	0.07
B95	0.05	13	1.003	15.34	0.06
C95E10	0.04	12	1.002	15.25	0.09
D95 E5	0.03	8	1.001	15.52	0.08
E100	0.04	12	1.002	15.34	0.09
F101	0.03	13	1.002	15.37	0.09

The choice of gasoline has had minimal impact on composition of the exhaust gases, and the vehicle has been able to meet all the legislative requirements while using each of selected gasoline.

3.7. The costs of fuel purchase depending on gasoline price

The costs of fuel purchase depending on gasoline price are shown in Figure 4. The gasoline D95 E5 was not taken into the results since it was bought at the time other than the rest of gasoline and its price significantly differed.

Lower axis shows the number of kilometres driven per year, and the vertical axis shows the costs of fuel purchasing in Euros.

As seen from Figure 4, the differences in costs of fuel purchasing are increasing with the number of kilometres driven.

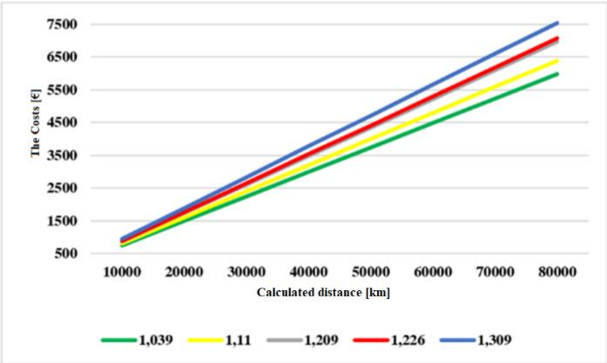

Fig.4. The costs of fuel purchase depending on gasoline price

Figure 5 shows the difference in costs of gasoline purchase depending on number of kilometres driven. The difference calculated is related to purchase of both the cheapest gasoline A95 and most expensive gasoline E100.

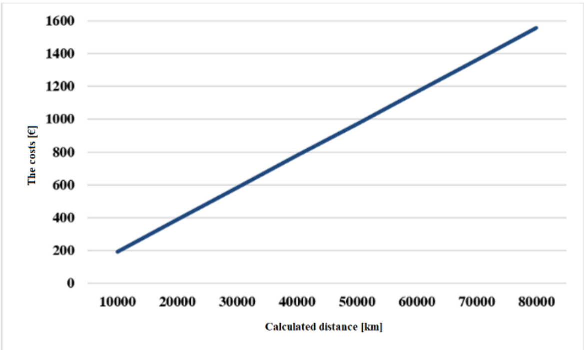

Fig.5. The difference in costs of gasoline purchase depending on number of kilometres driven

Using cheaper gasoline can reduce the fuel costs, especially when there is a higher number of kilometres driven per year, as seen in Figure 5.

4. CONCLUSION AND DISCUSSION

The purpose of the article was to determine the impact of gasoline used on the engine torque, costs of fuel purchasing, vehicle performance, its ability to accelerate and to meet legislative requirements in relation to composition of the exhaust gases.

Concerning the engine power and torque, there was only minimal impact seen. The biggest difference when using the cheapest and most expensive gasoline was 4 Nm and 3 kW as seen in Figure 1. Such a difference is small and in common road traffic difficult to be noticed, although the difference was measured at a broader spectrum of the engine speed, from 3,200 rpm up to the maximum of engine speed [32].

The purchase of 26% more expensive gasoline resulted in an increase in the engine torque by 2.5% and in the engine power by 3.5%. While measuring the engine power and torque, the acceleration pedal is fully applied and, thus, the control unit indicates the maximum amount of fuel. The same amount of fuel was injected in both cases and, therefore, the difference measured was a result of increase in engine energy efficiency, i.e. reduction of specific fuel consumption [33]. Reducing specific fuel consumption and keeping the same amount of fuel led to increase in the engine power. However, increase in the engine power and torque was low at the level of the cylinder test station MAHA MSR 1,050's deviation of measuring.

Similar results have been also measured while measuring the gasoline A95 with octane rating 95 and F101 with octane rating 101 (the second most expensive gasoline), see Figure 2. The differences measured have been slightly smaller as when comparing A95 and F101 fuels. However, both cases imply small differences. When compared to the results from publications [34-36], the differences measured have been considerably smaller. It can be due to fact that the composition of gasoline, the amount and features of additives differ in each state. The results are affected by vehicle used in measurements as well. While measuring with a vehicle that is turbocharged, the differences have been higher regarding octane rating [37-39]. Among the publications compared, the highest increase in the engine power as a result of gasoline octane rating has been measured in the publication [40], see Figure 6.

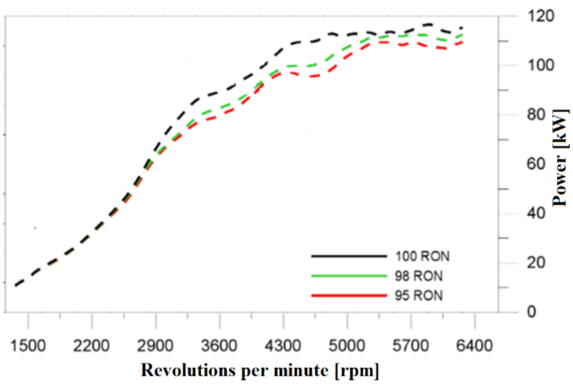

Fig.6. The gasoline octane rating and engine power [40]

As seen from Figure 6, the impact of gasoline octane rating on engine power has evinced predominantly in the higher engine speed. The higher engine speed is also connected with the stronger effect of turbocharger, and, thus, there is a higher inclination to knocking [41]. However, the difference engine power was not only a result of change in octane rating, but there were other factors such as the amount of biocomponent and additives in gasoline and many others [42].

The results from measuring the gasolines C95 E10 and D95 E5 refer to higher engine power and torque covering most of the engine speed area in relation to C95 E10. The reason can also lie in the fact that gasoline D95 E5 was stored in a tank of another vehicle for about 4 months, and it could lead to its degradation [43]. Difference in the engine torque is of about 2%, and in the engine power it reaches the value of 1.6%. 5% difference in the biocomponent content in gasoline caused only a slight change in the engine torque. A major change in the course of engine power and torque would probably happen only after a higher share in biocomponent content. In most cases, higher share in biocomponent content leads to reduction of the engine power and torque as seen in the publications [44-46].

Low impact of gasoline on dynamic properties of a vehicle has been also proved by calculation focusing on theoretical vehicle acceleration. Despite the calculation had being related to the highest difference measured among all the measurements, the calculated differences of force delivered onto the wheels as well as vehicle acceleration were small. When using the cheapest gasoline, the theoretical vehicle acceleration has reached 3.58 $m.s^{-2}$ and 3.73 $m.s^{-2}$ when using the most expensive one. The difference of 0.15 $m.s^{-2}$ in acceleration is very small. What is more, such a difference has covered only a small spectrum of the engine speed of approximately 250 rpm.

Based on the data comparison from Table 3 and Table 5 and Table 6, it can be said that, in this case, gasoline did not affect the vehicle' s ability to meet legislative requirements in relation to composition of the exhaust gases. In all cases the vehicle has complied with road traffic driving and the values of assessed components has been almost constant. Thus, there has not been shown an impact of choice of gasoline on reducing the gaseous emissions that have adverse effects on human health [47]. Fueling the gasoline with higher octane rating and which is of higher price does not have any immediate effect in the case of a vehicle that was used for this measuring. At the same time, the increase in costs of fuel purchasing is relatively high as seen in Figures 4 and 5 as well. However, this article does not focus on the long-term impact of fuel on particular vehicle parameters. This kind of measuring would require two same vehicles that are running under completely identical conditions with different fuels.

Besides the methodology of laboratory experiments, determining the impact of gasoline on selected vehicle characteristics can be also done by computer modelling as seen in [48,49]. Computer simulations can be used for determining the impact of octane rating, additives, and biocomponent in gasoline on the course of the engine power, its combustion and knocking [50-52]. Via computer modelling, there can be also a simulation of the amount of emissions produced [53,54]. Despite all the possibilities of computer modelling, experimental measurements are still irreplaceable, as for their ability to verify the accuracy of computer modelling measurement results. The measurement results in this article are affected by the characteristics and parameters of a particular vehicle used for measuring. These include the engine's technical condition, the piston rings' tightness, the efficiency of a catalytic converter, the lambda sensor's immediate technical condition, the intensity of a lambda sensor's voltage surge, and many others. Thus, the results reflect the impact of choice of gasoline in relation to a common used vehicle, it means in a vehicle commonly seen in road traffic, and, this has been an intention of the article.

Based on the measurements performed, it can be said that from the short-term point of view, the price of gasoline, its octane rating or the amount of biocomponent has not a significant effect on dynamic properties of a vehicle, or on composition of the exhaust gases.

ACKNOWLEDGEMENTS

This research was funded by the Slovak scientific grant agency VEGA of the Ministry of 472 Education—no. 1/0436/18—Externalities in road transport, an origin, causes and economic impacts of transport 473 measures.

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