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Evaluation of the chemical composition of car exhaust gases based on selected parameters

Abstract

The aim of this work is to compare the concentration of chemical compounds found in the exhaust gases of cars supplied with different fuels, depending on the engine speed and vehicle mileage. Testing the exhaust gas composition of low and high mileage cars showed significant differences in emissions. High mileage cars demonstrate higher emissions of toxic exhaust gas components. However, those emissions do not exceed permissible standards and the vehicles may still be operated. A comparison of exhaust emissions from vehicles fueled with LPG and unleaded petrol confirmed the advantage of the gaseous fuel in terms of the emission of toxic components into the surroundings. Tests performed on cars with compression-ignition engines showed a negligible difference in the emission of particulates into the surroundings, despite the differences in exhaust gas treatment systems and the vehicle mileage.

Keywords: exhaust emissions, compression-ignition engine, spark-ignition engine, LPG system.

Ocena składu chemicznego spalin samochodowych na podstawie wybranych parametrów

Streszczenie

Celem niniejszej pracy jest porównanie stężenia związków chemicznych występujących w spalinach samochodów zasilanych różnymi rodzajami paliwa, w zależności od prędkości obrotowej silnika i przebiegu pojazdu. Badania składu spalin samochodów o niskim i wysokim przebiegu wykazały znaczące różnice w emisjach. Samochody o wysokim przebiegu wykazują wyższą emisję toksycznych składników spalin. Emisje te nie przekraczają jednak dopuszczalnych norm i pojazdy mogą nadal być eksploatowane. Porównanie emisji spalin z pojazdów zasilanych LPG i benzyną bezołowiową potwierdziło przewagę paliwa gazowego pod względem emisji toksycznych składników do otoczenia. Badania przeprowadzone na samochodach z silnikami wysokoprężnymi wykazały nieistotną różnicę w emisji cząstek stałych do otoczenia, mimo różnic w układach oczyszczania spalin i przebiegu pojazdów.

Słowa kluczowe: emisja spalin, silnik wysokoprężny, silnik benzynowy, instalacja LPG.

1. Introduction

Despite the dynamic development of electromobility, combustion engines as an energy source are, and will continue to be, a topical issue for many years to come, particularly in the context of the diagnostics of gas emissions and their impact on living organisms (Kęska, 2022). Road traffic can be counted as a significant sector in terms of energy consumption and greenhouse gas emissions. Meanwhile, air quality is deteriorating, which continues to be a key issue related to public health worldwide. Cars are one of the biggest emitters of CO_2 and account for up to 60.6 % of total emissions generated by road traffic (Šarkan, 2022).

Road transport has a significant impact on the economic and social development of every region of the world (Kuranc, 2021; Di, 2023). Road transport has always been a key element ensuring economic growth (Kuppili, 2021). Using a vehicle is very convenient for an individual, but society pays a very high price for that – especially in congested cities, where the number of cars is bigger than in towns. Motor vehicles are a source of air pollution in cities facing various environmental problems. Air pollution is becoming increasingly international.

During engine operation, vehicles produce a variety of gases and particles, called exhaust emissions (Tiwari, 2023). After emission, gaseous and particulate compounds undergo further changes as a result of various atmospheric processes, including oxidation and functionalization by hydroxyl (OH) and nitrate (NO_3) radicals, ozone (O_3) and photolysis. These oxidation processes lead to the formation of secondary PM (particulate matter) in the atmosphere, including secondary organic aerosol (SOA) and secondary inorganic aerosol (SIA) (Hartikainen, 2023).

Air pollution is one of the main causes of global health issues. Today, nine out of ten people breathe polluted air, which causes premature deaths of more than 4 million people every year. One of the causes of environmental degradation is the presence of an increasing number of cars on roads. In particular, old and run-down cars account for a significant proportion of vehicles and machinery equipped with combustion engines. Car exhaust gases are much more harmful to people than industrial exhaust gases, because the former spread in high concentrations at low altitudes in the immediate vicinity of people (Rymaniak, 2021).

Environmental protection is a top priority, which is why various institutions and vehicle designers strive to reduce the amount of noxious compounds emitted with car exhaust gases. It should therefore be emphasized that improving energy efficiency and reducing exhaust emissions are environmental goals of the highest importance in the transport and road traffic sectors (Mijailović, 2019).

Over the last decade, the European Union has sought to reduce greenhouse gas emissions from road traffic, which in the first phase has led to a significant increase in the proportion of more energy-efficient diesel vehicles in the fleet (Hakkarainen, 2020; Zimmer, 2017). However, as diesel oil-powered vehicles are the major emitters of nitrogen dioxide (NO_2) and of greater mass emissions of particulate matter than petrol-fueled vehicles (Hakkarainen, 2020), newer and newer methods of vehicle fueling or other design details for vehicle exhaust systems continue to be sought.

In the transport sector, new renewable and alternative fuels are being introduced and engine cleaning and exhaust gas treatment technologies are being developed as emission standards become more and more rigorous. The Euro 6 emission standard was adopted in 2015 and several steps have been taken to control greenhouse gas emissions in Europe since then. In the evolving field of fuels, engines and emission control technologies, up-to-date and comparable data is needed on both the direct and indirect health and environmental impacts of these technologies. This is necessary to enable landmark decisions to be made to select the best low emission technologies and avoid investment in less efficient ones that could even lead to new emission-related issues (Aakko-Saksa, 2020).

The main NOx reducing technologies in modern diesel vehicles are exhaust gas recirculation (EGR) completed with exhaust gas treatment technologies such as the lean NOx trap (LNT) and/or selective catalytic reduction (SCR). Three-way catalytic converters (TWC) are widely used in petrol vehicles (Mera, 2021).

When investigating two experimental concepts of hydrogen combustion engines, the authors of (Sterlepper, 2021) found that in the case of the petrol engine-based concept, stoichiometric operation requires a three-way catalyst or a three-way NOX storage catalyst as the main exhaust gas treatment system. In the case of the concept based on the compression-ignition engine, state-of-the-art selective catalytic reduction (SCR) catalysts can be used to reduce NOx emissions provided that engine calibration ensures sufficient exhaust gas temperature levels.

The authors of (Shepelev, 2021) developed a generalized mathematical model of the changes in the exhaust gas composition as a function of changes in catalyst resistance, the spark plug gap and electromagnetic nozzle efficiency, and then conducted a technical and economic evaluation. The average return on investment in equipment enabling the implementation of that method was 3.5 months.

The authors of (Kadyrov, 2021) propose the use of ultrasonic radiation to remove particulate matter from the exhaust gases of combustion engines. Those authors proposed an experimental bench and conducted tests, the results of which confirm the feasibility and efficiency of using ultrasonic exhaust gas treatment a result of the particulate coagulation process. The experiment demonstrated the effectiveness of the ultrasound action on motor vehicle exhaust gases and thus proved to be a promising development towards the elimination of noxious pollutants from aerosols with the proposed method. The results of the experiment show that the concentration of hydrocarbons decreased by more than two times. The total weight of soot deposited in the experimental device under the influence of ultrasounds is more than 1.5 times greater than the weight of soot deposited without ultrasounds.

The aim of research presented in this article was to compare the concentration of chemical compounds in exhaust gases from cars fueled with different types of fuel as a function of engine speed and vehicle mileage.

2. Car exhaust gas components

Figure 1 presents the components of exhaust gases from cars equipped with both spark-ignition and compression-ignition engines. The breakdown of the components is presented from the point of view of their influence on the environment and human health.

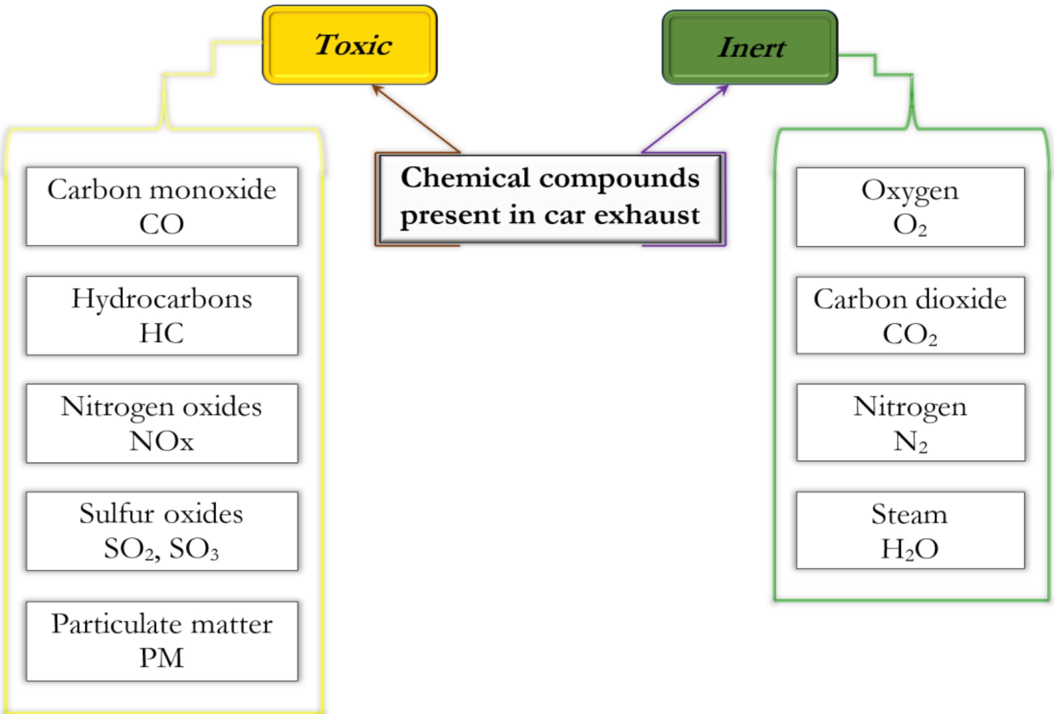

Figure 1. Chemical compounds in car exhaust gases

(source: own study)

In the first group, there are toxic compounds adversely affecting the environment. That group includes:

Carbon monoxide (CO), which is the product of the incomplete combustion of carbon as a result of the small amount of oxygen and the short time required for carbon to burn completely. Carbon monoxide is a colorless and odorless gas.

Hydrocarbons (HC) are unburned or partially burned fuel molecules and come into being in a similar way to carbon monoxide. The most dangerous group are single-ring aromatic hydrocarbons, which include benzene. These compounds are one of the causes of smog formation.

Nitrogen oxides (NO_x) include the following compounds: nitrogen oxide (NO) nitrogen dioxide (NO2) and dinitrogen monoxide (N2O). The volume of nitrogen oxide emissions depends on the combustion temperature and pressure in the engine chamber. Nitrogen oxides are a major cause of photochemical smog (Huang, 2022). NOX emissions directly contribute to a higher level of environmental pollutants such as nitrogen dioxide (NO2), while contributing to the formation of the ground-level ozone (O3) layer and fine particulate matter (Bernard, 2022).

Sulfur oxides (SO2 and SO3) are strongly irritant gases affecting mucous membranes. Sulfur oxides are involved in the formation of acid rain. Sulfur compounds in the exhaust gas can be partly stored in the exhaust gas treatment system at low temperatures and occasionally released at higher exhaust gas temperatures, which leads to the issue of short-term influence of sulfur content in fuel (Rönkkö, 2023).

Particulate matter (PM) is liquid or solid chemical compounds emitted by cars equipped with a compression-ignition engine. The quantity of particulate matter depends on the amount of free oxygen in such a way that the number of particles increases with the enrichment of the air-fuel mixture. Particulate matter contains a quantity of the chemical compounds discussed above. Air deficiency in the combustion chamber results in the formation of soot, which causes smoke. Particulate matter is very small in size, so it persists for a long time in the atmosphere thus affecting the human respiratory system (Lozhkin, 2018; Liu, 2021).

The second group of components in vehicle exhaust gases are chemical compounds that are neutral to the environment. Their excessive presence can cause damage to the environment, however. An example of such a compound is carbon dioxide (CO2). The excessive increase of that compound concentration contributes to the greenhouse effect causing climate change. The compound comes into being in the combustion chamber as a product of carbon combustion.

3. Research methodology

The analysis of exhaust gas chemical composition was made on the following vehicle group:

- cars with the maximum permissible weight of 3,500 kg, equipped with a spark-ignition engine (Group A);
- cars with the maximum permissible weight of 3,500 kg, equipped with a spark-ignition engine and, additionally, an LPG system (Group B);
- cars with the maximum permissible weight of 3,500 kg, equipped with a compression-ignition engine (Group C).

Twenty tests were performed in each vehicle group. The first half of the tested vehicles did low mileage (below 25,000 km) and the other half of the vehicles did high mileage (100,000-250,000 km).

The engines of the cars subjected to exhaust gas chemical composition tests were warmed up to an operating temperature, which is approximately 90oC for the coolant.

Tests for cars with spark-ignition engines were performed at the following engine speeds: 700 rpm (the idle value); 1,500 rpm; 2,000 rpm; 2,500 rpm and 3,000 rpm.

The basic technical parameters of the tested cars are presented in Tables 1-4.

Table 1

Basic technical data of the tested cars (Groups A and B) – low mileage

Year of manufacture	2023
Engine capacity	1498 cm^3
Engine power	150 HP
Torque	250 Nm
Emission standard	Euro 6d
Gearbox	Automatic DSG – 7 gears

(source: own study)

Table 2

Basic technical data of the cars tested (Groups A and B) – high mileage

Year of manufacture	2011
Engine capacity	1498 cm3
Engine power	115 HP
Torque	155 Nm
Emission standard	Euro 5
Gearbox	Manual – 5 gears

(source: own study)

Table 3

Basic technical data of the cars tested (Group C) – low mileage

Year of manufacture	2021
Engine capacity	1997 cm3
Engine power	177 HP
Torque	400 Nm
Emission standard	Euro 6d
Gearbox	Automatic EAT8 – 8 gears

(source: own study)

Table 4

Basic technical data of the cars tested (Group C) – low mileage

Year of manufacture	2003
Engine capacity	2453 cm3
Engine power	135 HP
Torque	310 Nm
Emission standard	Euro 4
Gearbox	Manual – 6 gears

(source: own study)

In the case of cars equipped with a compression-ignition engine, the measurements were performed in accordance with the conditions set out in the Regulation of the Minister of Infrastructure of 27 September 2022 on the scope and manner of the technical inspection of vehicles and on the specimens of documents used in these inspections.

The tests were conducted at a diagnostic station using an exhaust gas analyzer and opacimeter. The view of the measuring stand is presented in Figure 2.

Figure 2. The measuring stand for exhaust gas chemical composition tests

(source: own study)

The chemical composition of exhaust gases for Group A and B vehicles was evaluated with the use of a four gas analyzer.

The analyzer detects compounds such as carbon dioxide (CO2), hydrocarbons (HC), and carbon monoxide (CO). The measurement is based on the absorption of infrared radiation with a specific wavelength for each gas. The analyzer also detects the concentration of oxygen (O2), using the principle of an electrochemical cell, in which electrical voltage is generated with a value dependent on the amount of oxygen. The device also determines the excess air ratio λ, which is based on the oxygen content in exhaust gases. This measurement enables the determination whether the mixture burned by the engine is lean or rich.

Before the measurements, the leak-tightness of the exhaust system must be checked each time, which was also done. The result was successful, making it possible to perform the tests. In the event of a leak in the system, the vehicle would have been disqualified from the measurement until the defect was repaired.

During the tests, engine performance parameters should also be monitored. For that purpose, a measuring probe, installed in the place of the oil dipstick, was used to measure the engine oil temperature. The engine speed was monitored using an induction probe that reads parameters from the ignition cable.

To make the results more reliable, each measurement was repeated three times, and this article includes the averaging values.

Smoke evaluation for Group C vehicles was undertaken with the use of an opacimeter. The device enables the measurement of the range of light flux absorption by exhaust gases as they move along a chamber of a suitably selected length. That measurement permits the determination of the absorption coefficient (k) in the medium with the use of the BEER-LAMBERT law. The result may also be given in the form of the opacity index measured in percentages.

The opacimeter’s operating principle is that during the measurement, exhaust gases pass through the measuring probe into the measuring chamber, where the temperature is approx. 100oC. A light source is placed on one side of the chamber, and the light flux passes through the chamber and into a detector on the other side. If there are exhaust gases in the chamber, part of the light flux reaches the detector and the absorption coefficient is calculated on that basis.

As is the case with the measurements done by means of the analyzer, a leak check of the exhaust system was conducted before the tests here, too. The engine was warmed up to an engine oil temperature of approximately 80oC. The sensor and attachments provided with the opacimeter were used to measure the engine speed and temperature.

Soot particles were also removed from the exhaust system by maintaining maximum engine speed for ten seconds. Once the system was cleaned, the measuring probe was placed in the tip of the exhaust system to a depth of three tip diameters.

To substantiate the results, three measurements were taken for each vehicle and the averaging values are included in this article.

4. Test results

The chapter presents the results of the exhaust gas chemical composition tests of cars equipped with a spark-ignition engine first. Next, the test results for cars with a spark-ignition and LPG system will be analyzed, and finally for cars equipped with a compression-ignition engine.

5. Cars with spark ignition engine

Figure 3 shows the results of measurements of environmentally and humanly harmful chemical compounds in exhaust gases depending on the engine speed of spark--ignition cars with high mileage. Table 5 summarizes the values obtained for carbon monoxide and non-toxic compounds in exhaust gases.

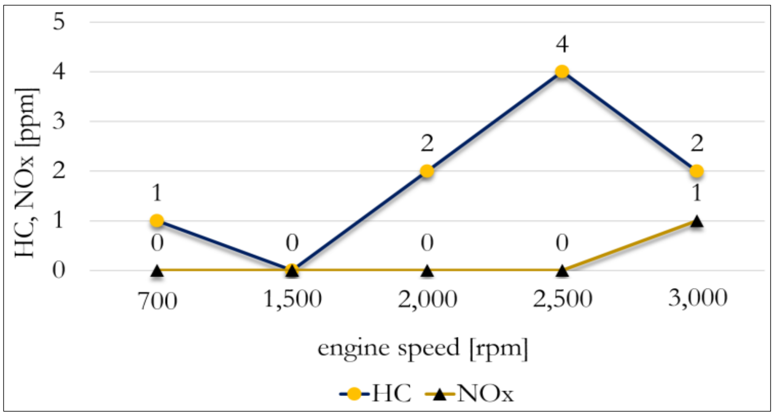

Figure 3. The values for toxic components of exhaust gases as a function of engine speed for a spark-ignition car with low mileage

(source: own study)

Table 5

Other measured components of exhaust gases for a car with a spark-ignition engine and low mileage

	Engine speed [rpm]				
	700	1,500	2,000	2,500	3,000
CO [% by volume]	0.00	0.00	0.00	0.00	0.00
CO_2 [% by volume]	14.5	14.6	14.8	14.9	14.7
O_2 [% by volume]	0.45	0.01	0.01	0.00	0.00
λ	1.021	0.999	0.999	0.998	0.999

(source: own study)

The analysis of the chemical composition of exhaust gases from the low mileage car showed the absence of nitrogen oxides at the engine speed range from idle to 2,500 rpm. At 3,000 rpm, a slight increase in the concentration of that chemical compound was noted. The increase by one unit is noted and the value is finally 1. That value should therefore be deemed to a measurement error and treated as insignificant.

One of the chemical compounds which is hazardous to people, namely carbon dioxide, was noted in the composition of exhaust gases.

The hydrocarbon content in exhaust gases varies with engine speed. The maximum content is 4 ppm. That value is insignificant in terms of standards recommended by Polish legislation. Pursuant to current legislation, the hydrocarbon content in exhaust gases from cars registered after 1 May 2004 must not exceed 100 ppm. The presence of hydrocarbons in the exhaust gases of new cars with low mileage may be caused by engine oil droplets penetrating into combustion chambers. In TSI engines, there is a considerable difference in operating temperature, it is therefore reasonable to increase the clearance of the piston ring locks, which is conducive to the penetration of small amounts of engine oil into combustion chambers. That phenomenon occurs particularly in the case of low viscosity synthetic oil.

Figure 4 shows the results of measurements of environmentally and humanly harmful chemical compounds in exhaust gases depending on the engine speed of spark--ignition cars with high mileage. Table 6 summarizes the values obtained for carbon monoxide and non-toxic compounds in exhaust gases.

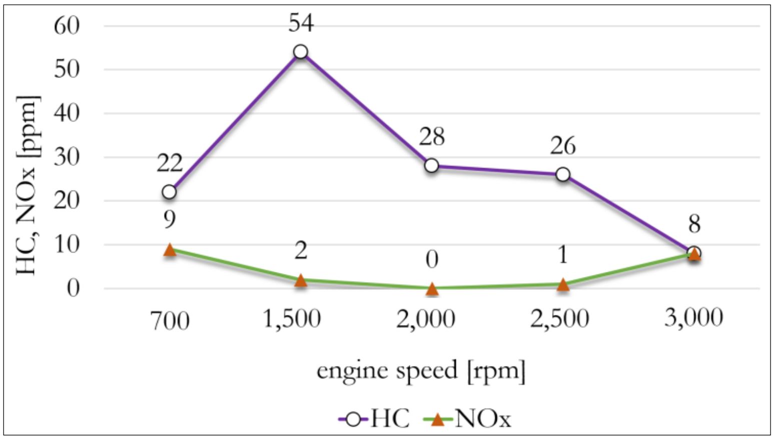

Figure 4. The values for the toxic components of exhaust gases as a function of engine speed for a spark-ignition car with high mileage

(source: own study)

The content of nitrogen oxides (NOx) in exhaust gases from high mileage cars varies from 0 to 9 ppm, which complies with the permitted values prescribed by Polish law.

The recorded nitrogen oxide values are indicative of the proper operation of systems responsible for the reduction of toxic emissions into the environment. NOx values above zero may be the result of the less efficient operation of the exhaust gas recirculation system or EGR valve due to them being heavily worn-out.

The hydrocarbon (HC) content in exhaust gases ranges from 8 to 54 ppm. As is the case with previously tested vehicles, those values are also within the range of the standards comprised by the Regulation of the Minister of Infrastructure, where the maximum HC value is set at 100 ppm.

Table 6

Other measured components of exhaust gases for a high mileage car with a spark-ignition engine

	Engine speed [rpm]				
	700	1,500	2,000	2,500	3,000
CO [% by volume]	0.06	0.30	0.27	0.30	0.19
CO_2 [% by volume]	14.5	14.5	14.6	14.5	14.6
O_2 [% by volume]	0.61	0.38	0.18	0.13	0.11
λ	1.026	1.055	0.999	0.990	0.997

(source: own study)

The varying amount of hydrocarbons depending on the engine speed may be indicative of the operational wear of the exhaust system components.

The highest hydrocarbons value was recorded at an engine speed of 1,500 rpm. This could be caused by engine leakage problems and engine oil penetrating into the combustion chamber.

At idle engine speed (700 rpm) engine oil may penetrate into the combustion chamber through leaking valve seals and then be combusted as the engine speed is increased.

The drop in hydrocarbon concentrations at higher engine speeds indicates that excess hydrocarbons that have penetrated into the combustion chambers have been combusted. In the case of high mileage cars, oil ingress can also be caused by wear on the piston rings resulting from vehicle operation, and the wear of the crankshaft venting system or so-called breather vents.

The increase in hydrocarbons may also be due to the incomplete combustion of the air-fuel mixture, which may result from the wear of the mixture ratio control components and the fuel supply system.

The diagnosed issues do not, however, exclude the tested vehicles from further operation, as they comply with the emission standards.

By analyzing the data in Table 6, it may be noted that the carbon monoxide (CO) content varies from 0.06 to 0.3 % by volume. Those values do not disqualify the cars from operation, as the values are within the limits set out by Polish law. It should be stressed, however, that those values fluctuate around the upper permissible limit. The standard for carbon monoxide as laid down in the Regulation of the Minister of Infrastructure is 0.3 % by volume at engine idle speed and 0.2 % by volume at 3,000 rpm.

The significant decrease in carbon monoxide values at 3,000 rpm may be related to combustion optimization at higher speeds. The increase, however, may result from the incomplete combustion of the air-fuel mixture due to a shortage of air.

That shortage may result from the wear of the components of the air-fuel ratio control system such as the flow meter or lambda probe. Mixture enrichment may also be affected by a very small leak in one of the injectors, so too much fuel enters the cylinder compared to air intake.

In the case of an increase in carbon monoxide in exhaust gases, mention should also be made of misfiring, which is a situation where the mixture is delivered to the cylinder, but not ignited. That phenomenon is due to the fact that misfiring is tolerated to a certain extent by the engine control system and not registered as an error by the EOBD system. Misfiring is usually caused by the wear of ignition system components such as coils and spark plugs.

An increase in carbon monoxide may also be caused by the wear of exhaust gas treatment system components resulting from vehicle mileage.

When comparing the two categories of spark-ignition cars being tested, it may be stated that low mileage vehicles emit toxic compounds at very low levels or not at all. This means that the systems responsible for the control of the mixture ratio and exhaust gas treatment operate faultlessly and meet the stringent quality control requirements to be satisfied by every new vehicle leaving the factory. High mileage vehicles emit more toxic compounds into the atmosphere, but the quantities do not exceed permissible standards and the vehicles may continue to be operated. However, the volume of emissions is a signal that the exhaust gas treatment and air-fuel mixture control issues in those vehicles should be looked at.

The remaining components of engine exhaust gases of both low and high mileage cars are at similar levels. Carbon dioxide (CO2) in all the tested vehicles oscillates between 14-15 % by volume. The situation is similar with the excess air ratio (λ), which varies between 0.997 and 1.026. The range indicates that the air-fuel mixture contains the correct amount of oxygen needed to burn the fuel.

6. Cars with a spark-ignition engine and LPG supply

Figures 5-7 shows the results of measurements of environmentally and humanly harmful chemical compounds in the exhaust gases depending on the engine speed of spark-ignition cars additionally fueled with LPG.

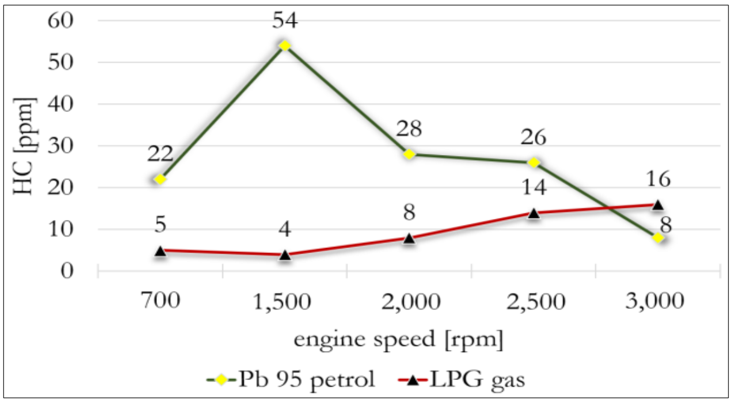

Figure 5. The hydrocarbon content in exhaust gases of spark-ignition cars additionally fueled with LPG

(source: own study)

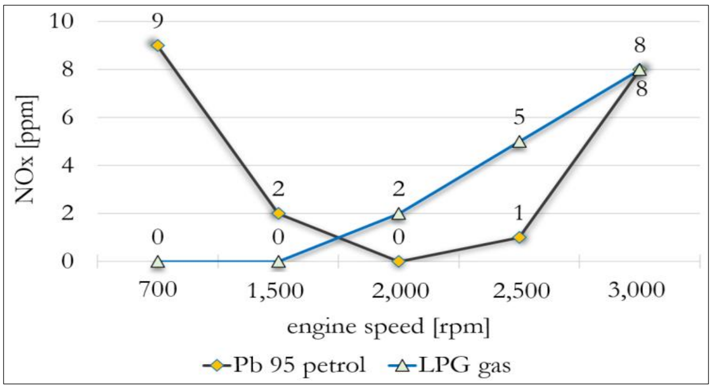

Figure 6. The nitrogen oxide content in exhaust gases of spark-ignition cars additionally fueled with LPG

(source: own study)

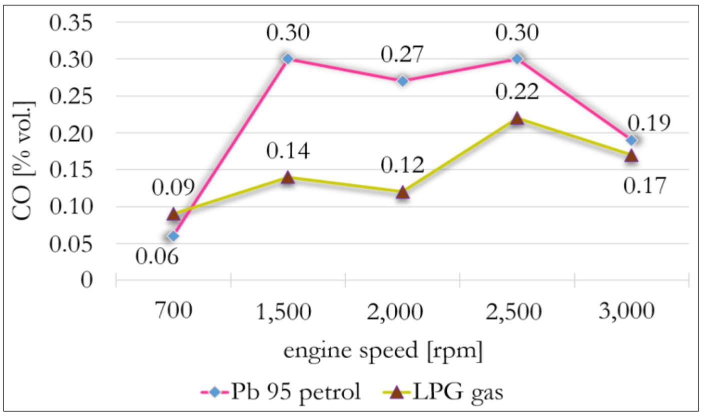

Figure 7. The carbon dioxide content in exhaust gases of spark-ignition cars additionally fueled with LPG

(source: own study)

Based on the diagrams above, it can be seen that both hydrocarbon and carbon monoxide contents are lower in almost the entire engine speed range in the exhaust gases from LPG fueling compared to the exhaust gases from unleaded Pb95 petrol combustion. The values are higher for hydrocarbons only at an engine speed of 3,000 rpm and for carbon monoxide at the idle speed (700 rpm). The difference of 0.03 % by volume is very small and may therefore be negligible. A similar situation occurs at an engine speed of 3,000 rpm, where the difference is 0.02 % by volume.

The lower hydrocarbon content in exhaust gases from LPG combustion is due to the fact that the mixture made with the use of propane-butane is more homogeneous. This improves combustion quality and, in the exhaust gases, there are fewer underburned particles, those being hydrocarbons. Hence, LPG is considered to be a more environmentally friendly fuel than unleaded petrol.

The difference in the carbon monoxide content in exhaust gases from LPG and unleaded petrol is due to the different combustion characteristics of the air-fuel mixture and the different fuel composition. LPG has a higher octane number and lower flash point, which may translate into lower emissions of carbon oxides into the atmosphere.

The content of nitrogen oxides found in the exhaust gases from an LPG-fueled engine is lower than that from an unleaded petrol-fueled engine for lower engine speeds. As engine speed increases, the nitrogen oxide content increases and at 3,000 rpm that content reaches the same value as in the case of exhaust gases from an engine running on unleaded petrol, i.e. 8 % by volume. LPG is free from fuel nitrogen and therefore the content of nitrogen oxides in the exhaust gases is significantly lower than in the case of petrol combustion. The opposite situation may be indicative of the incorrect installation of the LPG system or worn-out parts. In such cases, the system should be looked at and repaired if necessary.

Figure 8 shows the results of the carbon dioxide measurement in exhaust gases depending on the engine speed of spark-ignition cars additionally fueled with LPG.

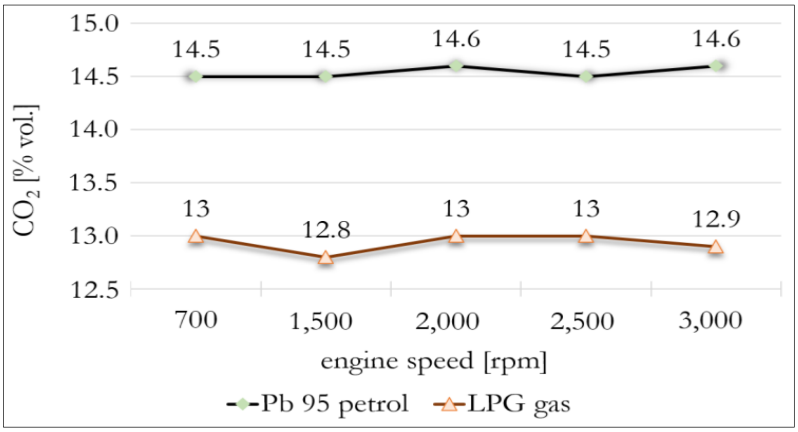

Figure 8. The carbon dioxide content in exhaust gases from spark-ignition cars additionally fueled with LPG

(source: own study)

The carbon dioxide content in exhaust gases when the engine is fueled with LPG is approximately 1.5 % by volume lower than in the case of unleaded petrol, and this follows from the properties of propane-butane. It may therefore be stated that that fuel is more environmentally friendly.

The issue of worldwide carbon dioxide emissions is currently one of the most frequently discussed environmental topics. Carbon dioxide is a gas which naturally occurs in the environment and also a product of complete combustion. The issue of carbon dioxide emissions relates to the current climate change as such emissions contribute to the greenhouse effect.

7. Cars equipped with a compression – ignition engine

Figure 9 shows the results of exhaust gas smoke measurements for low mileage cars equipped with a compression-ignition engine. The measurements were repeated three times for each acceleration. Acceleration 1 represents the measurement at idle speed, acceleration 2 shows the measurement at maximum engine speeds, and acceleration 3 represents the measurement at adjustable engine speeds. An average was taken from each measurement and presented in the diagram.

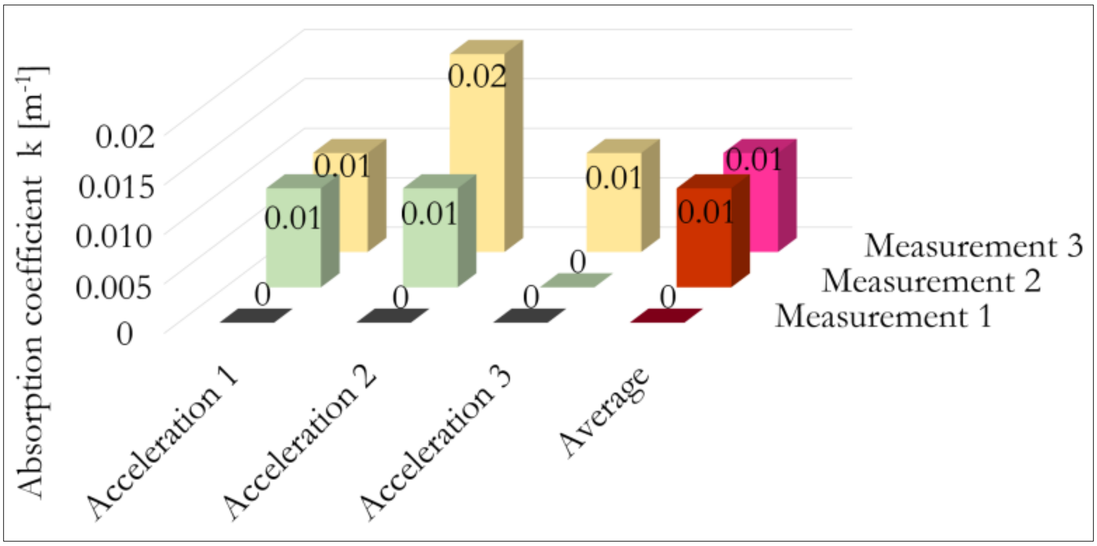

Figure 9. Exhaust gas smoke measurement for cars with compression ignition and low mileage (source: own study)

The mean values of the three exhaust gas smoke measurements indicate the correct operation of the components of the vehicle's exhaust gas treatment system. The mean values of the exhaust gas smoke measurements oscillate around 0.01 m-1.

In the regulations concerning vehicle technical inspection, the exhaust gas smoke standard for vehicles first registered after 30 April 2008 is k = 1.5 m-1. As regard those values, it should be stated that the exhaust gas treatment system of the tested vehicles fully eliminates the particulates emitted by the engine. The result of such low exhaust gas smoke content is also due to the faultless operation of the vehicle's fuel supply system components, the air-fuel ratio control and the exhaust gas recirculation system. The faultless operation of these components follows from the fact that the vehicle has done low mileage and the various components still operate like new, with no signs of wear.

Figure 10 shows the results of exhaust gas smoke measurements for high mileage cars equipped with a compression-ignition engine. The test procedure and presentation of the test results was analogous to the previously presented tests and results. Here too, three measurements were taken for each predetermined engine speed.

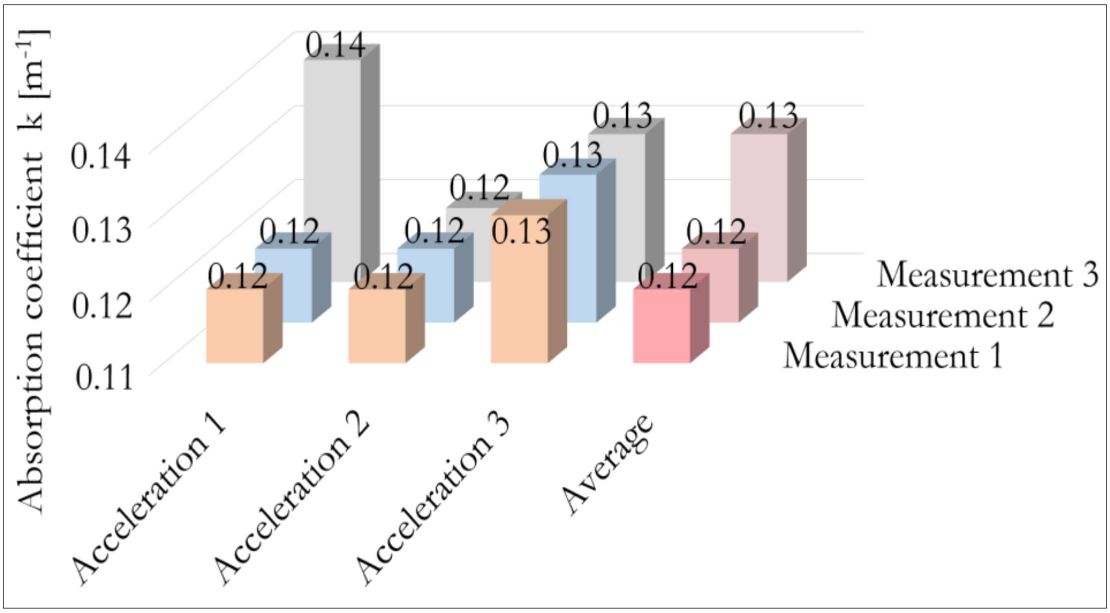

Figure 10. Exhaust gas smoke measurement for high mileage cars with compression ignition (source: own study)

The results of the exhaust gas smoke measurement indicate that the systems responsible for the reduction of particulate emissions operate properly. According to the values assumed in the standards, exhaust gas smoke content for vehicles registered for the first time before 30 April 2008 must not exceed k = 3.0 m-1. The average values of the various exhaust gas smoke measurements are k = 0.12-0.13 m-1. The tested cars, however, satisfy the more stringent standards applicable to vehicles registered after that date.

The results of the measurements authorize the conclusion that the various components of the exhaust gas treatment, fuel supply and air inlet, exhaust gas recirculation and air-fuel mixture control systems operate properly. The distribution of the results is far from the limit value for those vehicles. Such results may be influenced by the heavy repair of the components of the fuel supply system, including injectors, and the replacement of the exhaust gas recirculation valve, which was carried out not long before the test.

In summary, the measurement results for all the tested vehicles do not differ significantly from each other. The difference in the measurements between the low and high mileage cars is from 0.12 to 0.13 m-1. Those differences are most likely due to design differences in the exhaust gas treatment system of the various vehicles. Low mileage cars feature the latest design and technology relating to exhaust gas treatment systems. First of all, they are provided with particulate filters. High mileage cars are not equipped with such filters. It should therefore be concluded that the exhaust gas treatment system of high mileage vehicles operates properly and that the presence of untreated particulates is precisely the result of the absence of the particulate filter.

From the test results obtained, it can also be concluded that older, high mileage vehicles can also satisfy stringent exhaust emission standards applicable to newly manufactured vehicles provided that the former are properly used and serviced in accordance with the manufacturer's time schedule.

8. Conclusions

The aim of the tests presented in this article was to compare the concentrations of chemical compounds in the exhaust gases of cars fueled with various kinds of fuel in relation to the engine speed.

Based on the tests, the following conclusions can be drawn:

- Testing the exhaust gas composition of low and high mileage cars showed significant differences in emissions. High mileage cars demonstrate higher emissions of toxic exhaust gas components. However, those emissions do not exceed permissible standards and the vehicles may still be operated.
- The differences in the exhaust gas composition of low and high mileage vehicles are due to the mechanical wear of the exhaust and exhaust gas treatment system components. Repairs and appropriate maintenance can result in the reduction of the emissions of toxic components from run-down vehicles. Test results highlight the importance of regular diagnostics and repairs to minimize environmental impact.
- Increased emissions from high mileage vehicles may be due to differences in the design of exhaust gas treatment systems. New vehicles have more sophisticated systems designed to meet increasingly stringent emission standards.
- A comparison of exhaust emissions from vehicles fueled with LPG and unleaded petrol confirmed the advantage of the gaseous fuel in terms of the emission of toxic components into the surroundings. The tests have unambiguously confirmed lower emissions of these substances during the operation of an LPG-fueled vehicle, which is an important asset from the environmental point of view.
- An important aspect is lower carbon dioxide emission into the atmosphere when a car is fueled with LPG. Reducing that emission is crucial in the context of current environmental trends.
- The analysis of the test results suggests the need for a more in-depth consideration of the use of LPG as the main, or even only fuel for motor vehicles. Such a solution would bring tangible benefits not only for ecology, but also for drivers, in terms of reduced car operating costs.
- Tests performed on cars with compression-ignition engines showed a negligible difference in the emission of particulates into the surroundings, despite the differences in exhaust gas treatment systems and the vehicle mileage.

A common conclusion which arises for all analyzed scenarios is that vehicle age and mileage do not necessarily mean that a vehicle is excluded from operation due to emission standards being exceeded.

The way in which vehicles are operated and maintained plays an important role in their compliance with emission standards. Therefore, the authorities of cities in which access to the center is restricted should take into account the actual emissions of vehicles and not, as has been the case so far, the age of the vehicle and a note in the registration card stating that the vehicle satisfies emission standards.

The tests of the exhaust gas composition of vehicles with different parameters have provided important information that can be useful both for vehicle diagnostics and for the further development of environmentally friendly solutions in the automotive industry.

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