# RESEARCH IN VEHICLE EXHAUST GAS COMPLIANCE WITH EURO STANDARD

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**Abstract.** The actual problem of today is environmental pollution, and the main source of pollution is transportation. Air pollution from vehicles, especially in cities, has been a major problem worldwide for the past few decades. Last year we heard that diesel cars were the most polluting. Increasingly stringent emission requirements are being placed on these vehicles, so the pollution levels of newly produced vehicles are so low that they are equal to the emission standards of gasoline-powered vehicles. In recent years, global warming caused by carbon dioxide emissions has added another dimension to intense research efforts to develop more efficient engines and use low-carbon and renewable biofuels. Recently, very strict mass emission standards have been introduced, such as EURO 5-6. To measure the emissions of motor vehicles, unified cycles and test procedures have been developed, and harmonized by global test cycles, for all categories of vehicles to facilitate the transfer of information or technology exchange around the world. In Lithuania, the car fleet is 10-15 years old, so it is important to study the cars that drive on our roads. Cars of this age may not comply with the EURO 5-6 standard and therefore, for various reasons, pollute the city of Klaipeda with $CO_2$ or $NO_X$ pollutants. It is interesting and relevant to see how many cars drive with indicators corresponding to the EURO standard. This study aims to find out the different values between actual and factory vehicle exhaust emissions through measurements. Vehicle emissions are measured using the SGA 400 exhaust gas analyzer. Comparing the test vehicles of different years of production according to the standards of EURO 1-6, it was noticed that the most polluting internal combustion engines run on gasoline, and their operating age reaches 15-18 years complying with the EURO 3-4 standards. The amount of emissions of diesel vehicles from the EURO 1-6 standard has decreased even up to 12.5 times.

**Keywords:** automotive engineering, exhaust system, air pollution, climate, exhaust emissions, reduction of pollution, EURO 1-6 standards.

## Introduction

Air pollution caused by vehicles, especially in cities, has been a major concern worldwide for the last few decades. With increasing consumption of energy, which is mainly generated from fossil fuels, air pollution has become a major problem [1]. Cars powered by internal combustion engines using petroleum products dominate the road transport sector. The modern world is facing various challenges in the transport sector: climate change is forcing transport infrastructure to adapt to changing climatic conditions (extreme heat, floods, storms, etc.), while increasing GHG emissions in the transport sector impacting climate change are driving the search for solutions to reduce these impacts [2]. The European Commission has prepared an impact assessment roadmap for responsibly increasing the EU's target of reduction of greenhouse gas emissions by at least 50% by 2030, moving towards the goal of a 55% reduction compared to 1990 [3]. Sulphur dioxide, nitrogen oxides and particulate matter are pollutants posing the highest health risks, while other harmful pollutants include ammonia, non-methane volatile organic compounds (NMVOCs), persistent organic compounds (POPs) and other pollutants [4]. Toxic substances, such as carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides ($NO_x$) and particulate matter are produced in the cylinders of internal combustion engines during combustion [5; 6]. Levels of emissions of oxides of nitrogen (nitric oxide, NO, and nitrogen dioxide, NO, usually grouped together as NO), carbon monoxide (CO), unburned hydrocarbons (HC), and particulates are important engine operating characteristics [7]. There are two ways to reduce carbon dioxide ($CO_2$) emissions from vehicles: to increase fuel efficiency or to replace fossil fuels with more environmentally friendly alternatives. In 2019, the majority (66.7%) of Europe's road transport was powered by petrol, followed by diesel (24.55%) and other fuels, such as gas or electricity. Numerous studies have shown that emissions from road transport are a major contributor to air pollution in metropolises [8; 9]. In recent years, global warming caused by carbon dioxide emissions has added another dimension to the intensive research efforts to develop more fuel-efficient engines and the use of low carbon and renewable biofuels.

Lately, highly stringent standards for mass emissions, such as Euro 5 and Euro 6, have been implemented [8]. Emission levels for motor vehicles have been set by regulations of the European Parliament and the Council, also known as European standards. These standards specify the permissible levels of carbon oxides, hydrocarbons and particulate matter in compression ignition engines [10].

According to estimates, these regulations reduced $CO_2$ emissions 6 times compared to the EURO 1 standard, with a 97% reduction in particulate matter and eleven-fold reduction of hydrocarbons. There are rumours that a EURO 7 standard will soon be developed, but it is not yet known whether a new and even stricter standard will be introduced [10].

On average, in terms of the New European Driving Cycle (NEDC), the 2021 market was at about 95 $g \cdot km^{-1}$ of $CO_2$. Converted to the new Worldwide Harmonized Light Vehicles Test Procedure (WLTP), the market average was around 114 $g \cdot km^{-1}$ compared to an average target of around 118 $g \cdot km^{-1}$ as indicated in Figure 1. Throughout the years 2020 and 2021, manufacturers, on average, decreased their new car $CO_2$ levels by more than 1 $g \cdot km^{-1}$ per month. The average reduction rate for the years 2009 to 2021 was just about 4 $g \cdot km^{-1}$ per year, illustrating the particular efforts manufacturers put forward with actual target values imposed, rather than in the interim years in which the target values did not see any further tightening [11].

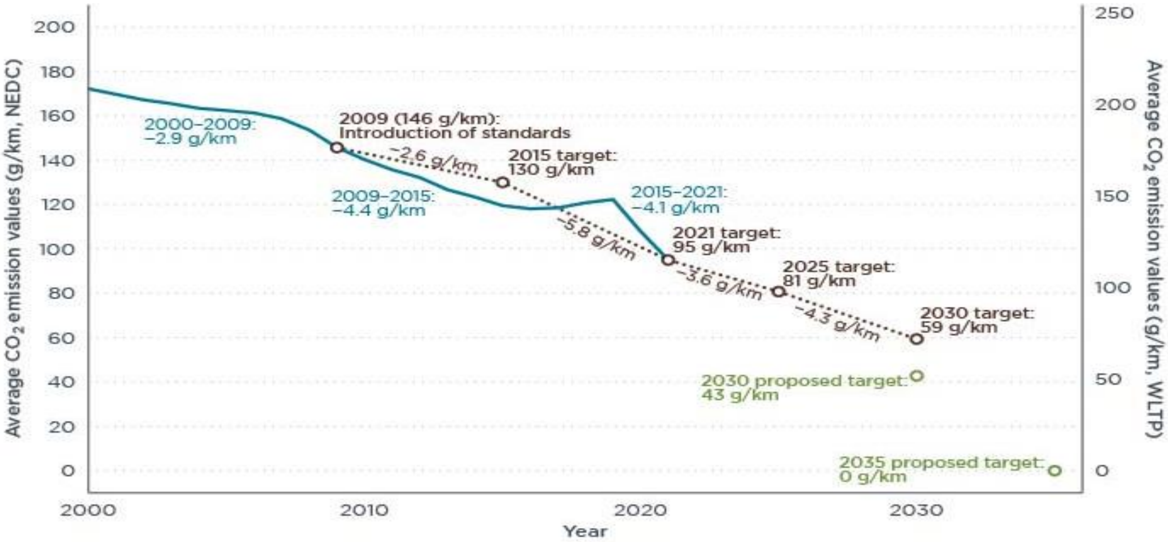


Fig. 1. **Average $CO_2$ values and fleet targets [11]**

In general, the amount and toxicity of harmful emissions from internal combustion engines has been observed to depend on the technical condition of the car engine, its operating mode, fuel quality and the fuel injection system. According to the environmental impact of pollutants, they are classified as environmentally neutral (N), environmentally active ($CO_2$, $H_2O$) and toxic pollutants, which include products of partial combustion (C, CO, HC, CHO), nitrogen-containing substances (NO, $NO_2$, $NH_2$, $NH_4$), and oxidation products of fuels and oils [12]. For many years, diesel engines have been the focus to reduce particulate matter emissions. However, modern diesel engines now emit less particles than similar petrol engines. This transformation makes it necessary to implement particle reduction strategies for petrol-fuelled vehicles [13].

CO emissions from diesel engines are relatively low. The content of carbon monoxide in diesel exhaust gases is normally expressed assessed as the light absorption coefficient [13]. In chemistry, the light absorption coefficient is defined as the extent of decrease in the intensity and velocity of the amount of light absorbed per atom or per unit of thickness or mass of a given material. Since this value can be measured using the SGA 400 exhaust gas analyser when measuring diesel vehicles automatically, it was not calculated in the research.

## Research methodology

Increased concentrations in exhaust gases of the tested cars with the lifetime of one to thirty-three years can provide important diagnostic information on the performance of the car engine. The most polluting exhaust gas components are hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides ($NO_x$). Three of the five gases measured in the tailpipe are pollutants subject to regulation, namely, HC, CO and $NO_x$. The other two gases – oxygen ($O_2$) and carbon dioxide ($CO_2$) – are not regulated, and therefore their content is an important diagnostic information.

Exhaust emissions of 100 cars with different power systems were measured for the research. The research also involved measuring the emission norms of the cars running on diesel and exhaust gas fuels and operated daily on the streets of Klaipėda city in the laboratory using the SGA 400 combustion analyser (Fig. 2, Table 1) and comparing them with the effective EURO standard norms, as well as with the norms of the environmental safety standards LAND 14-2000 and LAND 15-2000 approved in the Republic of Lithuania [14].

Fig. 2. **SGA 400 combustion analyser**

Table 1

**SGA 400 Technical Specifications**

| **Technical parameters** | **Range** | |
|---|---|---|
| Operating temperature range, ºC | 5-40 | |
| Accuracy class | 0 (OIML) | |
| Type of gas detector material | Silicon photodiode | |
| Power Supply, V | 100/240 (50 – 60 Hz) | |
| Dimensions, mm | 400 x 240 x 260 | |
| Weight, kg | 5.3 | |
| Pump capacity, $l \cdot min^{-1}$ | minimum: 5.5; nominal: 6.5 | |
| **Measured parameters** | **Measuring range** | **Accuracy** |
| Lambda | 0.6-1.7 | 0.001 |
| Engine speed, $min^{-1}$ | 0-20 000 | 10 |
| Oil temperature, ºC | 0-160 | 1 |
| Smokiness, % | 0-99.9 | 0.1 |
| Gas resolution, $m^{-1}$ | 0-16, 06 | 0.01 |
| **Measured gas components:** | | |
| $O_2$ – oxygen, % | 0-25 | 0.01 |
| CO – carbon monoxide, % | 0-10 | 0.01 |
| $CO_2$ – carbon dioxide, % | 0-20 | 0.01 |
| HC – hydrocarbons, ppm | 0-15 000 | 1 |
| NOx – nitrogen oxides, ppm | 0-5000 | 1 |

**Test methodology with OTTO engines:** the gas analyser is prepared for measurements in accordance with the user manual of this analyser provided by the manufacturer; the engine is started; the speed of revolutions is slightly increased and maintained at the level of 15 to 20 s; then the speed is reduced to the minimum, inserting the probe of the gas analyser in the exhaust pipe of the vehicle within 300 mm of the end of the pipe after 20 s at the earliest; exhaust gas quality with the engine running at the idling speed is determined at the minimum speed of revolutions; in cars equipped with a three-component exhaust gas neutralisation system with lambda (λ) value control, the lambda value is also measured with the engine running without a load at the speed prescribed by the manufacturer (which is no lower than 2000 $min^{-1}$); in the case of cars fitted with several exhaust system pipes, each pipe is measured separately. The final result is the maximum value of the measurement results obtained.

**Cars with diesel engines:** measurements are performed in the following steps: the opacity meter is prepared for measurement following the manufacturer's user manual; at least three free acceleration cycles are performed, or the exhaust system is purged in application of an equivalent method; the probe used to measure the opacity of the device is inserted into the exhaust flap; before each test coasting cycle, the engine operates in idle mode at the minimum engine crankshaft speed (hereinafter – RPM) for at least 10 s; during the coasting cycle, the accelerator pedal is depressed rapidly and steadily enough to maximise the power of the injection pump; during each coasting cycle, the engine must reach the limit revolutions or the speed regulated by the manufacturer. In the absence of such data, the highest revolutions per minute during the test must correspond to 2/3 of the maximum revolutions; at least three coasting cycles are performed; the final result is the arithmetic mean of the values determined during three coasting cycles; in the case of vehicles with several exhaust system pipes, each pipe is measured separately. In such a case, the final result is the highest determined value.

## Presentation of results

**Change of emissions in petrol-powered cars.** Depending on the operating mode of the engine, the amount of air introduced into the fuel mixture is higher or lower than the theoretical amount of air required to burn the fuel. Knowing how much air is needed and the value of the excess air coefficient ($\lambda$) as well as the theoretically needed air content ($l_o$), the amount of air that actually got into the flammable mixture (l) can be calculated [7]. Figure 3 presents the average air consumption of the petrol cars being tested.

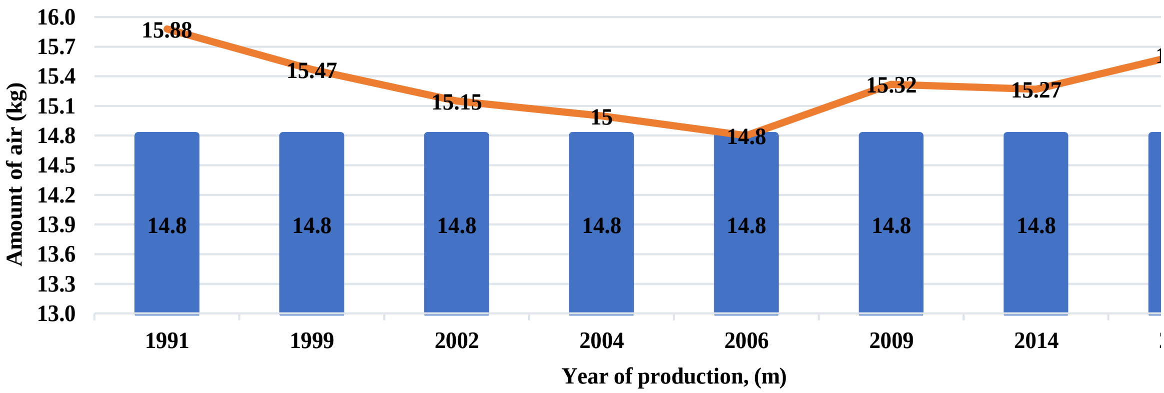


Fig. 3. **Difference between the normal and the actual amount of air required for combustion in the cylinder**

Figure 3 shows that the vast majority of cars use about 7% more air than running on a balanced fuel/air mixture. This is when the engine is most cost-efficient, but $NO_x$ emissions increase. Only a small share of the cars being tested operate with an average air consumption of 11% less due to their smaller engine displacement. The engine running on this mixture produces the highest power output, but has higher CO and HC emissions.

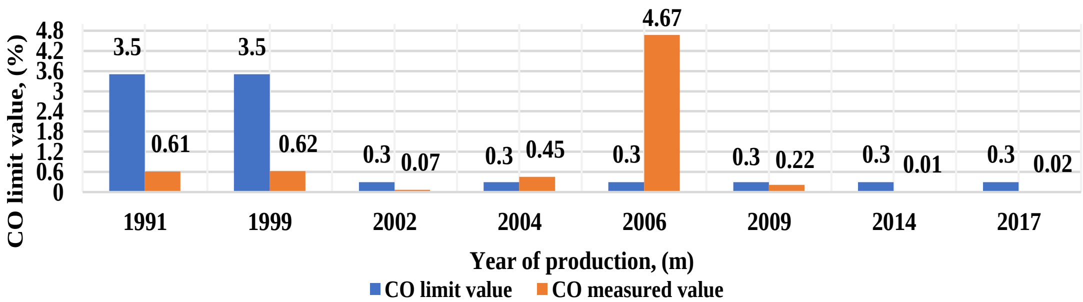


Fig. 4. **Carbon monoxide (CO) content in exhaust gases**

Figure 4 shows that the most polluting EURO 3 cars exceed the carbon monoxide (CO) limit values by a factor of 1.5 on average, while EURO 4 cars exceed the limit values as many as 15 times. Cars of the other standards do not exceed the limit values. The carbon monoxide limit value in cars manufactured in 1991 and cars produced in 2002 varies by approximately 12 times. In subsequent years, the limit value remained unchanged. The results show that the age of a car may have an impact on emissions, but it is not the main criterion affecting the emission norms.

Figure 5 illustrates that EURO 3 cars exceed the HC limit values by an average of 2.25 times, while EURO 4 cars exceed them by a factor of 3.21. It also shows that EURO 5 cars emit 1.22 times more hydrocarbons. Cars of other standards do not exceed the limit values. The limit value for hydrocarbons has decreased by a factor of approximately 4.9 from cars produced in 1991 to cars manufactured in 2002 and twice in cars from 2002 to 2017.

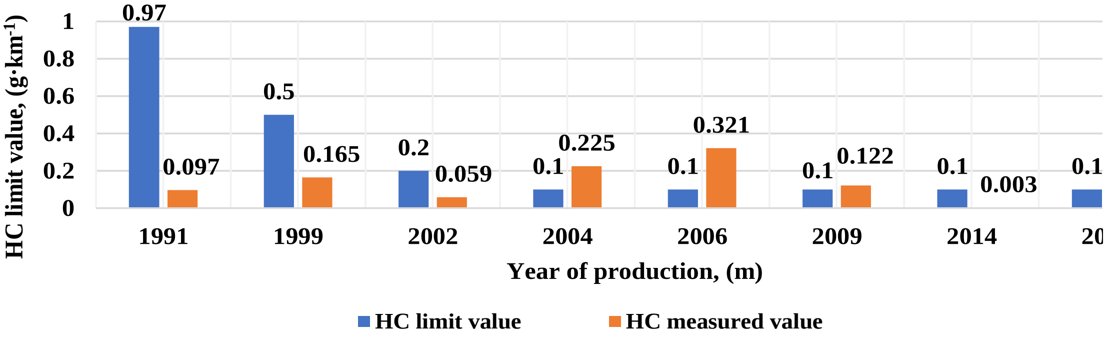


Fig. 5. **Content of hydrocarbons (HC) in exhaust gases**

Figure 6 shows that EURO 2 cars exceed the limit values for nitrogen oxides ($NO_x$) threefold, EURO 3 cars – twice, EURO 4 cars manufactured since 2004 – 5.75 times, EURO 5 cars manufactured since 2006 – 20 times, and EURO 5 cars – 3.6 times. Cars of the other standards do not exceed the limit values.

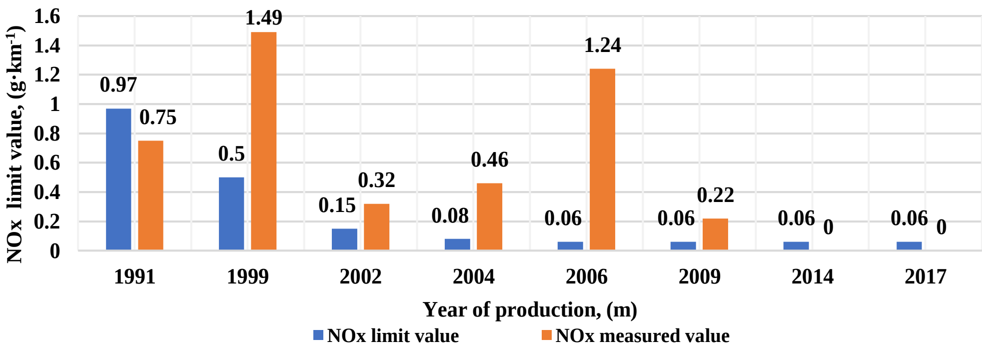


Fig. 6. **Nitrogen oxides (NOx) in exhaust gases**

The limit value for nitrogen oxides decreased approximately 2 times when comparing cars manufactured in 1991 and cars of 2002, and 0.25 when comparing cars of 2002 to cars released in 2017.

**Change of emissions in diesel-powered cars.** Figure 7 a) illustrates that the light absorption coefficient of cars manufactured since 1989 was 2 $m^{-1}$, since 1998 – 1.83 $m^{-1}$, since 2000 – 1.65 $m^{-1}$, and since 2001 – 1.73 $m^{-1}$. Thus, the measured coefficient does not exceed the light absorption coefficient limit value of 2.5 $m^{-1}$ and is even 1.4 times lower. The results show that in cars manufactured from 1989 to 2000, the instantaneous measured emissions value decreased 1.21 times, but in cars manufactured from 2000 to 2001, an increase in emissions of 5% was observed [14].

Figure 7 b) illustrates that the light absorption coefficient of cars manufactured since 2003 has averaged 1.52 $m^{-1}$, in cars manufactured since 2004 – 1.31 $m^{-1}$, in cars since 2005 – 1.21 $m^{-1}$, and in cars since 2006 – 0.87 $m^{-1}$. Thus, the coefficient measured does not exceed the light absorption coefficient limit value of 2.5 $m^{-1}$ and even is on average 2 times lower. The measured light absorption decreased 1.16 times when comparing diesel cars manufactured in 2003 to 2004, 1.08 times – in cars released in 2004 to 2005, and 1.39 – in diesel cars manufactured in 2005 to 2006.

Figure 8 a) illustrates that the light absorption coefficient of cars manufactured since 2007 is 1.1 $m^{-1}$, since 2008 – 1.31 $m^{-1}$, and since 2009 – 0.8 $m^{-1}$. Although particulate matter emissions have been reduced to 1.5 $m^{-1}$ since July 2008 only, older cars that meet EURO 3 and 4 standards are still within this value, and even more so within the light absorption coefficient limit 2.5 $m^{-1}$ in force at the time and are 2,7 times lower. The light absorption coefficient limit decreased by a factor of 1.6 between 2007 and 2008, but the average reduction in emissions for cars manufactured in the same year was only 1.2 times. The difference between the light absorption coefficient of cars manufactured since 2008 and those manufactured since 2009 is also 1.2 times. Thus, it can be concluded that having reduced the emission limit value in 2008, the light absorption coefficient demonstrated a tolerable decrease from 2007 to 2009.

a) b)

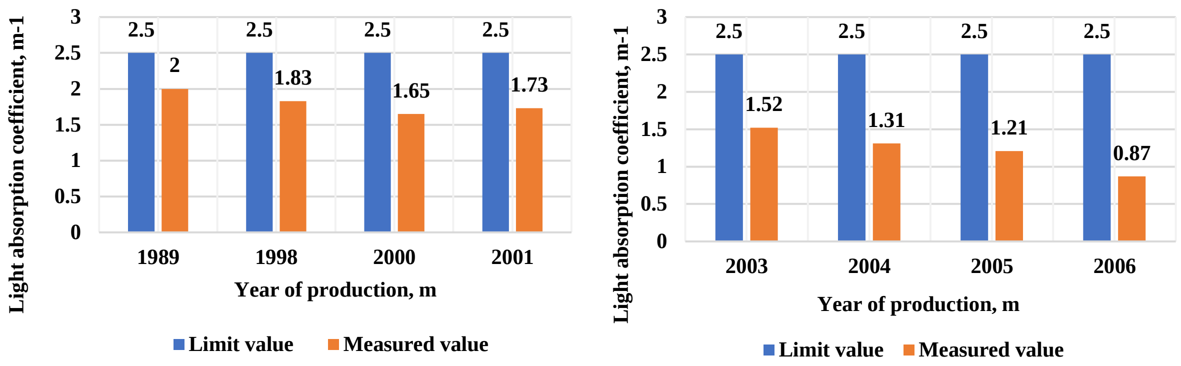


Fig. 7. **Light absorption coefficients in cars 20-30 years of age (a); light absorption coefficients in cars 15-20 years of age (b)**

a) b)

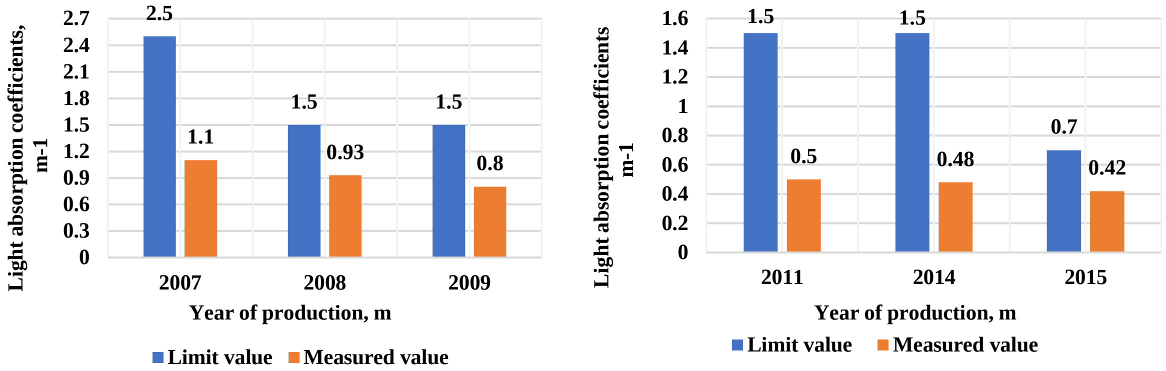


Fig. 8. **Light absorption coefficients in cars 10-15 years of age (a); light absorption coefficients in cars 5-10 years of age (b)**

Figure 8 b) illustrates that the light absorption coefficient of cars produced since 2011 is on average 0.5 $m^{-1}$, since 2014 – 0.48 $m^{-1}$ and since 2015 – 0.42 $m^{-1}$. Cars in line with EURO 5 standard were observed to be 3 times less polluting, and EURO 6 cars – had 2,4 times lower pollution levels. The light absorption coefficient normative limit decreased 2.14 times between 2014 and 2015. The results show that the measured instantaneous light absorption coefficient remains essentially unchanged with the age of the car.

Figure 9 shows that for cars manufactured since 2017 onwards, the light absorption coefficient is 0.24 $m^{-1}$, since 2019 – 0.21 $m^{-1}$ and since 2021 – 0.16 $m^{-1}$. Thus, the measured coefficient is within the permissible limit of 0,7 $m^{-1}$ and 3,5 times lower. The measured light absorption coefficient decreased by an average of 1.14 times between 2017 and 2019 and 1.31 times between 2019 and 2021. The results show that the measured instantaneous light absorption coefficient remains essentially unchanged with the age of the car.

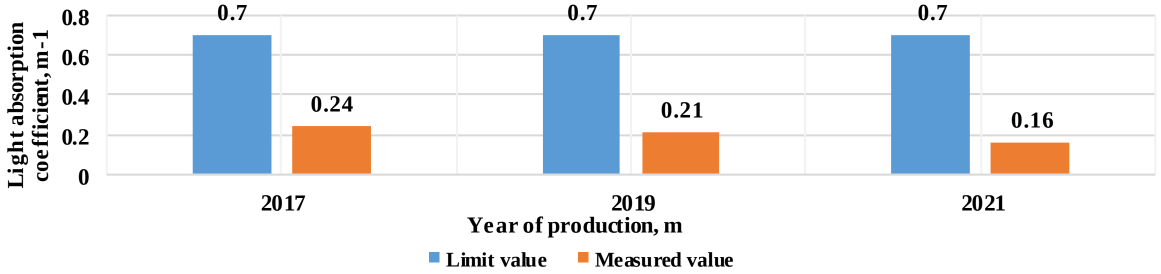


Fig. 9. **Light absorption coefficients in cars 1-5 years of age**

## Conclusions

1. The comparison of the cars being tested manufactured in different years according to the EURO 1, 2, 3, 4, 5 and 6 standards revealed that the most polluting internal combustion engines are petrol-powered engines with the service life of 15-18 years and in line with both EURO 3 and EURO 4 standards. For the tested cars that meet the requirements of the EURO 3 standard, the measured CO emission value is 50% higher, HC emission - 2.25 times higher (125%) and NOx emission - 2 times higher compared to the values of the EURO 3 standard. The CO emission of EURO 4 cars is even 15 times higher (CO limit value 0.3% and measured value 4.67%), HC emission – 3.21 times higher (HC limit value 0.1g·km$^{-1}$ and measured value 0.321g ·km$^{-1}$) and NOx emission – 5.75 times higher (NOx limit value 0.06 g·km$^{-1}$, and the measured value reaches 0.22 g·km$^{-1}$) compared to the values of the EURO 4 standard.
2. When it comes to diesel car emissions in terms of the light absorption coefficient: thus, the measured coefficient does not exceed the light absorption coefficient limit value of 2.5 m$^{-1}$ and is even 1.4 times lower. The results show that in cars manufactured from 1989 to 2000, the instantaneous measured emissions value decreased 1.21 times (average 1.82 m$^{-1}$). Results show that the light absorption coefficient of cars manufactured since 2003 does not exceed the light absorption coefficient limit value of 2.5 m$^{-1}$ and even is on average 2 times lower. The measured light absorption decreased 1.16 times when comparing diesel cars manufactured in 2003 to 2004, 1.08 times – in cars released in 2004 to 2005, and 1.39 – in diesel cars manufactured in 2005 to 2006. The light absorption coefficient limit decreased by a factor of 1.6 between 2007 and 2008, but the average reduction in emissions for cars manufactured in the same year was only 1,2 times. Cars in line with EURO 5 standard were observed to be 3 times less polluting, and EURO 6 cars – had 2.4 times lower pollution levels. The measured light absorption coefficient decreased by an average of 1.14 times between 2017 and 2019 and 1.31 times between 2019 and 2021. The results show that the measured instantaneous light absorption coefficient remains essentially unchanged with the age of the car. The comparison of EURO 1 to EURO 6 revealed that the emissions of diesel engines decreased by up to 12.5 times.
3. It can be concluded that the emissions content received instantaneously measuring the car smoke content and emissions at technical inspection stations according to the “Cars with Otto engines. Standards and measurement methods” (LAND 14-2000) and “Cars with diesel engines. Standards and measurement methods” (LAND 15-2000) do not show compliance with the norms enshrined in the European standards. Also, as the requirements of European standards became stricter for manufacturers, manufacturers had to improve the designs of engines, exhaust, and fuel supply systems in order to meet the requirements of EURO standards.

## Author contributions

Indicate the contribution of each author. Example: Conceptualization, V.J.; methodology, V.J. and J.L.; software, Y.I.; validation, V.J. and J.L; formal analysis, V.J and J.L.; investigation, V.J., and J.L.; data curation, V.J. and J.L.; writing – original draft preparation, V.J.; writing – review and editing, V.J. and J.L.; visualization, V.J., J.L.; project administration, J.L.; funding acquisition, J.L. All authors have read and agreed to the published version of the manuscript.

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