

climatic changes, greenhouse gases, damage of the transportation, traffic subsystem, harmful gases, measurement of emission of exhaust gases

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## **THE VIEWPOINTS OF CHEMICAL AIR POLLUTION CAUSED BY TRAFFIC SUBSYSTEMS AND PRESENTED BY THE EXAMPLE OF EMISSION MEASUREMENTS OF TRUCKS' EXHAUST GASES**

**Summary.** For a long time, experts have been emphasizing that we are in an era, in which dangerous climatic changes are getting more and more notable. We have been witnessing large climatic changes, caused by greenhouse gases, for several years. The question is no more "Are there climatic changes or are there not?", nor "Are they being accelerated by human actions or are they not?" The fact is, the climate is changing more and more rapidly and that extreme weather conditions are becoming a daily matter. Furthermore, even if we stopped polluting the atmosphere immediately, the processes triggered by human-caused pollution would be going on for several decades.

Modern logistic systems cannot operate without means of transport which enable the realization of transport. They form a transport system that makes the function of other economic systems possible. The use of different ways of transport has a bad influence on the environment in which we daily live and work. The damage of transportation has a bad influence on human health and nature, too. For that reason, we cannot treat the safety of the transportation means only through the technical impeccability of the devices which make possible direct execution of particular technological phases in different traffic subsystems. Ecological impacts of particular traffic subsystems are very complex, they have a long-term impact on our everyday existence and despite that we still do not devote enough attention to this.

We have been aware that traffic, especially road and air traffic, is one of the largest sources of emissions of harmful exhaust gases of combustion engines and particles into the environment. The environmental impact of traffic is especially large due to greenhouse gases, which are part of exhaust gases being produced by internal combustion engines. In addition to that, there are many more toxic components in exhausted gases.

## **ХИМИЧЕСКОЕ ЗАГРЯЗНЕНИЕ ВОЗДУХА ТРАНСПОРТНЫМИ ПОДСИСТЕМАМИ И ПРИМЕР ИЗМЕРЕНИЯ УРОВНЯ ВЫБРОСОВ ВЫХЛОПНЫХ ГАЗОВ ГРУЗОВЫХ АВТОМОБИЛЕЙ**

**Аннотация.** Долгое время эксперты подчеркивали, что мы живем в эпоху, в которой действие опасных климатических изменений становится все более и более заметным. В течение нескольких лет мы стали свидетелями больших климатических изменений, вызванных парниковыми газами. Уже не стоят вопросы "Имеют место климатические изменения или нет?" или "Ускорены ли они вследствие действий человека или нет?" Дело в том, что климат меняется все

быстрее и быстрее, и экстремальные погодные условия становятся повседневным фактом. Кроме того, даже если бы мы прекратили загрязнять атмосферу сразу, процессы, вызванные загрязнением вследствие деятельности человека, будут происходить в течение нескольких десятилетий.

Современные логистические системы не могут работать без транспортных средств. Они образуют транспортные системы, что позволяет функционировать другим экономическим системам. Использование различных средств транспорта оказывает плохое влияние на окружающую среду, в которой мы ежедневно живем и работаем. При этом дефекты транспортных средств оказывают наиболее вредное влияние на здоровье человека и природы. По этой причине мы не можем рассматривать безопасность транспортных средств только путем технической безупречности устройств, которые делают возможным прямое выполнение конкретных технологических фаз в различных подсистемах движения. Экологические последствия воздействия подсистем движения являются очень сложными, они имеют долговременное воздействие на наше повседневное существование и несмотря на это мы все еще не уделяем достаточного внимания этому.

Мы понимаем, что дорожное движение, особенно для автомобильных и воздушных перевозок, является одним из крупнейших источников выбросов вредных выхлопных газов двигателей внутреннего сгорания и частиц в окружающую среду. Данное воздействие на окружающую среду особенно велико из-за парниковых газов, которые являются частью выхлопных газов для двигателей внутреннего сгорания. Кроме того есть много других токсичных компонентов в выхлопных газах.

## 1. INTRODUCTION

As a form of economic activity, traffic began to develop very rapidly in the first half of the 19th century, a period of rapid industrial development. The invention of steam and internal combustion engine played an important role in the development of traffic and allowed the invention of nowadays widely used means of transport (train, automobile). Due to a great number of automobiles, short length transit became very widespread, the number of daily migrations between rural and urban areas increased, multiplied passenger traffic and, in many cases, deprived the rail of almost all freight traffic on short routes, thereby positively influencing areas, previously suffering due to the lack of rail.

The role of transport in economic development of countries is constantly increasing. Because of the exceptional technological and organizational progress, modern transport allows more extensive and faster production, exchange of goods and promotes economic development. Before the year 1999, the European Environment Agency has already identified transport as the industry market, which will grow quickly in the European community, particularly freight and transport related to tourism [11].

## 2. TRAFFIC AND ENVIRONMENT

For physical manifestation of transport, means of transport are required. Some of them have a variety of negative influences on natural environment and mankind. Those influences are very complex and diverse and most of them are problematic in long terms. Not only that it causes air pollution, traffic is causing a variety of harmful influences. Most negative impacts on the environment can be attributed to road transport, which seriously threatens natural resources and people [7].

A research that tried to compare the level of environmental impacts, categorized by transport subsystems, is presented by Bainster and Button [1].

Means of transport are among the major polluters of air, or better, of the atmosphere. Vehicles powered by internal combustion engines are the cause of pollution, especially in dense populated

areas. As a rule, air pollution from vehicles is less than that of industry and households, but with the constant increase of the number of vehicles it is becoming an issue that cannot be ignored, especially in urban areas. High concentrations of CO, also Pb and VOC ( $C_xH_y$ ) in the atmosphere are caused by fossil fuel combustion and evaporative emissions in engines of transport vehicles.

### 3. TRAFFIC POLLUTION OF ATMOSPHERE

Polluting the atmosphere is considered one of the most important issues of environmental burdening, for it is causing long term global and very complex impacts on natural environment that is often directly linked, not only with global climate changes, but also with the health of people and other living beings. Many experts say that the chemical pollution of atmosphere is causing an increased number of diseases in the past few years (lung cancer).

#### 3.1. The composition of atmosphere

The atmosphere is composed of layers called the troposphere, stratosphere, ionosphere or the mesosphere and thermosphere or protosphere, which differs in composition and physical properties of gases [12, 13].

The atmosphere regulates the amount of solar radiation reaching the Earth, while it also regulates the amount of radiation, emitted by the Earth. Problem arises if too much gas is present in the atmosphere in order to prevent the Earth-emitted heat to go into space. This phenomenon is called the greenhouse effect and occurs when the greenhouse gases, concentrated in the atmosphere, prevent the movement of infrared rays (heat) into space because they behave as isolators. Thus, the heat remains trapped in the troposphere and impacts global warming severely. The presence of greenhouse gases is essential nevertheless, because without them the Earth would emit too much heat and the temperature on the Earth would be that of an ice age.

The air consists of 78.08% nitrogen, 20.95% oxygen, 0.03% carbon dioxide, 0.935% argon and 0.02 to 2% of water vapor and other gases in small quantities (CO, O<sub>3</sub>, and noble gases).

#### 3.2. Air pollutants

The most important primary air pollutants from known sources are SO<sub>2</sub>, CO, NO<sub>x</sub>, SO<sub>x</sub>, solid particles, VOC ( $C_xH_y$ ) and metals.

Secondary air pollutants, formed by chemical reactions in the atmosphere, are O<sub>3</sub>, photochemical oxidants – peroxyacetyl nitrates PAN and oxidated hydrocarbons.

According to the EC, WHO and USEPA air pollutants, identified as critical pollutants, are CO, NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>, solid particles (diameter < 10 μm) and lead [7].

#### 3.3. Air pollutants and combustion processes in internal combustion engines

Most modern vehicles are still powered by conventional internal combustion engines in which, regardless of the type (petrol, diesel) the air/fuel mixture burns. Air pollution is affected by fuel combusting in the engine.

The main components of exhaust gases are divided into toxic and non-toxic. Classified as toxic are solid particles (soot, lead) and gases (CO,  $C_xH_y$ , SO<sub>2</sub>, NO<sub>x</sub>), while the non-toxic component are gases O<sub>2</sub>, CO<sub>2</sub>, N<sub>2</sub> and H<sub>2</sub>O vapor. The general public thinks of CO<sub>2</sub> as toxic, but it is not toxic. It has a very negative impact on global warming (most important component of the greenhouse phenomenon) [8].

Lead is the only component of gasoline engine exhaust, which can be removed before combustion. Other dangerous ingredients can only be removed by treating exhaust gases of vehicles for the time

being. The problem of lead is still present, as in the past a lot of lead particles got accumulated in the atmosphere as a result of combustion of leaded fuels [8, 22].

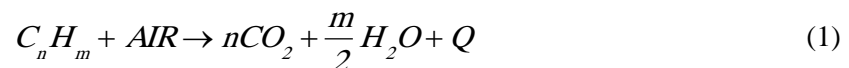
Internal combustion engine caused emissions are the crankshaft housing emissions (leaks caused by piston rings, the largest share is caused by unburned fuel mixture), vapor (evaporation of fuel in the tank and injection system, the evaporation is more explicit at higher temperatures), resulting from fuel spills, exhaust gases, leaving the combustion chamber through the exhaust system and the catalytic converter [3, 22].

These emissions are joined by dust from tire wear and braking and clutch use. The weakness of internal combustion engines is that they are able to produce useful mechanical work only with the process of fuel combustion in the presence of oxygen, which is indispensable for the oxidation of fuel.

The combustion of one liter of fuel (gasoline) produces about a thousand liters of exhaust gas. The spectral analysis of the exhaust gas of an internal combustion engine showed it contains over a thousand different chemical compounds, mainly of unburned or partially burned hydrocarbons, which is logical, because the fuel is produced from oil, which is a mixture of various hydrocarbons.

The amount of components in the gases can be fairly well controlled with proper and regular engine maintenance. This is especially true for diesel engines that pollute the environment with soot, where very dangerous substances are collected. For example – benzopyrene, which is among the cause of lung cancer [7].

The chemical process of the perfect oxidation of fuel can be described as shown in equation (1).



Such combustion creates two toxic substances – carbon dioxide  $CO_2$  and water vapor  $H_2O$ . Complete combustion under realistic conditions is difficult to reach because the fuel oxidation process takes place very quickly and through a multitude of interrelated reactions. The varying composition of fuel mixture (fuel mixture inhomogeneity) in the combustion chamber, caused by the way of flame spreading and the cold walls of the cylinder, causes the oxidation not being the same in every point of the combustion chamber. Therefore, some hydrocarbons from the fuel do not even manage to get in contact with oxygen, some of the possible partial oxidation, and some are already oxidized hydrocarbons, because the combustion temperatures in the combustion chamber again decompose. The course of combustion is also affected by engine operation mode that can make a difference in the rich filling [7].

Hydrocarbon emission results from basic hydrocarbons contained in fuel, and hydrocarbons resulting from the dissolution of the fuel. Their concentration increases with decreasing velocity and temperature of the combustion of fuel in the combustion chamber. Raising the speed accelerates the combustion reaction in which the thermal fuel decomposition occurs. Furthermore, the photochemical reactivity of exhaust hydrocarbon emissions depends on fuel composition. The reactivity increases with more presence of toluene, which means that there are significant emissions of  $C_xH_y$  in unleaded petrol, so Otto engines are the major producers of hydrocarbons (hydrocarbons in the gasoline engine exhaust gases contain about 5% of highly toxic benzene).

Engine exhaust gases of road vehicles have a very distinctive smell, which is due to the presence of nitrogen oxides, sulfur compounds and partially oxidized hydrocarbons. Exhaust odors are the first warning on the toxicity of these gases, because combustion products with especially intense odors represent a very toxic compound [4, 22].

The process of combustion in internal combustion engines is quite complicated. When burning, the combustible elements merge with oxygen in the air in precise quantitative relationships. This relationship can be theoretically determined by stoichiometric equations of complete combustion.

In real processes, to achieve complete combustion a little more oxygen is needed, as demonstrated by stoichiometric equations. This means that the CO levels in combustion products can be reduced and its complete combustion is achieved, if the amount of air is increased or a poor fuel and air mixture is used. On the other hand, by reducing the amount of toxic CO, the amount of nitrogen monoxide NO significantly increases [13].

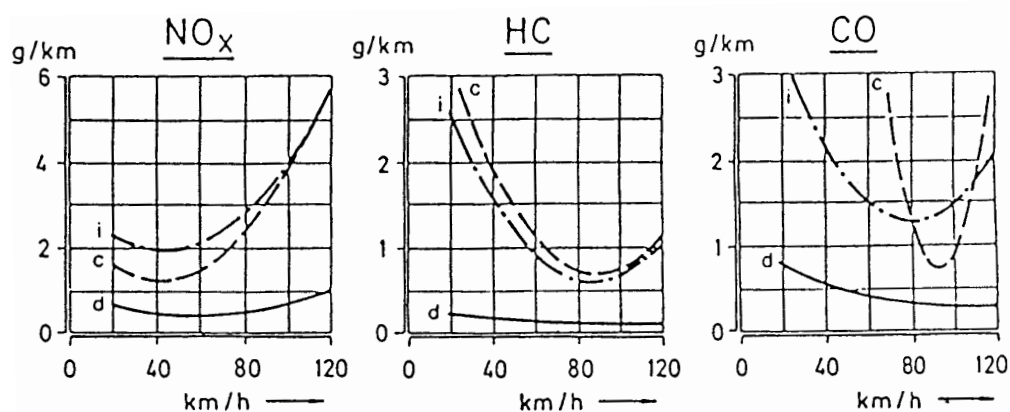


Fig. 1. Emissions of NO, HC and CO in dependence of passenger vehicle velocity [10] (from left to right: gas engine with carburetor, gas engine with injection, diesel engine)

Рис. 1. Выбросы NO, HC и CO в зависимости от скорости пассажирских транспортных средств [10] (слева направо: газовый двигатель с карбюратором, газовый двигатель с впрыском, дизельный двигатель)

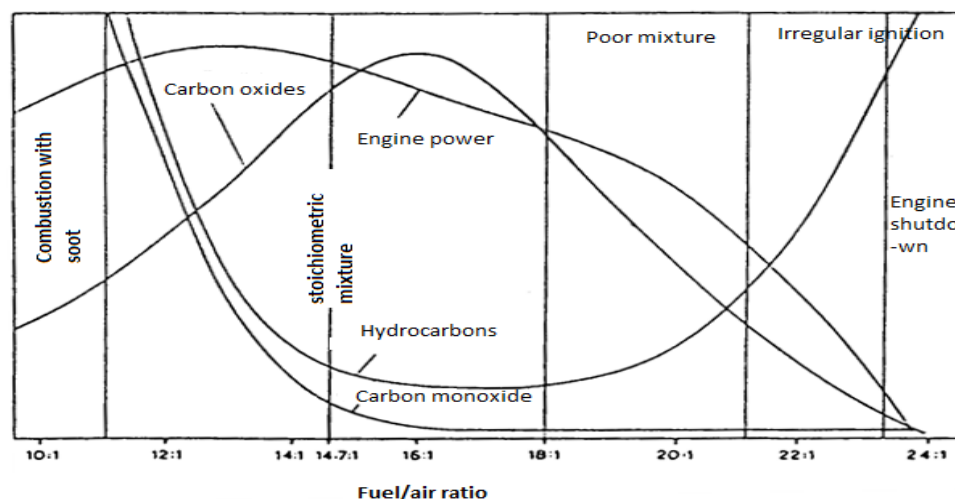


Fig. 2. Dependence of NO, C<sub>x</sub>H<sub>y</sub> and CO concentrations in exhaust gases and engine power in relation to air/fuel in gasoline mixture [8]

Рис. 2. Зависимость концентрации NO, C<sub>x</sub>H<sub>y</sub> и CO в выхлопных газах и мощность двигателя в зависимости от топливно-воздушной смеси [8]

Impurities can also be found in fuel, in the form of sulfur (0.05 to 0.15%), and in some cases tetraethyl or tetramethyl lead. Therefore, in addition to several other compounds, sulfur and lead compounds can be formed in the process of combustion [21].

### 3.4. Nitrogen monoxide and nitric oxides NO<sub>x</sub>

The presence of oxygen and nitrogen in the air during combustion in the engine generates nitric oxide NO by reaction from equation (2) [13].



NO is produced in chemical reactions that take place near the maximum flame temperature. Its formation is subject to the combustion temperature, the amount of oxygen and the holding time of justburned gases in the vicinity of the flame. When the temperature is unsuitable NO becomes inactive, whereas reactions in which it appears, occur too slowly. NO concentrations increase with temperature and reach their maximum value at the maximum combustion temperature and excess

oxygen in the combustion chamber. The amount of NO is also dependent on the proper time for ignition and fuel injection, which is an important issue for the engine designers [13].

With continued oxidation, nitric oxides NO<sub>x</sub> start to appear. In the process of combustion the engine produces mainly colorless nitric oxide NO, which first in the exhaust manifold and later in the surrounding atmosphere is oxidized to red-brown nitrogen dioxide NO<sub>2</sub>. It is very dangerous gas, which only needs a very low concentration in the atmosphere (150 ppm) with the simultaneous presence of UV-rays to produce ozone, O<sub>3</sub>. Ozone formation near Earth is carried out as seen in equation (3).



Such ozone (bad ozone – troposphere ozone) is a powerful oxidizing agent that is strongly irritating to the eyes and respiratory organs, in case of higher concentrations causes bleeding in the nose and headache after exposure it can also cause degradation of lung tissue [7].

NO and NO<sub>2</sub> are also toxic gases, attacking mucous membrane and causing respiratory infections and catarrh. It was found that one to three years long inhalation of air containing 0.1 ppm NO<sub>2</sub> caused a rise in bronchitis and adversely affects lung function in children. Animal experiments showed that 0.25 ppm of NO<sub>2</sub> leads to changes in lung tissue, while 0.5 ppm causes inflammatory reactions and cellular changes.

Except for ozone, photochemical reactions with nitrogen compounds and some hydrocarbons are generating nitrogen oxides (N<sub>2</sub>O, N<sub>2</sub>O<sub>3</sub>, N<sub>2</sub>O<sub>4</sub> and N<sub>2</sub>O<sub>5</sub>), organic peroxides and free radicals. All of these products of photochemical reactions of the engine exhaust gases are called oxidants because they contain strong oxidants, which irritate the human organism, are harmful to plants, reduce visibility and impact (N<sub>2</sub>O) on the formation of the greenhouse effect. NO<sub>x</sub> in the air form nitrozoamine, which is highly carcinogenic [21].

In Slovenia, the NO<sub>x</sub> emissions since 1991 have been rising sharply (almost 100%). The share of transportation in the creation of NO<sub>x</sub> emission is greater than 65%. Therefore, drastic measures in transport are required to reduce emissions of NO<sub>x</sub> [12, 23].

### 3.5. Carbon monoxide CO

CO is odorless and nearly colorless. It is flammable and highly toxic. It binds with chlorine or in the coastal area with chlorine compounds (NaCl), which in combination with photochemical synthesis forms a highly toxic gas called fozgen (COCl<sub>2</sub>). When entering the respiratory system it reacts with hemoglobin in blood to form a persistent compound called carboxyhemoglobin. Hemoglobin thus loses the ability to transfer oxygen, because CO has an almost 250-fold greater affinity to hemoglobin than oxygen. This prevents binding of oxygen to hemoglobin in the lungs, which makes it harder to supply the brain with sufficient oxygen. CO operates only on those beings that have red blood cells (eg. this does not work on insects) [17].

Even at 2% carboxyhemoglobin in blood (corresponding to 13 ppm of CO in the inhalation air) an effect on the central nervous system was noted, resulting in a decreased sense of time. 3% carboxyhemoglobin content in blood causes disruption to light sensitivity and visual focus, in the case of 4 to 5% concentration a measurably decreased vision and psychomotor disturbances are already present. At 30% concentration of CO in hemoglobin in blood poisoning occurs, and at 65 to 80% concentration death occurs. The deterioration of fertility is also a result of CO poisoning [18].

In the U.S., it was even concluded that it has an effect on driving skills of drivers of motor vehicles, since some drivers who have committed a traffic accident had increased carboxyhemoglobin levels. Truck drivers at night have elevated carboxyhemoglobin levels, and thus have a 10% longer reaction time to brake lights and the change in speed of the vehicle in front of them [18].

The basic origin of CO are both transport and energy facilities. Transport is currently the largest source of CO that is formed as a product of combustion of carbon in gasoline engines in the process of incomplete combustion at about 1000 °C. CO emissions from engines of vehicles are highly dependent on the weight of the load, speed, ambient temperature, and injection system. The presence of CO is

very problematic in urban areas, where, by interaction with other pollutants, it formats the ground – level ozone and photochemical smog [7]. In Slovenia, the share of traffic CO is estimated at 65% [8].

### 3.6. Carbon dioxide CO<sub>2</sub>

Carbon dioxide CO<sub>2</sub> is most associated with the impact on the development of global climate change. Almost 20% of global CO<sub>2</sub> emissions are caused by combustion of fossil fuels in internal combustion engines. This proportion is significantly higher in economically developed countries where it reaches 70% [14, 20, 25].

Lately, the industry's contribution to global emissions of CO<sub>2</sub> is decreasing, but that of transportation is increasing (also in Slovenia) [9, 23]. Therefore, the traffic sector has a lot of work to do, if they are to reduce the levels of CO<sub>2</sub> (we need radical changes in the behavior of all users of the transport system). Transport in Slovenia generated 35% of CO<sub>2</sub> emissions.

### 3.7. Sulfur dioxide SO<sub>2</sub>

It is a colorless gas with a strong characteristic odor. Under the influence of moisture in the air it quickly oxidizes to form the sulfurous acid H<sub>2</sub>SO<sub>3</sub>, which in contact with oxygen produces another sulfuric acid, H<sub>2</sub>SO<sub>4</sub>, which causes very strong corrosion. In small quantities it creates an unpleasant taste in the mouth and irritates mucous membrane and eyes. Inhalation of large quantities in lungs with air and moisture creates the above mentioned acid, which is treated as highly toxic. Prolonged exposure to SO<sub>2</sub> causes bronchial and other respiratory diseases [9]. SO<sub>2</sub> is also known as one of the basic causes of acid rain (sulphate aerosol form), which causes harmful effects on vegetation.

Traffic generates most of the emissions on the account of diesel engines, since diesel fuel contains more SO<sub>2</sub> than petrol. In Slovenia the proportion of SO<sub>2</sub> emissions from transport is around 30% [12].

### 3.8. Volatile organic compounds (VOC)

They arise mainly due to incomplete combustion of fossil fuels, as well as the evaporation of petrol from fuel tanks and injection systems (source of emissions of aromatic hydrocarbons – e.g. benzene). Benzene (one in a group of aromatic hydrocarbons, for which we know that they sun-react with OH radicals to form aromatic aldehydes, such as benzaldehyde from benzene, further leading to PAN – peroksiacilnitrata and nitrophenol), is often mentioned and treated in this group of substances which is also pleasantly fragrant, but can cause cancer, especially leukemia. Nearly 80% of benzene emissions originated from the operation of gasoline engines.

VOC contain a series of hydrocarbons and other compounds (methane, phenol, phosgene, ethylene oxide, chlorofluorocarbons, formaldehyde, polychlorinated biphenyls, benzene, tetrachloride, etc.) [7].

The important representatives of VOC are halogenated hydrocarbons C<sub>x</sub>H<sub>y</sub>. These are organic compounds of carbon with hydrogen and halogens, particularly chlorine and fluorine. This reaction opens the door for a whole series of further reactions [5]. Road transit in Slovenia generates about 22% of all VOC emissions [12].

For C<sub>x</sub>H<sub>y</sub> hydrocarbons and some other VOCs it is characteristic that in combination with NO<sub>x</sub> in the presence of photochemical processes they create ground-level ozone, which is an essential component of photochemical smog. They cause respiratory health problems, irritate eyes, and some are believed to be carcinogenic, mutagenic and teratogenic.

Motor vehicles emit a lot of polycyclic aromatic hydrocarbons PAHs (e.g. naphthalene), and their oxygen and nitrogen products. These are also considered to be mutagenic or/and carcinogenic.

Even chlorofluorocarbons (CCl<sub>3</sub>F, CCl<sub>2</sub>F<sub>2</sub>) as members of the VOC group deplete the environment, as a very important part in the decomposition of ozone in the troposphere. Basic components generated at the Earth's surface, are transported into the stratosphere, where they irreversibly photooxidate and form free radicals, which then degrade the precious ozone in the stratosphere [5].

According to recent studies, the way into the stratosphere lasts for about two years. They accumulate in the stratosphere and by decades of energy-rich UV rays break them down. Thereby the

chlorine atoms are formed, which chain react with thousands of ozone molecules in stratosphere and thereby destroy the protective layer of the Earth. Even if CFC emissions would be obliterated completely, according to experts, the state of the ozone layer would not be renewed until the 2060 [12].

For mankind, the ozone layer in the troposphere is very important as it protects us from harmful electromagnetic ultraviolet radiation. It also promotes certain chemical reactions in the stratosphere and converts solar radiation into mechanical energy of atmospheric winds and warming of the atmosphere. Wavelengths of electromagnetic radiation, lesser than 320 nm, are covering the photoabsorbive DNA spectrum and can cause adverse biological effects, including skin cancer. Therefore, the existence of ozone in the stratosphere is so important [2].

UV rays are extremely dangerous for the eyes. After two hours of this light, eyepain, tearing, swelling, headache, increased heart rate, rhythm, nervousness and insomnia can occur [6].

### 3.9. Additives

In to the fuel, particularly petrol, in the past, has been added substances (additives) to improve the fuel's antidetonation properties in the process of combustion in internal combustion engines. With their presence, the chemical structure of the fuel changes, which affects the combustion process itself and thereby the new compounds form, many of which are toxic and dangerous to mankind and the environment. As fuel additives we use or have used substances used on the base of lead, manganese, nickel, and cobalt [7].

Notwithstanding the fact that for a few years now the majority of vehicles uses unleaded gasoline, we still perceive the presence of lead in the environment (also in Slovenia). On roads with more traffic and congested road, an increased concentration of lead dust appears in the soil and sediments and also often in plants. The lead concentration decreases with increasing distance from the road surface and at least 50 to 100 meters away, falls well below the permitted levels [4].

As for lead is a cumulative poison, its influence is dangerous. With its presence in the organism, lead has adverse effects on the fetus, causing malfunctions of kidneys and liver failure, reproductive disability, impairment of mental development of children and causes genetic changes.

### 3.10. Solid particles

Main source of floating solid particles in the air is transport. Their emergence is largely dependent on the type of fuel the vehicle uses. Products of incomplete combustion, especially diesel engines (their main problem is the smoke), are classified among the suspended particles and substances.

Diesel engines are often accompanied by smoke. There is cold (white) smoke, resulting from the engine start (cold temperature in the combustion chamber) or from a low engine load. The main components include unburned fuel with particle size between 1 and 1,5  $\mu\text{m}$ . Warm (dark) smoke resulting from incomplete combustion. At full loads and high temperatures in the combustion chamber, smoke particles to the size up to 1  $\mu\text{m}$  can appear. The smoke from the exhaust system can be of unpleasant smell. It also binds other toxic substances –  $\text{NO}_x$  and sulphate, and a set of hydrocarbons (such as carcinogenic benzopyrene) [4].

Soot in diesel engine (according to some studies, is carcinogenic) appears in the form of elementary black carbon. Condensed hydrocarbons, resulting from unburnt motor oil accumulate on the upper layers.

Still we should not ignore the presence of asbestos particles that originate from the brake pads for road and track vehicles and tire particles that are released by contact between tire and road. Experts are trying to determine for some time now whether the proportion of carcinogenic diseases in urban centers will also depend on the airborne asbestos particles originating from transport [4].

Aerosols with very complex structure are also present in urban areas (called urban aerosols). These are mainly particles with a diameter of 2  $\mu\text{m}$ , which strongly affect the deterioration of visibility. They may be inhalable and often contain toxic and mutagenic compounds [12, 15, 16, 19].



### 3.11. Thermal pollution

Heat is emerging as a by-product of combustion processes. During combustion, a certain part of energy is released into the environment. We are considering the energy necessary to drive the car are the biggest heat polluters. The release of heat in the atmosphere can cause weather anomalies, also local climate change is known to occur. In the area of Los Angeles the thermal pollution reached 5% of total solar energy received in that area [15].

## 4. APPLICATION – THE MEASUREMENT OF EMISSIONS ON A ROAD FREIGHT VEHICLE

For effective reduction of harmful emissions in transport, a wide spectrum of analysis and measurement must be carried out. In almost all the previous analyses of these emissions, measurements were used and calculations performed, taking the average values of important parameters into account (e.g. fuel consumption).

In 2007, the first realistic freight vehicle measurements in the Republic of Slovenia were published. They gave accurate and direct answers on the question of freight vehicle emissions. TRAENVIA project, presented in March of 2007 at an international conference on transport and environment in Milano, which was organized by the Joint Research Centre of the European Union Commissioner for Research and Development, was introduced by the firm F.A. Maik from Maribor. The conference was attended by over 500 participants from around the world. It was an exchange of experience and knowledge in the field of alternative fuels and real measurements of emissions produced by transport.

The TRAENVIA project would precisely evaluate some types of transportation emissions, especially on long freight distances and reach some comprehensive goals: measure and compare real emissions, caused by different transport means in real terms of traffic flow, among themselves, to evaluate the influence of those emissions on the environment and air quality, to evaluate the contribution of the transport sector in urban areas to air pollution, to evaluate the influence on the air quality for several means of transport, to evaluate potential possibilities and options of »nonroad« transport modes and new transport technologies, to offer support to European transport policy.

The F.A. Maik company committed to participate in actual emissions preliminary measurements with their vehicles on the route Maribor - Barcelona. They help to determine the emissions per tonne of goods transported by various means of transport on the route corridor 5.



Fig. 3. The Fifth European corridor

Рис. 3. Пятый Панъевропейский коридор

Just for the execution of preliminary measurements with a truck on the route Maribor - Barcelona, it was necessary to organize a team of three people who were working on the project for more than three weeks only at the field of integrated measurement and an additional two weeks for processing.

The measurements covered the determination of the following levels: CO<sub>2</sub>, CO, NO<sub>x</sub>, VOC, SO<sub>2</sub>, greenhouse gases (CO<sub>2ekv</sub>, CO<sub>2</sub>NH<sub>3</sub>, N<sub>2</sub>O, CH<sub>4</sub>).

The emissions analyzed were:

- ✓ driving a heated engine
- ✓ driving a cold engine
- ✓ volatile organic compounds due to evaporation (daily emissions - due to tank aeration, emissions of heat transfer - with engine stopped, emissions during operation).

The mobile measuring system installed in the vehicle of the company F.A. Maik, measured the following emissions (in g/s):

- ✓ CO<sub>2</sub>,
- ✓ CO,
- ✓ NO<sub>x</sub>.

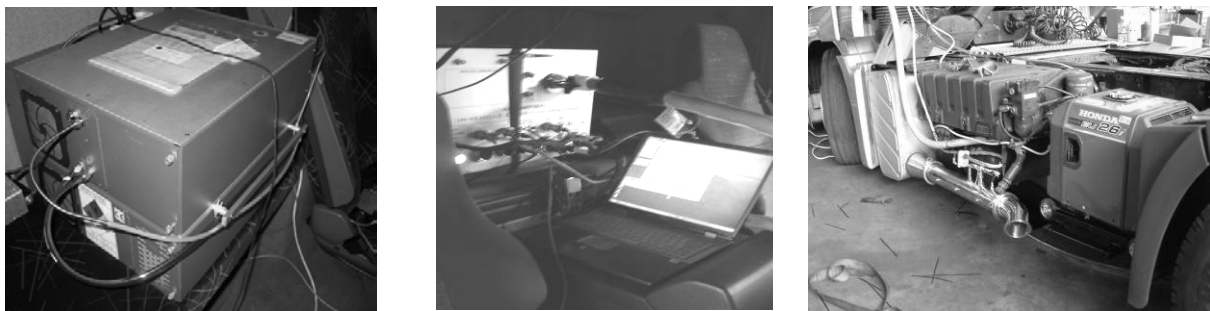


Fig. 4. Mobile measuring device, equipment in a vehicle cabin and on exhaust system (from left to right)

Рис. 4. Мобильный измерительный прибор, оборудование в салоне автомобиля и инсталляция на выхлопной системе (слева направо)

Experts installed a device for measuring emissions while driving (fig. 4, left), and the necessary computer equipment for data storage into the cockpit (fig. 4, middle). A hose with sensors unit and alternative source of energy was installed onto the exhaust manifold, it measured emissions on their way out of the engine (fig. 4, right). The measuring sensors were connected to the vehicle's electronic system that controls the operation of engine (monitors parameters such as engine plants, gear ratio, speed, fuel consumption, fuel production, etc.).

Such an equipped and properly marked vehicle (with the promotion of the project and companies) then traveled the road from Maribor to Barcelona and back, meanwhile the measuring devices measured emissions in some-second intervals. Vehicle was located by means of continuous GPS devices, enabling analysis of emissions at almost the precise location.

#### 4.1. Measurement results

The results can be seen in the following pictures, representing CO<sub>2</sub> (fig. 5) and NO<sub>x</sub> (fig. 6) emissions between Maribor and Ljubljana (cca 135 km). Figure 6 left shows a rough distribution of CO<sub>2</sub> emissions from the engine of a fully loaded vehicle. It can be seen, that the emitting of CO<sub>2</sub> was greater in the vicinity of Maribor, Celje and Ljubljana, due to an urban driving regime (accelerating and braking). Further on, the emission increases in the region of Trojane, which can be contributed to changes in geodetic height, which increased the engines load. This can be better seen from fig. 5 right, showing the relation between emissions and geodetic height.

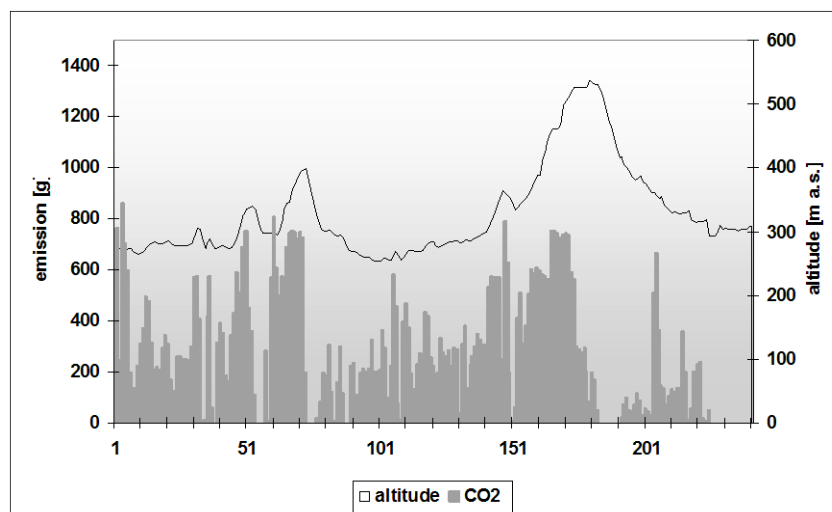
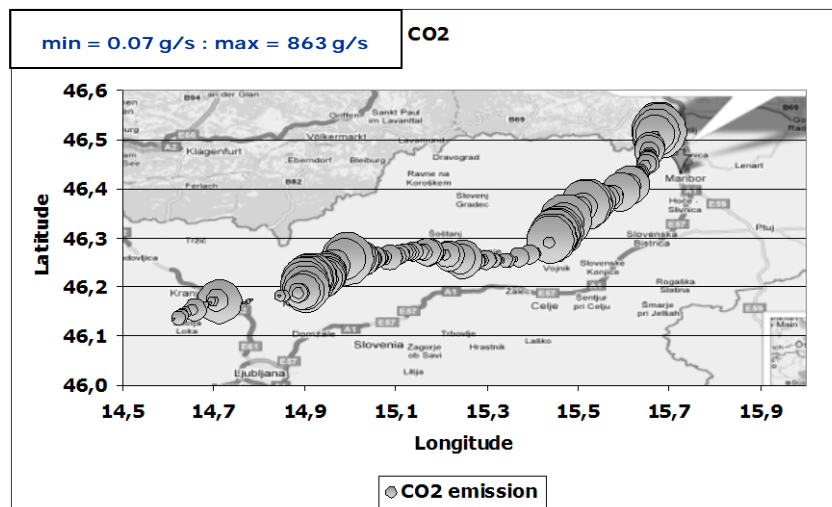


Fig. 5. Emissions of CO<sub>2</sub>  
 Рис. 5. Эмиссия CO<sub>2</sub>

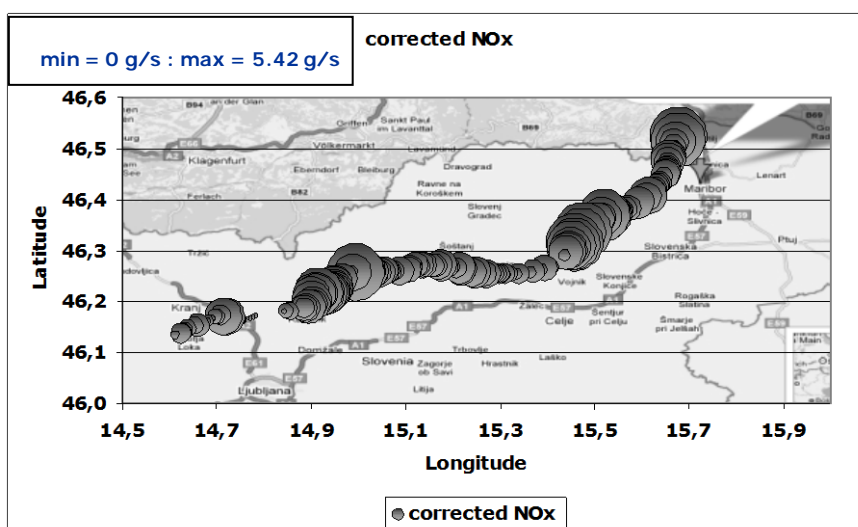


Fig. 6. Emissions of NO<sub>x</sub>

Рис. 6. Эмиссия NO<sub>x</sub>

#### 4.2. Result interpretation

The emissions' data, presented on the figures, are approximate; the actual results are much more accurate (further information is available at the company F.A. Maik and research institution). Through the measurements quality route data were obtained, which can be used in a special computer model, which includes all vehicles within a certain "traffic" condition.

By considering the fact, that several types of transport vehicles and many factors influence the development in transport flow, many other measurements will be required. At the same time we must not forget that such measurements are very complex and time-spending (installation of measuring instruments, calibration of instruments takes place every two hours).

#### 5. CONCLUSION

In the transport system there are many factors that affect the deterioration of natural environment. Transport policy makers should allow and encourage the development and use of such transport techniques and technologies that are environmentally friendly. It will not be achieved without a coordinated policy and scientific research approach. It is necessary for economy to participate, which is reflected in the case of F.A. Maik.

An effort to reduce environmental pollution caused by traffic should be subject to all other traffic participants. They must reduce air pollution from traffic generated by individual vehicles, which can be achieved by different technical measures on the vehicle, the appropriate management of traffic and, ultimately, with different habits.

Air pollution, caused by vehicles, can be reduced by some short-term measures. Among them, the measurements of traffic management or organization have to be mentioned in regard to traffic profession and traffic managers, but still with no real practical validity. But through the results of the project, which was briefly presented, can be clearly seen that such validity is essential.

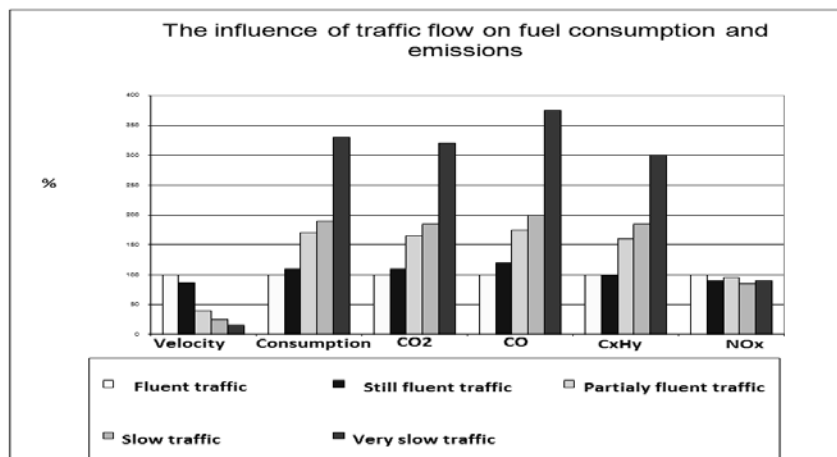


Fig. 7. The influence of traffic flow on emissions [24]

Рис. 7. Влияние транспортного потока на выбросы [24]

The transport organization should improve traffic flows and adapt them to drive sets operating mode, since we know that motor vehicle emissions are associated with acceleration, braking and unnecessary idling of vehicles. Unfortunately, experiences in many cases are poor as the organization and management of transport, especially in urban areas, do not comply with these environmental components. Alignment of major roads should allow an uninterrupted traffic flow of vehicles. These should be built in a way that they do not impede the continuous flow of vehicles and at the same time

avoid more populated residential areas. The levels of  $\text{NO}_x$ ,  $\text{C}_x\text{H}_y$  and CO emissions are different in urban areas, on motor roads and highways. The most  $\text{NO}_x$  is emitted in the areas of highways, while urban areas are considered the areas with the largest concentration of CO and  $\text{C}_x\text{H}_y$  [10].

When accelerating from 100 to 130 km/h, the emission of  $\text{CO}_2$  increases by 15% [7, 17]. The amount of harmful emissions depends on the driving velocity, as shown in figure 9. Driving too fast increases fuel consumption and the combustion consumes more oxygen, thus depleting breathable oxygen from the atmosphere.

□

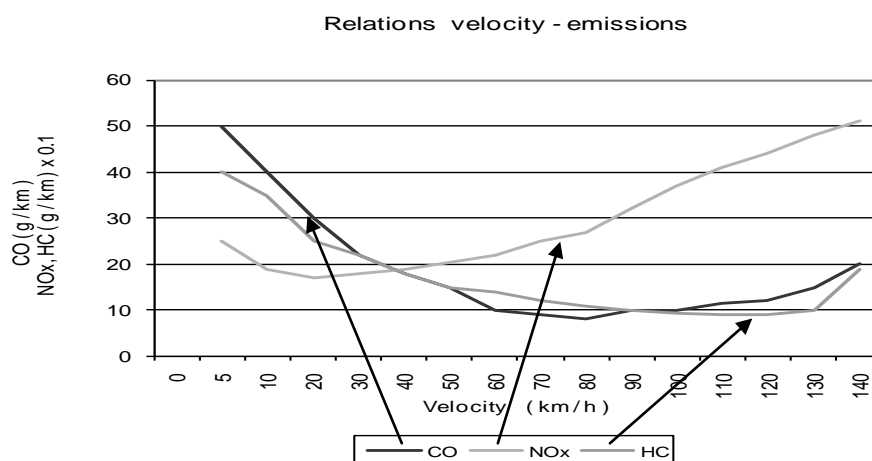


Fig. 8. The influence of velocity on emissions [24]

Рис. 8. Влияние скорости на выбросы [24]

The transport system's negative environmental impacts can be improved by increasing the volume of integral means of transport. Thus, from the traffic and technical point of view, the connection of traffic and transport operation services should be transferred to a higher level. The integrity of means of transport (e.g. bimodal rail systems), which becomes more and more important, allows the implementation of such a transport policy that is more friendly to the environment.

The main and most important measure to improve the state of chemical air pollution from traffic is the reduction of pollution caused by individual vehicles, which can be achieved by using properly maintained and operating vehicles, engines and catalysts, using vehicles with lesser fuel consumption, installing devices that help soot reduction, or solid particle filters, limiting unnecessary trips, supplementing individual transportation with public transport, setting stricter standards for motor vehicles power load capacity, moderate acceleration, driving at the optimum number of rotations per minute, driving moderately even on highways, using different types of fuel, but this is a long-term measure.

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