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ANALYSIS OF THE INDOOR AIR QUALITY INSIDE MOTOR VEHICLES

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Abstract

Air quality inside motor vehicles is becoming an important issue worldwide because of the ever-increasing number of motor vehicles on the road. These vehicles are a source of exhaust emissions such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), volatile organic compounds (VOCs) and others. Motor vehicles are also source of a non-exhaust emissions such as particulate matter (PM). This article deals with the issue of air pollution in car interiors caused by the pollutants from both external and internal sources. Article focuses on the issue of air quality in motor vehicles interiors and the impact of this indoor environment on the health and of passengers. The paper also provides an overview of recently published studies on the issue and their results, as well as the information about the impact of these pollutants on human health. The research will serve as a theoretical basis for future research in this area.

Keywords: Indoor Air Quality; Motor Vehicle; VOCs; CO_2; Particulate Matter

1. Introduction

Modern lifestyle is related to indoor environment, whether it is time spent at home, at work, in a shopping centre, or in a vehicle, many activities take place indoors. Such way of life with a lack of fresh air and natural daylight contributes to the origin and development of many diseases.

In developed countries, many times one family has more than one car. Overall, car transport is one of the most used, mainly due to the many benefits it offers, such as convenience, time savings, privacy and the possibility of direct transport to a specific location, almost anywhere in the world. We can say that the benefits that this transport offers to people are so significant that it is worth the extra expenses. However, the increasing number of cars on the road lead to burden on the environment and reduction in the effectiveness of the above-mentioned benefits. Travel time is increasing due to traffic congestion, lack of parking spaces, drivers are becoming more and more aggressive, impatient and ruthless, and also for these reasons, the number of accidents is rising. This which contributes to the fact that motorcycle and car travel is ranked as most dangerous.

From an environmental point of view, road transport makes a significant contribution to the deterioration of the quality of the environment. With the growing number of cars, the demand for raw materials to produce automotive components and fuels. Mining and industrial production generate large amounts of greenhouse gases and waste as a by-product. The operation and maintenance of motor vehicles does not lag behind. The air quality around busy roads, especially in big cities, is poor. Motor vehicles pollute the air with toxic particles and vapours. Drops of oil, fuel and other toxic substances, together with tire fragments, are trapped on the roads and with the rain they get to pollute the groundwater and soil around the roads. The modern way of life is taking its toll and the quality of life in the future will reflect the decisions of individuals, large corporations and whole society.

With ever-increasing information about the consequences of air pollution and its leading position in the ranking of the most common causes of premature death, the issue of the quality of the air we breathe in our motor vehicle is gaining in importance. The air quality in the car's interior is influenced by various factors, such as the way and intensity of use of the ventilation system, air conditioning and heating, the ambient air quality and the individual characteristics of the car (make, age, model ...).

The purpose of the research is to raise awareness of the possible risks associated with poor air quality in motor vehicle interiors. The article aims to provide theoretical knowledge about the occurrence of the most common air pollutants in the car interior and their impact on human health. The paper also covers research on the results of recent studies on the subject.

2. Air pollutants inside the motor vehicles

The most common external air pollutants are those emitted by motor vehicles include particulate matter (PM), nitrogen dioxide (NO_2), carbon dioxide (CO_2), carbon monoxide (CO) and volatile organic compounds (VOCs) and they are most concentrated in the vicinity of frequently used roads and in the environment and can penetrate car interior. Internal pollutants include cigarette smoke, CO_2 accumulation as a result of passenger breathing, volatile organic compounds from plastic components and the use of various chemicals to clean the interior. Various bacteria and fungi may also be present in the interior. Exposure to these pollutants is associated with short-term or long-term adverse effects on human health and in the worst case can lead to premature death.

1.1. Volatile organic compounds (VOCs)

Volatile organic compounds (VOCs) are an important group of pollutants. VOCs include benzene, formaldehyde, acetone, toluene, and others. They also participate in the formation of photochemical smog, of which the most harmful component is ground-level ozone. Sources of VOC emissions caused by human activity include oil and gas production, fuel combustion, chemical and industrial processes (production and use of paints and organic solvents, processing of synthetic rubber ...), use of pesticides and cigarette smoke. VOCs can cause a variety of health problems, such as headaches, breathing problems, skin and eye irritation, cardiovascular disease, and more. Some volatile organic compounds are carcinogenic, such as formaldehyde and benzene [1].

Sources of VOCs in the car interior may include various plastic components, textiles, the use of chemicals to clean the interior and leather seats, various car fragrances and more. Recommended exposure values for individual VOCs vary depending on the toxicity of the volatile substance, the exposure values of tVOC (total VOC concentration) in the indoor environment are given in the following Table 1. None of the individual VOCs should exceed 10% of the concentration in the total VOC concentration [1], [2].

tVOC [ppb]	Exposure	Recommended exposure time
0-65	recommended range	No limit
65-220	low danger, recommendation for increased ventilation	No limit
220-660	medium danger, recommendation for increased ventilation and removal of the source	< 12 months
660-2200	high danger, need for ventilation and removal of resources	< 1 months
>2200	unacceptable level, need for intensive ventilation and immediate removal of the source	Several hours

Table 1. tVOC Exposure levels

1.2. Particulate matter (PM)

Airborne dust is the sum of solid particles of various sizes that are freely dispersed in the air. They enter the air in a natural way, but also as a result of human activity (combustion of solids, tire wear, exhaust gases ...). Their impact on human health depends on the toxicity, number and size of these particles. While larger particles above 10 μm (PM10) are trapped in the upper respiratory tract and can cause irritation of the upper respiratory tract and eyes, particles smaller than 10 μm reach the lower respiratory tract, where they can settle and cause health problems. The most dangerous are particles smaller than 2.5 µm (PM2.5), which can penetrate into the lung vesicles and settle there or continue into the bloodstream. It is proven that air pollution with dust particles causes increased mortality of the population from diseases of the respiratory and cardiovascular system [3].

Air pollution by solid particles around roads is caused mainly by the wear of tires, followed by exhaust gases. The number of particles released by tire wear depends on the size and weight of the vehicle as well as the driving style. For example, SUVs and electric cars experience increased tire wear. In addition to causing air pollution, rain also causes contamination of the surrounding soil, water sources and groundwater with microplastics [4].

The WHO (World Health Organization) guideline stipulates that the concentration of PM2.5 must not exceed an annual average of 10 µg/m³ or a daily average (24 hours) of 25 µg/m³. And the concentration of PM10 must not exceed an annual average of 20 µg/m³ or an average of 50 µg/m³ [5].

1.3. Carbon Dioxide (CO_2)

Carbon dioxide (CO_2) is a colourless, tasteless, odourless gas that is heavier than air and can accumulate in lower spaces and cause a lack of oxygen. It is naturally present in the Earth's atmosphere as a trace gas and a product of cellular respiration or the burning of fossil fuels. Its unstable solid form is referred to as dry ice.

Typical outdoor CO_2 concentrations are approximately 380 ppm (0.038%), with air concentrations depending on local conditions, altitude and relative humidity. As a result of human activities such as burning fossil fuels, cement production, deforestation, the concentration of CO_2 in the atmosphere is increasing. The main source of CO_2 in interiors is human respiration. It has a negligible toxic effect at low concentrations. At higher concentrations, it leads to an increase in respiratory rate, arrhythmias, nausea and loss of consciousness. The severity of symptoms depends on the concentration of CO_2 and the time of exposure. At high concentrations (> 4%) it causes immediate danger to life and health [6], [7].

CO_2 [ppm]	**Exposure**
250 - 400	concentration similar to ambient air
401 - 1000	normal concentration for indoor living areas with good air exchange
1001 - 2000	higher concentrations, or prolonged exposure causing drowsiness
2001 - 5000	high concentration with prolonged exposure causing headache, drowsiness, loss of attention, nausea
> 5000	represents the occupational exposure limit value for 8 hours. change
> 40000	threat to life and health

Table 2. CO_2 Exposure levels

1.4. Carbon Monoxide (CO)

Carbon monoxide (CO) is a colourless, tasteless and odourless gas produced by the incomplete combustion of carbon-containing materials. It is lighter than air, is present in the atmosphere in a small amount and is formed by photolysis of carbon dioxide by ultraviolet radiation. Natural resources also include volcanic activity and fires. Carbon monoxide is the gas that has caused the most poisoning in human history. It is present in the exhaust gases of cars, it is also formed during heating by gas, diesel and petrol heaters and accumulates especially in small and poorly ventilated rooms. Other important sources include smoking and wooden grills.

Carbon monoxide (CO) is released as a by-product of both diesel and gasoline internal combustion engines and is toxic to humans and animals in concentrations above ~ 35 ppm. A properly functioning exhaust system must prevent CO from entering the cab. Broken system exhaust seals, cracks or openings along the exhaust pipe, open trunk, or improperly tightened connections can result in toxic gases entering the cab. Pregnant women, young children, people with cardiovascular diseases and the elderly are the most sensitive to carbon monoxide. To protect health, it is important to avoid cigarettes, long-term stays in smoking areas and places with a high concentration of road traffic emissions [8].

At high concentrations of carbon monoxide, intoxication occurs, which seriously impairs the ability to drive. People with CO intoxication think slowly and irrationally, are confused and unable to drive a motor vehicle safely. This condition is especially dangerous because one does not realize it.

CO [ppm]	Exposure
9	maximum long-term exposure (ASHRAE standard)
35	maximum exposure during 8 hours shift (OSHA)
>800	death within hours
>12 800	death within 1-2 minutes

Table 3. CO Exposure levels

1.5. Nitrogen Dioxide (NO_2)

Nitrogen dioxide (NO_2) is a yellow-brown, aggressive, toxic gas. It causes acid rain and smog in the air. It irritates the mucous membranes of the respiratory tract and reduces their immunity against infections.

Up to 50% of nitrogen dioxide comes from road transport, another important source is the combustion of natural gas. The transition from petrol to diesel vehicles exacerbates the danger of NO_x. NO_x is a mixture of nitric oxide (NO), which is harmless, and nitrogen dioxide (NO_2). Combustion of diesel in the engine instead of petrol produces more NO_x overall, of which up to 70% is NO_2, compared to only 10 to 15 percent of NO_2 when burning petrol. From certain concentrations (> 20 ppm for a few minutes), inhalation of NO_2 causes poisoning associated with toxic lung edema, and immediate life-threatening [9], [10].

NO_2 [ppm]	Exposure
< 0,1	minimal impact on health
0,1 - 5	adverse health effects, especially in vulnerable populations (asthmatics, the elderly, people with respiratory problems…)
>5	threat to life and health

Table 4. NO_2 Exposure levels

3. Research review

The issue of the impact of road transport on human health and the environment is extensive and current. It is the subject of several international studies and research. "Bad air" in the interior is often a cause of discomfort, but it can also lead to serious health problems. By breathing, harmful substances from get into the lungs and blood circulation. Air quality therefore plays an important role in protecting human health as well as environment. This part of the paper presents review of studies dealing with issue of air quality inside motor vehicles.

Recently published studies in this area include the study by Bakhtiari et al. [11], which focused on the evaluation of volatile organic compound (VOC) concentrations in taxi interiors depending on the age of the vehicle and the type of fuel. The study was performed on four models of taxis in three age groups and powered by three different types of fuel (petrol, CNG - compressed natural gas and LPG - liquefied petroleum gas). The amount of volatile organic compounds in the interiors of taxis was measured before and after refuelling. The results of the study show that refuelling increased the concentrations of pollutants in the vehicle, especially for CNG and LPG fuels, the concentrations of volatile organic compounds were most pronounced in petrol models and the age of the taxi indirectly affected the concentration of formaldehyde and acetaldehyde in the interior.

Barnes et al. [12], in their study tested fifty-one vehicles for the presence of particulate matter (PM0.3 and PM2.5), total volatile organic compounds (tVOC), carbon monoxide (CO), carbon dioxide (CO_2), airborne bacteria and fungi. Of the total number of tested vehicles, up to 24% of them exceeded the recommended level of volatile organic compounds and this concentration correlated positively with the age of the vehicle. Also, the presence of tVOC was significantly higher when the engine was idling than while driving. The level of carbon monoxide (CO) in all vehicles did not exceed the recommended values, while 96% of vehicles exceeded the recommended level of CO_2 1000 ppm and 16% of vehicles even the value of 5000 ppm. The presence of microbes, bacteria and fungi in the interior was relatively low. Further in the study by Barnes et al. up to 96% of the tested cars exceeded the recommended CO_2 values (1000 ppm) while driving, the values ranged on average around 3 413 ppm, 16% of vehicles exceeded the value of 5,000 ppm. A total of 90% of the cars tested exceeded the recommended CO_2 values in the cab during engine idling.

According to Chen et al. [13] VOC concentrations increase with temperature and relative humidity and decrease with the age of the car and the total mileage. They are also higher for cars with small cabs and depend on the car model and the sampling location.

Particulate matter (PM) pollution from transport emissions has a significant impact on human health. Dröge et al. [14] examined PM levels in the car cabin with a mobile aerosol spectrometer under various conditions. The particle concentrations depended on the particle size and the concentration of PM in the ambient air. The concentration of smaller particles showed small fluctuations, but the concentration of coarse particles showed high fluctuations with maximum values on busy roads. Closing the vehicle window reduced PM exposure, especially to coarse particles.

Particulate matter (PM) concentrations inside vehicle cabs are often extremely high. Another study from 2019 [15] looked at the relationship between the emissions of the lead vehicle and the PM concentration levels in the cab of the immediately following vehicle. The study was performed on a 26 km long fixed route, where 10 repeated tests were performed during a 60-minute drive. Monitoring of particle concentrations of different sizes (PM0.3-1 and PM1-2.5) was performed inside the cab of the vehicle with a fixed ventilation setting (i.e. windows closed, air conditioning off and recirculation off). The results showed that the PM levels in the cab were significantly affected by the emissions of the leading vehicle.

A study by Hudda, N. & Fruin, S.A. of 2018 [16], examined the effect of driving and ventilation on cab CO_2 accumulation. The results indicate that recirculation of the interior air and closing of the windows reduces the levels of fine particles in the vehicle but increases the CO_2 concentration as a result of the passengers' breathing. The CO_2 concentration is greatly affected by circumstances such as the number of passengers, the age of the vehicle, the ventilation setting, the volume of the cab, the speed and the driving time. By adjusting the internal air circuit, the CO_2 level can exceed a threshold value (2,500 ppm), which has negative cognitive or physiological consequences such as difficulty concentrating and fatigue). For longer journeys or number of passengers, the use of air recirculation should be regularly interrupted or partially mixed with the outside air, ideally so that the CO_2 concentration is below 1000 ppm.

Nitrogen dioxide (NO_2) is also a pollutant and harmful substance in the exhaust gases of motor vehicles. A Polish study [17] examined the exposure of drivers, passengers, and pedestrians to NO_2 during various excursion scenarios. NO_2 samples were collected in the interiors of cars, trucks and buses, as well as in the ambient air using passive samplers, and other NO_2 concentrations were analysed using spectrophotometric techniques. The results of the research suggest that the highest concentrations of NO_2 were associated with travel on urban roads, while lower concentrations were associated with movement in suburban traffic, on roads with low traffic intensity.

A Korean study [18] also looked at the personal NO_2 exposure of 31 taxi drivers in two Korean cities. Exposure was estimated based on measurements in the outdoor environment and the indoor environment of the home and taxi. Based on the results, we can consider driving a car at work as the main source of NO_2 exposure for taxi drivers. Research also shows that NO_2 exposures in LPG taxis are significantly lower compared to diesel vehicles.

5. Conclusion

Although we often do not even realize it, air quality has a significant impact on the environment and our health. For several years now, road transport has been at the top of the list of air pollutants. Every year we record an increase in road mobility and transport, which leads to a deterioration in air quality. This can be felt especially by people living in big cities and near busy roads. Modern lifestyle is associated with motor vehicles and long time spent on the road, so maintaining a suitable indoor air quality is gaining in importance. Regular ventilation, proper use of air conditioning systems, inspection and replacement of filters can be useful tools to improve the quality and hygiene inside the vehicles.

The issue of air quality in the car interior is very broad and, despite the studies carried out so far, provides space for further experiments, such as obtaining information on the influence of individual characteristics of the vehicle, such as age, model, manufacturer etc. and performing tests under various conditions.

The results of the research should lead to an increase in awareness of the possible risks associated with poor air quality in motor vehicle interiors. Reducing the adverse effects of transport is also an important goal of EU policy. EU strategy papers focus on zero greenhouse gas emissions, emphasize the importance of moving to low-carbon regimes and zero-emission vehicles, emphasize the central role of electrification and renewable energy sources, and prioritize operational efficiency improvements. Better spatial planning and full use of public transport are also required. All of this can help reduce the health risks of poor air quality. An accelerated shift to the use of hydrogen-powered vehicles can also play an important role in reducing the negative impact of road traffic on overall air quality.

Future research will focus on measuring individual air pollutants under different conditions and thus obtaining information on how to ensure the best possible conditions of air quality in vehicles. Measurement and comparison of air pollutants in the car and public transport. Carrying out seasonal measurements in order to determine the effect of weather on the quality of air in the interior of vehicles.

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