



ANALYSIS AND EVALUATION OF THE EFFECT OF STUDDED TYRES ON ROAD PAVEMENT AND ENVIRONMENT (II)

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Abstract. In order to reduce a negative impact of studded tyres on the environment (i.e. emissions of fine (PM_{2.5}) and coarse (PM₁₀) particulate matter and noise) various scientific investigations are carried out to decide if the use of studded tyres shall be allowed or prohibited. This is especially topical for the countries belonging to the northern latitudes of the Earth's hemisphere where in winter months the air temperature drops below 0 °C, i.e. Scandinavia (Norway, Sweden, Finland), East and Middle Europe (Lithuania, Latvia, Estonia, Germany, etc.), also USA, Japan, Canada and Russia. Based on the scientific investigations that the use of studded tyres causes emissions of pollutants, especially of PM_{2.5} and PM₁₀ (Al, Si, K, S, Zn, W etc.), into the ambient air several tens of times higher than by the use of non-studded tyres and generates the increase in the noise emissions up to several tens of times, it could be stated that the use of studded tyres should not be obligatory. Thus, in "mild" Lithuanian winter when the air temperature often varies around 0 °C the use of studded tyres when travelling of icy and more rarely cleaned roads of Lithuania should be only recommended since the ice layer of the road pavement is effectively surmounted by the new generation winter tyres, i.e. less dangerous for the environment, manufactured from a more soft rubber mixture, containing a chemical element silicon.

Keywords: studded tyres, traffic emissions, fine (PM_{2.5}) and coarse (PM₁₀) particulate matter, noise, road wear, road dust.

1. Introduction

In winter road traffic, especially when using studded tyres, causes also a secondary pollution with particulate matter (PM). Studded winter tyres destroy road pavement, lift into the ambient air the remnants of destroyed pavement, the spread sand and salt mixture and not collected mud, and when using such tyres on "bare" road pavement (without ice or snow) – fine and very dangerous micro elements initiated during traction. For example, by the words of salespeople, the market of studded tyres in Lithuania makes 10% (sometimes even up to 15%) of the total sales of tyres. Thus, it could be stated that Lithuania, though not determines but contributes to the total pollution of urban air with (PM_{2.5}) and (PM₁₀) particulate matter and to the exceeded permissible noise level. Data of observations, carried out in several recent years, shows that in Lithuanian cities, like in many other European cities, pollution of ambient air with PM₁₀ remains one of the most important problems of environmental protection. In the year 2006, like in the previous 2004–2005, the average daily concentration of PM₁₀ in certain days exceeded the limit value in all the largest cities of Lithuania. In Vilnius, Kaunas and Šiauliai concentration of PM₁₀ at high-volume streets was

increased for more than 35 days per year, i.e. more often than this is allowed by the European Union (EU) Directives and Lithuanian legal acts.

In the recent 10 years emissions of fine and PM₁₀ in the EU and Lithuania will be limited by the newest and significantly more-binding EU and Lithuanian legal acts. A new *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe* decided until the year 2020 to reduce the currently valid annual and daily limit values for particulate matter (with the permissible number of days of exceeded limit values), for example, the annual limit values for PM₁₀ will be reduced from 40 to 10 µg/m³, for PM_{2.5} – from 25 to 7 µg/m³. Correspondingly, the daily limit values for PM₁₀ will be reduced from 50 to 30 µg/m³, for PM_{2.5} – to 20 µg/m³ and could not be exceeded for more than 7 times per a calendar year.

In the recent 10 years noise in the EU member-states and Lithuania has increased by 0.5–1 dBA per year on average, whereas in some cities – even by 10–12 dBA. This is demonstrated by the data of 2006–2007 strategic mapping of Kaunas City, based on which 26.5 thousand inhabitants are affected by the equivalent sound level higher than

65 dBA caused by noise from roads, railways and industrial activities. For example, in Lithuania the permissible noise level is often exceeded at the motorways where 2.3 thousand inhabitants live.

In future the newest EU and Lithuanian legal acts will also limit noise emissions. Until 2012 it is suggested to even more reduce emissions from vehicle tyre noise – by 2.5–5.5 dBA, from heavy vehicle tyres – by 5.5–6.5 dBA. According to the experts of Nordic countries, the most danger for the environment due to generated noise is represented by studded tyres, the noise emissions of which are from 3–5 dBA to several tens of dBA higher than the currently valid limit values for non-studded winter tyres.

According to the scientists, the use of studded tyres not only increases fuel costs (approx by 4–8%) but also “aggressively” affect asphalt pavement. The scientists affirm that a vehicle in such “shoes” having travelled 1 km on “bare” asphalt mills out about 20 mg of dust from the asphalt wearing course of road pavement. Tyre studs also form deep ruts on roads, thus, restricting traffic in a warm period of the year and reducing a service life of road pavement and horizontal thermoplastic marking. Due to above reasons in many countries (Poland, Germany, Japan etc.) studded tyres are prohibited. However, they are still allowed to be used in Lithuania, Latvia, Estonia, also in Scandinavian countries and Russia.

2. Traffic-generated environmental pollution in the European Union and Lithuania

2.1. Pollution of ambient air with fine and coarse particulate matter

In the largest cities of the world nearly 75% of pollutants in the ambient air are generated by road traffic. Together with vehicle exhaust gases the following emissions could be found in the atmosphere: carbon monoxide, nitrogen monoxides, volatile organic compounds, heavy metals, $PM_{2.5}$ and PM_{10} . According to the *Manual for Ambient Air Quality Assessment*, the largest problem of the urban air quality – pollution with fine particulate matter. In winter road traffic, especially when using studded tyres, causes a secondary pollution with $PM_{2.5}$ and PM_{10} .

The appearance of $PM_{2.5}$ and PM_{10} in the EU and other world countries is also determined by a set of other reasons, i.e.:

- pollutant emissions from stationery and mobile pollution sources;
- increased pollutant emissions due to freeze-up (especially in winter);
- increased pollution due to insufficiently cleaned streets and their environment (in spring);
- construction works, repair of streets, burning grass, forest fires;
- transferred pollutants from other territories (long-distance air transfer).

General pollution of ambient air with $PM_{2.5}$ and PM_{10} is well demonstrated by air quality measurements in the largest cities of Lithuania – Vilnius, Kaunas, Klaipėda, Šiauliai and Panevėžys, and in industrial centres – Jona-

va, Kėdainiai, Mažeikiai and Naujoji Akmenė where the largest air quality problems are related to pollution with $fPM_{2.5}$ and PM_{10} . The quality of ambient air is used to be assessed by comparing the measured pollutant concentration to the established pollution standard – limit values. Based on the currently valid requirements of EU directives and Lithuanian legal acts and data of the *Environmental Protection Agency*, the average concentration of PM_{10} ($50 \mu g/m^3$) shall not exceed the established limit value (24-hour limit value including the permissible deviation) for more than 35 days per a calendar year (Fig. 1).

Based on data of the Air Monitoring of Lithuania, in the year 2009 concentration of PM_{10} was exceeded more often compared to the previous years. This is showed by the max concentration of coarse particulate matter which nearly twice exceeded the limit value and was recorded in January 2009, in Jonava and Kaunas City (Petrašiūnai District), a slightly less concentration – in Vilnius City (Savanorių pr., Lazdynai District), in the centres of Klaipėda and Panevėžys. Compared to the previous year 2008, in January–February 2009 the number of exceeded daily limit values of PM_{10} in some air quality measurement stations has already overtaken or reached the annual number of exceeded limit values. For example, in 2008 the station located at the heavy traffic street in Klaipėda recorded 8 days with the exceeded PM_{10} , whereas, in the first two months of 2009 the number of exceeded values has already reached 13. In January–February 2008 only one case of exceeded daily limit value of PM_{10} was recorded in Kaunas, whereas, in the same period of 2009 the days with exceeded limit values were recorded already in all larger cities of Lithuania. The increased pollution with PM_{10} was most probably influenced by the more cold weather in January–February 2009, where the mean air temperature was approx. 3–4 °C lower than in a previous year, also by the prevailing unfavourable conditions for pollutant dispersion and the use of studded tyres. During the freeze-up of 2009 due to a more intensive heating more pollutants were emitted into the air where conditions for their dispersion were often unfavourable. However, in January–February 2008 the comparatively warm, humid and windy weather prevailed favourable for pollutant dispersion.

In previous years PM_{10} had also exceeded the limit values. For example, in 2007 the highest pollution of ambient air with PM_{10} between the whole Lithuanian industrial centres was recorded in Kaunas. Based on data provided by the *State Analytical Control Division of Kaunas Regional Environmental Protection Department Under the Ministry of Environment*, on 28 March 2007 in Petrašiūnai District concentration of PM_{10} exceeded the limit value twice, on 29 March – by 3 times. Meanwhile, concentrations of carbon monoxide, sulphur dioxide, nitrogen dioxide and ozone did not exceed the permissible values.

According to the *Public Safety Division of Kaunas Public Health Centre*, the largest influence to the increase in air pollution concentration was made by unfavourable meteorological conditions in those days – the settled dry and windless weather. According to data of *Environmental Condition*, at that time PM_{10} was accumulating in the

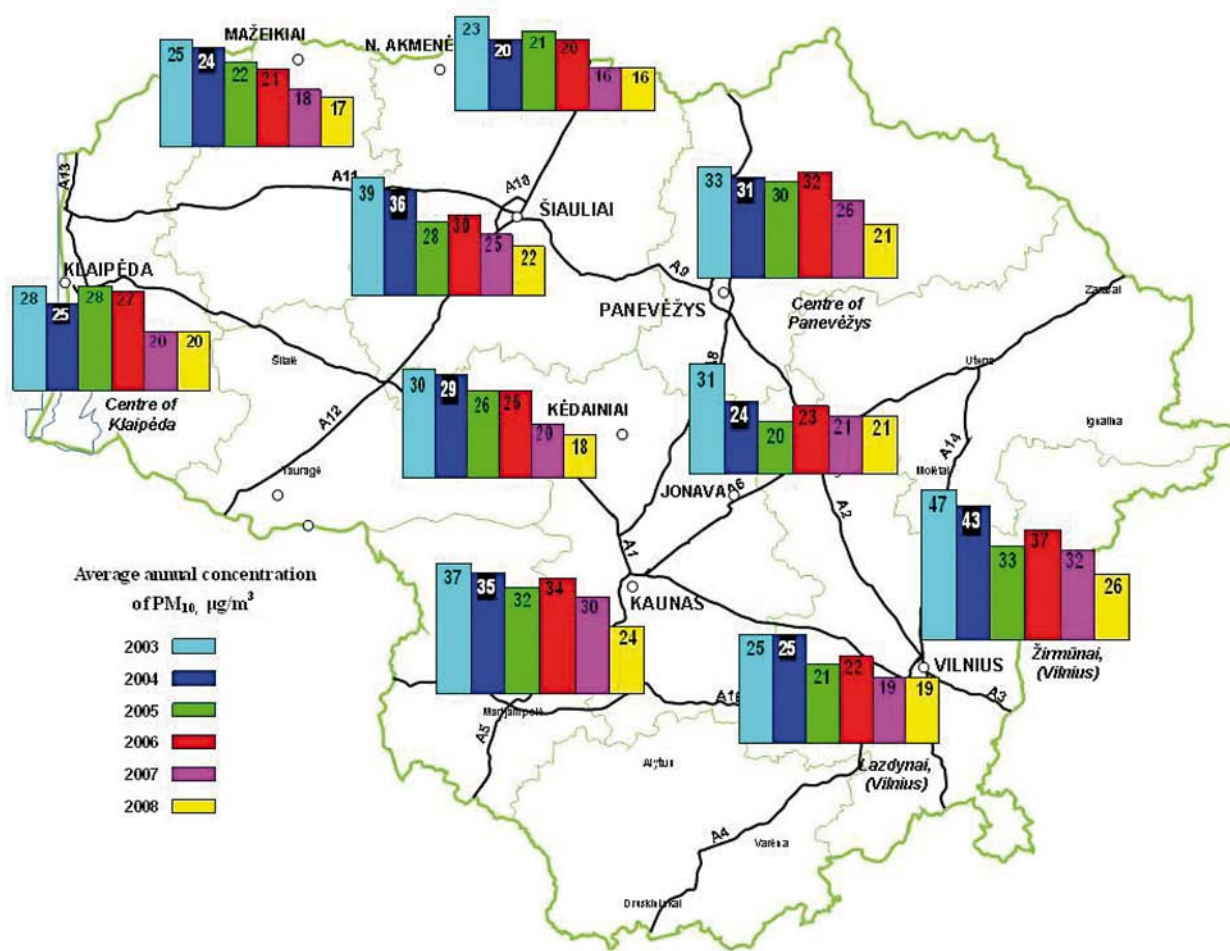


Fig. 1. Average annual concentration of PM_{10} in Lithuania (2003–2008) according to 2009 data of Environmental Protection Agency

ambient air and its concentration was increasing. The main pollution source was vehicle exhaust gases and traffic-generated dust from insufficiently cleaned streets and their environment.

Scientific investigations of Vilnius Gediminas Technical University (VGTU) showed that concentration of PM_{10} at a 30 m distance from the street decreases by 10–60%. Having measured the amount of PM_{10} in various road profiles (i.e. at a different distance – 2, 5, 10 and 20 m from the road edge), it could be stated that the largest concentrations of pollutants were recorded at the locations with the heavy traffic. For example, the measured particle concentrations on the main roads Panevėžys – Šiauliai, Šiauliai – Palanga and Kaunas – Zarasai – Daugavpils showed that concentration of PM_{10} in the cross-sections of the main roads Panevėžys – Šiauliai and Šiauliai – Palanga was twice as large as on the main road Kaunas – Zarasai – Daugavpils. Correspondingly, on the main road Šiauliai – Palanga (A11) the largest amount of particles was determined on the shoulder: in Kuršėnai A11(1) up to $203 \mu g/m^3$; at a 2 m distance from the road edge: in Plungė A11(3) – $201 \mu g/m^3$; at a 5 m distance from the road edge: before Telšiai A11(2) – $189 \mu g/m^3$; at a 10 m distance from the road edge: before Telšiai A11(2) – $160 \mu g/m^3$; at a 20 m distance from the road edge: before Telšiai A11(2) – $146 \mu g/m^3$.

Thus, air pollution is determined by several causes and in order to reduce air pollution not one but several measures should be used: cleaning and planting of streets, regulated traffic flows, spreading of slippery road pavement in winter with not sand but crushed stone, cleaning of road pavement surface, restricted use of studded tyres especially in the cities, on main and national roads.

2.2. Pollution of ambient air with noise emissions

In Lithuania, like in the whole EU, part of noise impacted on the inhabitants is caused by transport or industrial infrastructure – the traffic of vehicles, trains and airplanes, also industrial enterprises. Road transport is recognized to be the main source of noise. The level of noise level, unlike climate, landscape and other natural factors, has been changing very rapidly. In some Lithuanian cities the noise of streets has increased even by 10–12 dBA. When assessing these changes one must know that the increased sound pressure by 10 dBA is perceived by a human being as the double increase in sound. This is clearly shown by the daily noise dispersion map of the Klaipėda City agglomeration. Noise at the main motorways is often exceeding the permissible noise level. For managing noise of the main infrastructures, Lithuania, like the other EU member-states, has been committed to assess the extent of ambient noise.

For this purpose, with the help of strategic mapping the noise levels are determined and a number of people exposed to a certain level of noise at the main roads, railways, large airports and other agglomerations. Based on the mapping results, the noise management actions plans are developed. According to 2008 *Activity Report of Joint Research Centre*, this is a way to manage noise and to reduce its impact on human health.

In Lithuania the largest noise generated by street traffic is recorded close to those streets. The noise level of wheel and pavement interaction depends on vehicle speed, pavement roughness, etc. For example, noise generated by the tyres of vehicles driving at a speed of 100 km/h is 16 times higher than driving at a speed of 50 km/h. Therefore, restriction of speed could help to avoid a hazardous impact of noise. With the increasing pavement roughness noise generated by vehicle tyres is also increasing. For example, according to 2005 the Lithuanian Ecological Monitoring Program, in a warm and cold period of the year in Kaunas City a variable noise was measured, i.e. noise the change in the level of which is larger than 5 dBA and which is constantly changing and pulsing. Noise was measured in 12 locations, inside of residential quarters, in the yards of schools and kindergartens, and in 18 locations at the most intensive city streets (measuring location was selected at a 7.5 m distance from the middle of the first carriageway, in that part of the street where vehicles move at the same speed) and at Savanorių pr., Taikos pr. and the intersection of Tvirtovės pr. According *Environmental Protection Agency*, in residential and public buildings and their territories a variable noise is assessed according to the equivalent sound level (dBA). For example, based on 2005 measurement data, the equivalent noise level at the residential houses, in a day time, in a warm and cold period of the year 2005 exceeded (from 20 to 40%) the *Hygienic Norm of Lithuania HN 33 – 1:2007 Acoustic Noise; According to Permissible Levels for the Residential and Working Environment; General Requirements for Measurement Methodology*. According to data of Environmental Protection Agency, it was noticed that in a warm period of the year, under a natural foliage screen of trees and bushes, the noise level is lower than in a cold period of the year. During scientific investigations, carried out by VGTU in winter, the highest noise level at a 7.5 m distance from the road edge was measured on the main road A1(11) at Kryžkalnis settlement. Here, the heavy vehicles caused the noise of 89 dBA, thus, exceeding the permissible noise level by 40%, the vehicles of average weight – 84 dBA, thus, exceeding the permissible noise level by 20% and the light vehicles – 71 dBA, thus, exceeding the permissible noise level by 1.4%. This was influenced by the fact that during measurements the thaw took place: road pavement was wet, traffic volume was high and the use of studded tyres was comparatively larger.

Various measures could be used to reduce traffic-generated noise level: reduction of noise level caused by vehicle itself as of a source of noise, the use of various structures – screens, noise barriers, special windows with glass packets. The main noise reduction measure in the city is

the change of its traffic scheme by reducing traffic volume on the most intensive streets, constructing city by-passes and bridges, implementing street renovation and repair, avoiding the use of studded tyres in winter and using other protective measures – various acoustic screens, protective lanes of trees and bushes. On a national scale it is recommended to restrict the number of old, technically disorderly vehicles imported to Lithuania as well as the use of studded tyres. These measures would help to fight noise, would reduce the urban air pollution with vehicle exhaust gases and suspended fine and PM_{10} .

3. Negative impact of the use of studded tyres on environmental quality

3.1. Emissions of fine ($PM_{2.5}$) and coarse (PM_{10}) particulate matter from studded tyres

According to its origin pollution of ambient air with $PM_{2.5}$ and PM_{10} may be primary or secondary. It was determined by the scientists that pollution of ambient air $PM_{2.5}$ and PM_{10} from road vehicles is a primary pollution. It is caused by $PM_{2.5}$ and PM_{10} getting into the ambient air with vehicle exhaust gases and by the wear of road pavement and vehicle tyres destroying the pavement (especially – studded tyres) (Schmit, Schlender 2003).

$PM_{2.5}$ and PM_{10} is a mixture of particles and liquid droplets (aerosols) suspended in the ambient air and consisting of different components – acids, sulphates, nitrates, metals (Al, Si, K, S, Zn, W etc.), organic compounds, soil particles, dust, smut. In winter road vehicles, especially those using studded tyres, cause also a secondary pollution with $PM_{2.5}$ and PM_{10} (Baltrėnas et al. 2007; Baltrėnas, Kazlauskienė 2009; Schmit, Schlender 2003; Viklander 1998).

Emissions of PM_{10} into the ambient air are highly dependent on vehicle speed. For example, when a passenger car with studded tyres travels at a speed of 30 km/h, pollution of ambient air with PM_{10} amounts even to $200 \mu\text{g}/\text{m}^3$ and is 10 times larger than the currently permissible annual limit value (Fig. 2).

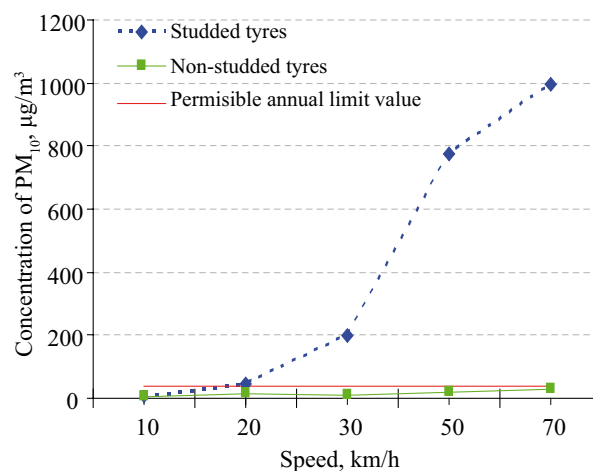


Fig. 2. Dependency of PM_{10} emissions on the speed of vehicles with and without studded tyres by Kupiainen 2007

For the comparison, at present the permissible annual limit value for PM_{10} is only $20 \mu\text{g}/\text{m}^3$. Correspondingly, when a passenger car travels at a speed of 50 km/h – PM_{10} emissions into the ambient air increase up to $800 \mu\text{g}/\text{m}^3$ and by 40 times exceed the permissible annual limit value; when a passenger car travels at a speed of 70 km/h – PM_{10} emissions amounts even to $1\,000 \mu\text{g}/\text{m}^3$ and by 50 times exceed the permissible annual limit value. Meanwhile, if a passenger car uses no studded tyres, pollution of ambient air with coarse particulate matter is comparably lower, coming to only $20\text{--}30 \mu\text{g}/\text{m}^3$ and practically causing no pollution of ambient air. With the use of studded tyres the emissions of PM_{10} start to gradually increase from the beginning when vehicle gathers speed. When the vehicle uses no studded tyres, pollution with coarse particulate matter (PM_{10}) is originated and increased by about $10 \mu\text{g}/\text{m}^3$ at the speed of 50 km/h or higher (Brannvall, Martinėnas 2007; Gustafsson 2005; Kupiainen 2007).

With the increasing vehicle speed concentrations of $PM_{2.5}$ and PM_{10} , emitted into the ambient air, are gradually increasing, as well as the size of PM_{10} (Fig. 3).

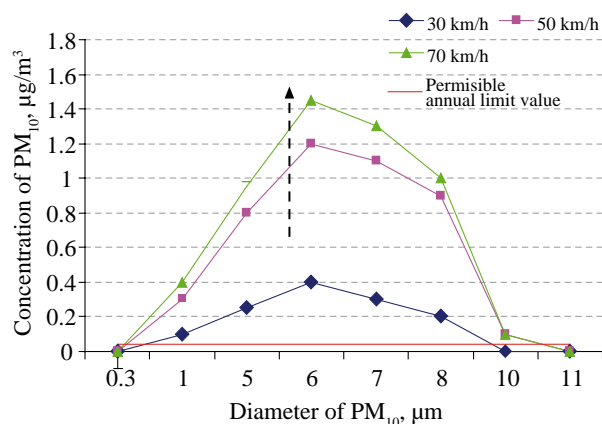


Fig. 3. Dependency of PM_{10} emissions on particle diameter, when a passenger car moves at a 30, 50 and 70 km/h speed by Gustafsson *et al.* 2008

The above mentioned measurements were carried out when the asphalt wearing course of road pavement consisted of stone mastic asphalt (SMA). Dispersion phases of the airborne, $PM_{2.5}$ and PM_{10} most often were of size from 0.1 to $10 \mu\text{m}$. When a passenger car with studded tyres moves at a speed of 30 km/h, the $PM_{2.5}$ and PM_{10} is emitted into the ambient air, varying from 0.5 to $10 \mu\text{m}$ and distinguished by a larger dispersion ability. Even 70% is taken by fine particulate matter with the size of $2.5 \mu\text{m}$. Totally, the emitted amount of these particles is about $0.2 \text{ mg}/\text{m}^3$ and this exceeds the permissible annual limit value by 10 times. When a passenger car moves at a speed of 50 km/h, emissions of these pollutants into the ambient air is increase to 0.8 or even $1 \text{ mg}/\text{m}^3$, but their dispersion ability is decreasing, i.e. the emitted particles become more coarse. The size of PM_{10} varies from 2.5 to $10 \mu\text{m}$. They make up to 70%. 30% is taken up to $2.5 \mu\text{m}$ $PM_{2.5}$. When a passenger car moves

at a speed of 50 km/h, these pollutants exceed the permissible annual limit value by 50 times. Whereas, when a passenger car moves at a speed of 70 km/h, emissions of $PM_{2.5}$ and PM_{10} amount to $1.3 \text{ mg}/\text{m}^3$ and exceed the permissible annual limit value by 65 times. Up to 85% is made of comparatively coarser particles, from 2.5 to $10 \mu\text{m}$. 15% is made of fine particulate matter varying from up to $2.5 \mu\text{m}$. Consequently, when the moving vehicle gathers the largest speed the larger fractions up to $10 \mu\text{m}$ of separate (i.e. not stuck together) particles are emitted into the ambient air. Besides, it was determined during the investigations that the higher vehicle speed the more often the emitted $PM_{2.5}$ and PM_{10} takes an irregular shape and has uneven surface. $PM_{2.5}$ and PM_{10} of this structure is especially dangerous for human health and environment (Gustafsson *et al.* 2008; Ketzel *et al.* 2007).

$PM_{2.5}$ and PM_{10} emissions into the ambient air are increased not only with the increasing vehicle speed but also with the vehicle weight, especially when heavy vehicles use more and heavier studs. At present, studded tyre of a passenger car has about 100 studs, the weight of each is 0.85 g. For example, when the weight of studs is 4 g the road pavement made of granite wears away at 1.5 cm^3 , made of quartzite – at 0.7 cm^3 . Consequently, in case if the weight of studs is increased to 4 g and the asphalt wearing course contains granite, $PM_{2.5}$ and PM_{10} emissions into the ambient air will increase even twice (Zubeck *et al.* 2004).

The implemented investigations apparently show how a dispersion ability of particulate matter varies with the use of studded tyres on a passenger car moving at a lower, i.e. only 15 km/h, speed. When the vehicle with studded tyres moves at a speed of 15 km/h, concentrations of airborne PM_{10} with the size from 2.5 to $10 \mu\text{m}$ are increased by 30%. Analogical results of investigations were obtained also for the vehicle moving at a 30 km/h speed (Figs 4, 5) (Ketzel *et al.* 2007).

During investigations the scientists derived the average for a percentage variation in the size of $PM_{2.5}$ and PM_{10} emitted into the environment when a passenger car travels at an average and constant speed, i.e. taking no consideration of vehicle's acceleration or sudden deceleration like in previous tests. For example, when a passenger car travels at an average speed of 50 km/h, it was determined that 30% of $fPM_{2.5}$ suspended into the environment are of up to

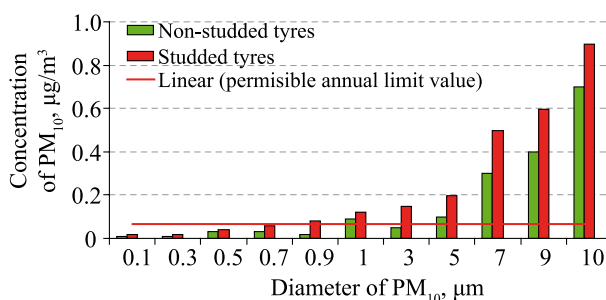


Fig. 4. Dependency of PM_{10} emission concentration on particle diameter, when a passenger car travels at a speed of 15 km/h by Ketzel *et al.* 2007

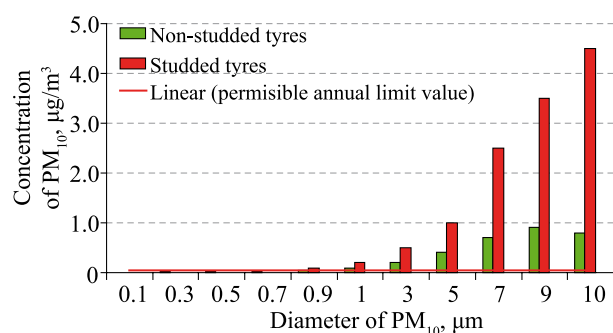


Fig. 5. Dependency of PM₁₀ emission concentration on particle diameter, when a passenger car travels at a speed of 30 km/h by Ketzal *et al.* 2007

2.5 µm, and 70% is taken by the remaining PM₁₀, i.e. with the size from 2.5 to 10 µm. This proved the results of the previously described investigations. Also, PM₁₀ and PM_{2.5} emission factor was evaluated, i.e. a volume of PM_{2.5} and PM₁₀ emissions when a passenger car moves at an average speed of 50 km/h with and without the studded tyres. It was determined that when using studded tyres emission factor is increased by 1.6 times (Table 1) (Johansson *et al.* 2007).

Table 1. Emission factor of PM_{2.5} and PM₁₀ (number of particles/km) depending on asphalt wearing course by Johansson *et al.* 2007

Vehicle speed, km/h	Type of tyre	Type of asphalt wearing course	Emission factor of PM _{2.5} and PM ₁₀ , number of particles/km
50	Non-studded winter tyre	SMA	3.8×10^{11}
50	Studded winter tyre	SMA	6.1×10^{11}

Analogical investigations were carried out when asphalt wearing course was made of not only SMA but also of granite. The mentioned investigations lasted for 4 h and a passenger car was moving at 70 km/h. When a passenger car travelled at 70 km/h on asphalt pavement the SMA wearing course, the emissions of PM_{2.5} and PM₁₀ amounted to about 1.2–1.3 mg/m³ and by 65 times exceeded the permissible limit value (0.04 mg/m³). However, when a passenger car moved at the same speed on asphalt pavement the wearing course of which was made of granite, the emissions PM_{2.5} and PM₁₀ amounted to 4.0–5.0 mg/m³ and even by 250 times exceeded the permissible limit value (0.04 mg/m³). Thus, emissions of PM_{2.5} and PM₁₀ depend on the mineral materials the asphalt wearing course is made of. Another investigations showed that with the use of studded tyres the least wear of asphalt wearing course (up 2.2 mm) was observed when it was made of quartzite. Meanwhile, when asphalt wearing course is made of gneiss it wears away even to 4.1 mm, when of granite – the wear

is also large and reaches even 2.7–3.2 mm. This shows that the larger the wear of asphalt wearing course the higher is ambient air pollution with PM_{2.5} and PM₁₀. Scientists affirm that the wear of asphalt wearing course is stimulated also by the specific features of road pavement surface, for example, relative humidity, temperature of ambient air (especially when it is lower or close to 0 °C) etc. (Gustafsson *et al.* 2008).

On the surface of road pavement studded tyres generate the effect of “sandpaper”. Based on scientific research data, a passenger car with studded tyres having travelled 1 km at a speed of 50 km/h on “bare” asphalt mills out about nearly 20 mg of PM_{2.5} and PM₁₀. With the increasing speed the amount of milled out PM becomes even larger, i.e. at a speed of 70 km/h – up to 27 mg, at a speed of 90 km/h – up to 42 mg and at a speed of 110 km/h – even more, up to 78 mg. This particulate matter originated during the tyre-pavement traction, milled out from asphalt wearing course and made of spread sand gets into the ambient air. For example, a passenger car having travelled 1 km distance at a speed of 50 km/h, causes up to 4 mg/m³ emissions of PM₁₀ into the ambient air which exceed the annual permissible limit value for PM₁₀ by 100 times. It was determined that the composition of this coarse particulate matter was made of 1.8 mg/m³ of milled out asphalt wearing course, 0.2 mg/m³ – the remnants of tyre (i.e. rubber and studs) and 2 mg/m³ – the remnants of spread sand, salt mixture and uncollected mud. Consequently, 50% of pollution with PM₁₀ is made of road spreading with sand and salt mixture in winter. In order to reduce pollution with particulate matter some scientists suggest spreading of road pavement not with sand but with crushed stone (Gustafsson *et al.* 2008).

Analogical investigations were carried out allowing to determine emissions of PM₁₀ and their composition when a passenger car with and without studded tyres travelled the same distance, i.e. 0.5 km. When a passenger car, travelling at a speed of 50 km/h with studded tyres, has covered a 0.5 km distance, emissions of PM₁₀ into the ambient air made 1.8 mg/m³ and exceeded the permissible annual limit value (0.04 mg/m³) for PM₁₀ by 90 times. It was determined that their composition was made of 1.1 mg/m³ of milled out asphalt wearing course, 0.2 mg/m³ – the remnants of tyre (i.e. rubber and studs) and 0.5 mg/m³ – the remnants of spread sand, salt mixture and uncollected mud. When a passenger car covered the same distance (0.5 km) without studded tyres, moving at a speed of 50 km/h, emissions of PM₁₀ into the ambient air made 0.6 mg/m³ and exceeded the permissible annual limit value by 30 times. PM was made of 0.4 mg/m³ of milled out asphalt wearing course, 0.1 mg/m³ – the remnants of tyre (i.e. rubber and studs) and 0.1 mg/m³ – the remnants of spread sand, salt mixture and uncollected mud. This shows that the use of studded tyres increases the PM emissions into the ambient air by 3 times on average. This means the 3 times increase in the milling-out of the asphalt wearing course, 5 times increase in the amount of spread sand, salt mixture and uncollected mud and 2 times increase in the scattered remnants of tyres (i.e. rubber and studs) (Johansson *et al.* 2007; Norman, Johansson 2006; Räisänen *et al.* 2005).

Others investigations (Norman, Johansson 2006) showed a dependency of air pollution with particulate matter on the spreading of roads with sand and salt mixture in winter (Fig. 6).

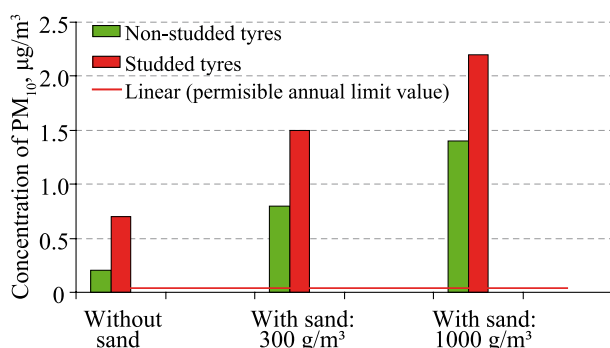


Fig. 6. Dependency of PM₁₀ emission concentration on the type of tyres and the amount of sand spread by Johansson 2006

First of all, PM₁₀ emissions on “bare” road pavement were determined, i.e. using neither sand nor salt. Without the use of studded tyres the PM₁₀ emissions of a “bare” pavement made only 0.3 mg/m³ and exceeded the permissible annual limit value by 15 times. With the use of studded tyres the PM₁₀ emissions on “bare” pavement made already 0.7 mg/m³ and exceeded the permissible annual limit value by 35 times. Later on, the dependency of pollution was determined on a certain amount of sand spread in a one square meter. With the increasing amount of sand spread in 1 km², pollution of the ambient air also increases both with and without the use of studded tyres. When in 1 km² 300 g of sand was spread and the studded tyres were used, the PM₁₀ emissions amounted to 1.5 mg/m³, without the use of studded tyres – to 0.8 mg/m³. When in 1 km² 1000 g of sand was spread and the studded tyres were used, the PM emissions increased by 1.5 times (2.2 mg/m³), without the use of studded tyres – by 1.7 times (1.4 mg/m³). In all cases emissions of PM₁₀ did exceed the permissible annual limit value. For example, when in 1 km² 1 000 g of sand was spread and the studded tyres were used, the PM₁₀ emissions amounted to 2.2 mg/m³ and exceeded the permissible annual limit value by 110 times (Hääl *et al.* 2008; Norman, Johansson 2006).

Having generalized the results of scientific investigations, it could be stated that the increase in the concentrations and size of PM_{2.5} and PM₁₀ by several tens of times is caused by the increasing vehicle speed (km/h) and weight (t), spreading of roads with sand and salt mixture in winter, mineral composition of asphalt wearing course, ambient air conditions, weight and number of studs used in tyres, etc. Consequently, prohibition or restriction of the use of studded tyres would allow to improve the quality of ambient air, since with the use of studded tyres pollutant emissions, especially those of particulate matter (Al, Si, K, S, Zn, W etc.), into the ambient air are several tens of times higher than using non-studded tyres (Hääl *et al.* 2008; Viklander 1998).

3.2. Noise emissions from studded tyres

In recent 10 years noise in the EU member-states and Lithuania has increased from 0.5 to 1 dBA per year on average. This was highly influenced by traffic-generated noise. If a certain vehicle speed is exceeded, in the total noise from road vehicles the noise from the interaction between the tyres (especially – studded tyres) and road is prevailing. It depends on vehicle speed, type of road pavement (especially porous and noise-reduction pavement) and type of tyres (studded or non-studded).

When assessing noise emissions one must admit that studded tyres cause more noise. For example, based on data of Icelandic scientists, when a passenger car travelled at a speed of 60 km/h the *Green Diamond* non-studded tyre caused noise of 81 dBA, whereas, the analogical tyre with studs – noise of 85 dBA and by 9 dBA exceeded the currently valid noise emission limit value. Thus, studded tyres generate not only higher noise but also reduce driving comfort and are distinguished by a higher vehicle rolling resistance.

With the increasing speed of a passenger car the noise emissions have been gradually increasing. A passenger car equipped with studded tyres and travelling at a speed of 30 km/h generates noise emissions of nearly 80 dBA and, thus, by 4 dBA increases the currently valid noise emission limit value (Fig. 7).

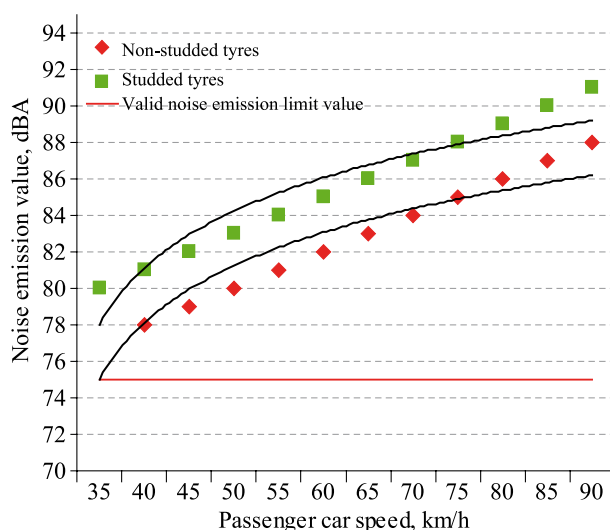


Fig. 7. Dependences of noise emission value on speed and type of tyres of a passenger car by Kropp *et al.* 2007

When the speed increases to 85 km/h, noise emissions make even 90 dBA. Correspondingly, when the same car travels without studded tyres at a speed of 30 km/h, noise emissions make 76 dBA and do not exceed the noise emission limit value. When a passenger car without studded tyres increases speed up to 85 km/h the noise emissions make 86 dBA. Consequently, irrespective of vehicle speed, the studded tyres increase vehicle-generated noise by 4 dBA on average due to their larger interaction be-

tween the tyres and road. Compared to the currently valid Lithuanian noise limit value within the environment of living and public buildings, it could be stated that when a passenger car travels at a permissible 50 km/h speed and uses studded tyres, the sound level is equal to 84 dBA, when using no studded tyres – to 80 dBA. This means that when using studded as well as non-studded tyres the equivalent and max sound level in a various time of the day exceeds the permissible noise limit values. For example, from 6 a.m. to 6 p.m. the equivalent noise level is exceeded by 19 dBA, the max – by 14 dBA, from 6 p.m. to 10 p.m. – by 24 and 19 dBA, and from 10 p.m. to 6 a.m. – by 29 and 24 dBA, respectively (Kropp *et al.* 2007).

Based on data of Swedish scientists, with 20% restriction of the use of studded tyres the max and equivalent sound levels are reduced by 2 and 1.0–1.5 dBA, on average. Whereas, if the use of studded tyres is fully prohibited, the max. and equivalent sound levels would be reduced more, by 4 and 2.0–3.0 dBA, respectively. This means that such preventive measures would significantly reduce noise emissions (Table 2) (Kropp *et al.* 2007).

Table 2. Change in the equivalent and max sound levels having reduced or prohibited the use of studded tyres by Kropp *et al.* 2007

Description	Equivalent sound level, dBA		Max sound level, dBA		Notes
	Passenger cars	Heavy vehicles	Passenger cars	Heavy vehicles	
20% restriction of the use of studded tyres	2	0	1.0–1.5	0	valid only in a winter period
Prohibition of the use of studded tyres	4	0	2.0–3.0	0	valid only in a winter period

Noise emissions are highly dependent on a mineral composition of asphalt wearing course. When a passenger car travels at a speed of 60–80 km/h the lowest noise emissions (0.5–1.0 dBA) are reached when asphalt wearing course is made of stone mastic or asphalt concrete. Even up to 2.0 dBA the noise emissions are reduced by a porous, not older than 5 years asphalt wearing course.

A porous asphalt wearing course has 20% of voids. Of course, such a porous asphalt surface gets less and less absorptive in time as the voids are filled. It was determined that the effect of sound reduction of a porous asphalt wearing course depends on vehicle speed. The higher vehicle speed the less reduction of noise emissions is achieved or not achieved at all (0 dBA). Meanwhile, the asphalt surface of rough texture increases noise emissions by nearly

2.0 dBA. Paving stones of fine texture (when the stones are laid at $< 5 \text{ mm} \leq$ between each other) increase the noise level by nearly 3.0 dBA. The highest increase in the noise emissions (even by 6.0 dBA) is caused by the road surface made of coarse paving stones (i.e. when paving stones are laid at a larger distance than 5 mm between each other) (Peeters, Blokland 2007).

Consequently, prohibition or restriction of the use of studded tyres would allow to significantly reduce noise emissions. The use of studded tyres causes the increase in noise emissions (up to several tens of dBA). Noise emissions are also increased when the speed and weight of vehicle with studded tyres is increasing as the interaction of studded tyre and road is higher compared to non-studded tyre; when road pavement gets worn-out and when asphalt wearing cause is made of a more coarse texture of mineral materials (i.e. when paving stones are laid at $> 5 \text{ mm} \geq$ between each other), etc. (Peeters, Blokland 2007).

4. Conclusions

Prohibition or restriction of the use of studded tyres would allow to significantly improve the quality of ambient air, since with the use of studded tyres pollutant emissions, especially those of fine ($\text{PM}_{2.5}$) and coarse (PM_{10}) particulate matter (Al, Si, K, S, Zn, W etc.), into the ambient air are several tens of times higher than using non-studded tyres.

The increase in the concentrations and size of fine $\text{PM}_{2.5}$ and coarse PM_{10} particulate matter by several tens of times is caused by the increasing vehicle speed (km/h) and weight (t), spreading of roads with sand and salt mixture in winter, mineral composition of asphalt wearing course, ambient air conditions, weight and number of studs used in tyres, etc.

The use of studded tyres causes the increase in noise emissions (up to several tens of dBA). Noise emissions are also increased when the speed and weight of vehicle with studded tyres is increasing as the interaction of studded tyre and road is higher compared to non-studded tyre; when road pavement gets worn-out and when asphalt wearing cause is made of a more coarse texture of mineral materials (i.e. when paving stones are laid at a distance $< 5 \text{ mm}$ between each other), etc. Consequently, prohibition or restriction of the use of studded tyres would allow to reduce noise emissions (even by 6.0 dBA).

Having assessed pollution of the ambient air with particulate matter and noise emissions in a cold period of the year caused by road vehicles with studded tyres in Lithuania and EU, it could be stated that Lithuania should restrict the use of studded tyres.

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