Article citation info:
KIERACIŃSKA, A., et al. Evaluation of the effectiveness of operation of a system to reduce particulate matter emission from the motor vehicle braking system in the conditions of special driving tests. *Combustion Engines*. 2013, **154**(3), 208-213. ISSN 0138-0346.

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PTNSS–2013–SC–009

Evaluation of the effectiveness of operation of a system to reduce particulate matter emission from the motor vehicle braking system in the conditions of special driving tests

Abstract: Particulate matter is counted among the air pollutants that are particularly harmful to human health. An important source of the emission of this substance is motor traffic. A significant part of the particulate matter emission from the motorization–related sources comes from the tribological pairs existing in motor vehicles, chiefly from their braking systems. This paper presents results of empirical tests of a system to reduce the emission of particulate matter from the braking system. The tests were carried out on a vehicle chassis dynamometer in the conditions of special driving tests. The effectiveness of operation of the system under tests was found to be good: the particulate matter emission was reduced by about 50 to 75%.

Keywords: *particulate matter emission, braking systems, motor vehicles*

Ocena skuteczności układu do ograniczania emisji cząstek stałych z układu hamulcowego samochodu w warunkach specjalnych testów jezdnych

Streszczenie: Cząstki stałe należą do zanieczyszczeń powietrza szczególnie szkodliwych dla zdrowia ludzi. Istotnym źródłem ich emisji są pojazdy samochodowe. Znaczna część emisji cząstek stałych ze źródeł motoryzacyjnych pochodzi z par trybologicznych pojazdów, przede wszystkim z układu hamulcowego. W pracy przedstawiono wyniki badań empirycznych urządzenia do ograniczania emisji cząstek stałych z układu hamulcowego. Badania przeprowadzono na stanowisku hamowni podwoziowej w warunkach specjalnych testów jezdnych. Stwierdzono dobrą skuteczność urządzenia – zmniejszenie emisji cząstek stałych o około (50 ÷ 75)%.

Słowa kluczowe: *emisja cząstek stałych, układy hamulcowe, pojazdy samochodowe*

1. Introduction

One of the air pollutants that exert the most severe environmental impact, especially in urban agglomerations, is dust, alternatively referred to as particulate matter (PM) [1, 6, 8, 9, 13, 14]. Dust is categorised as follows, depending on conventional dust particle size [2–5]:

a) TSP (total suspended particles) – a mixture of small solid particles of conventional size below 300 μm, suspended in the air (the dispersed phase of the solid–gas two–phase system);
b) PM10 (suspended dust) – of conventional particle size below 10 μm;
c) PM2.5 (fine dust) – of conventional particle size below 2.5 μm;
d) PM1 (very fine dust) – of conventional particle size below 1 μm.

When the testing of combustion engines is considered, “nanoparticles” with characteristic particle dimensions of the order of nanometres, i.e. below 100 nm, are distinguished [12]; such particles constitute practically invisible dust.

The harmfulness of dust in the air to human health is commonly known. It was as long ago as in 1524 when a work “De re metalica” [1] was written by Georgius Agricola, where information about the harmful impact of dust on human health was provided.

The harmful impact of dust on human health varies depending on chemical and mineralogical composition and physical structure of dust particles [8, 9, 13, 14]. The way of how dust affects living organisms depends very much on dust particle size as well [13], see Fig. 1.

Depending on dust origin, the dust sources are classified as natural and anthropogenic [2–6, 13].

The main natural dust emission sources are sedimentary materials; marine, vegetable and animal aerosols; volcano eruptions; and forest fires [2–6, 13].

The anthropogenic causes for the presence of dust in the air actually include all the civilisation activities, especially production processes, in particular those where the combustion of fuels (chiefly solid fuels) is involved, including the use of domestic fires. An important source of the emission of particulate matter is transport.

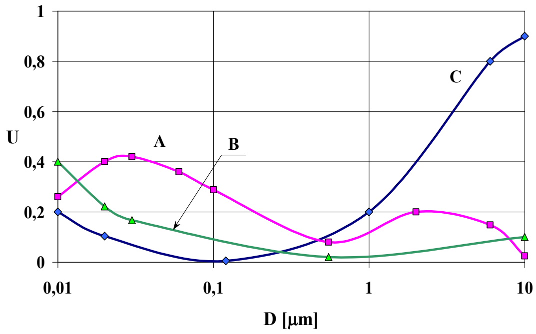

Fig. 1. Distribution of dust particle diameters D (shares of deposition, U) arrested in various parts of the human respiratory system (based on [13]):
A – lungs; B – trachea and bronchi; C – epipharynx

The particulate matter emissions from motor transport predominantly come from the following sources [2–6]:

a) Combustion engine, which emits particulate matter together with exhaust gases;
b) Tribological pairs in the vehicle;
c) Road wheel tyres and pavement material, rubbed off in result of the tyre–road interaction;
d) Materials of other vehicle parts when undergoing wear processes;
e) Dust stirred up from the road surface by vehicles moving on the road.

The major factors that affect the particulate matter emissions from motor transport include [2–6]:

a) Environmental characteristics of the vehicle with regard to particulate matter emissions, chiefly the engine type (spark ignition or compression ignition), and the environmental protection class of the vehicle (in terms of pollutant emissions);
b) Properties and materials of components of tribological pairs in the vehicle;
c) Properties of vehicle tyres;
d) Vehicle specifications characterizing the conventional size and construction of the vehicle;
e) Vehicle movement conditions, above all the speed and acceleration (especially in the case of vehicle wheels going into a skid);
f) Weather conditions, especially wind and precipitation;
g) Road surface type and quality.

Fig. 2 shows the relationship, obtained by modelling, between the on–road emissions of particulate matter PM from passenger car engines and particulate matter PM10 from the whole traffic of the passenger cars and the average speed of the cars [7]. The emission of particulate matter from combustion engines was modelled with the use of the databases provided in the INFRAS AG software [10]. An assumption was also made that the structure of passenger cars in terms of their conventional size (defined by engine displacement), ignition type, and environmental protection class (defined by pollutant emission characteristics) corresponded to the situation prevailing in Poland in 2010. To determine the particulate matter emission from motor traffic, the Lohmeyer model [11] was used. Among the assumptions made, the share of rainy days in the period of determining the emission balance was adopted as 0.3.

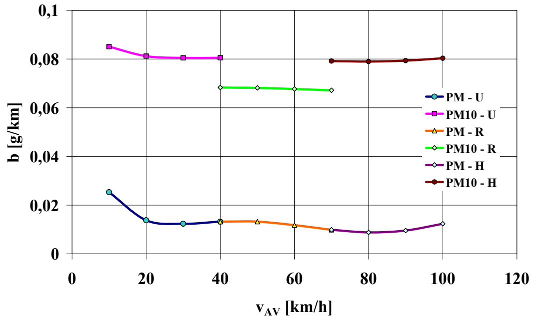

Fig. 2. Relationship between the on–road emissions of particulate matter PM and PM10 from passenger cars and the average speed of the cars: U – urban traffic; R – extra–urban ("rural") traffic; H – high–speed traffic (on fast roads and motorways)

It is specific to the Lohmeyer model that its forms for different traffic types, i.e. for the urban traffic, extra–urban traffic, and high–speed traffic on fast roads and motorways, differ from each other. This is the reason for the discontinuities occurring in the curve representing the relation between the on–road emission of particulate matter PM10 and the average vehicle speed.

It can be clearly seen in the graph, how big a share in the total dust emission is taken by the emission of particulate matter from sources other than the combustion engines. Among the tribological pairs in motor vehicle, a special role in the emission of dust is played by the braking system. The friction pairs in the braking system make an important source of dust emission in connection with the function fulfilled by the braking system and consisting in the dissipation of kinetic energy of the vehicle. An average motor vehicle annually consumes about 0.5 kg of friction material of its braking system, according to estimates.

2. Examination of a system to reduce particulate matter emission from the braking system of a motor vehicle

Test systems to reduce dust emission from braking systems of both disc and drum type were developed at the Automotive Industry Institute (PIMOT) [2–5]. Laboratory tests of such systems, carried out on test rigs at PIMOT, gave very promising results. Especially for disc brakes, the coefficient of effectiveness of the reduction of dust emission from the braking system reached a value of up to 0.8 [2–5].

The task to develop and test special vehicle systems to reduce the particulate matter emission from braking systems was undertaken within National Research and Development Centre's development project No. 10–0050–10/2010 entitled "Development of systems to reduce dust emission from disc brake and drum brake mechanisms of motor vehicles," carried out at PIMOT.

The effectiveness of operation of the systems developed within this project was tested on a vehicle chassis dynamometer. The vehicle movement was simulated in a special driving test, which ensured adequate braking intensity and repeatability of test conditions. The vehicle wheels were driven with a constant speed of 20 km/h by dynamometer rolls instead of vehicle engine. The vehicle brakes were cyclically operated with constant frequency, with each of the cycles consisting of a brake application period of 5 s followed by a period of 10 s without braking. The test consisted of 240 single braking cycles in total; in consequence, the test duration time was 3 600 s and the distance travelled by the vehicle totalled 20 km. The share of the brake application time in the total test duration time was 0.33.

In the initial phase of each braking period, the vehicle speed decreased. Then, despite of the fact that a constant pressure was applied to the brake pedal, the vehicle speed returned to a level of about 20 km/h due to the operation of a governor of the dynamometer roll speed. When the brake pedal was released, the vehicle speed rapidly rose and immediately after that it was brought again to the level of 20 km/h by the governor.

A fragment of the special test aimed at examining the effectiveness of operation of the system to reduce dust emission from the passenger car braking system has been presented in Fig. 3.

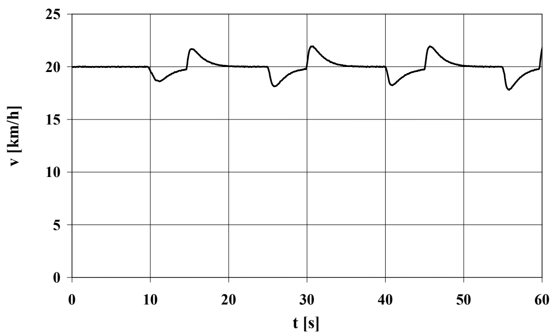

Fig. 3. Schematic diagram of the driving test aimed at examining the effectiveness of operation of the system to reduce particulate matter emission from the passenger car braking system: v – vehicle speed

During the tests, six measurement series were carried out; each of them consisted of four cyclic braking tests (single realizations of the special driving test).

The values of the coefficient of effectiveness of the reduction of dust emission from the passenger car braking system, obtained from individual test series, as well as the average value and standard deviation of the set of values of this coefficient have been shown in Figs. 4 and 5.

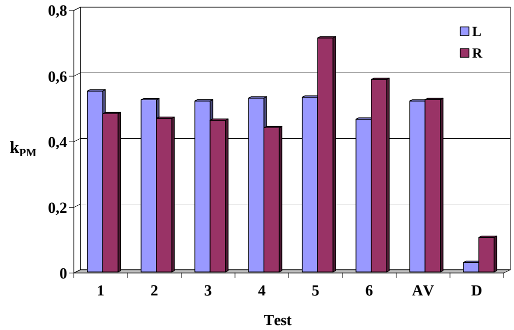

Fig. 4. Coefficient of effectiveness of the reduction of dust emission (k_{PM}) from disc brakes of the car at individual test series: AV – average value of the coefficient; D – standard deviation of the coefficient

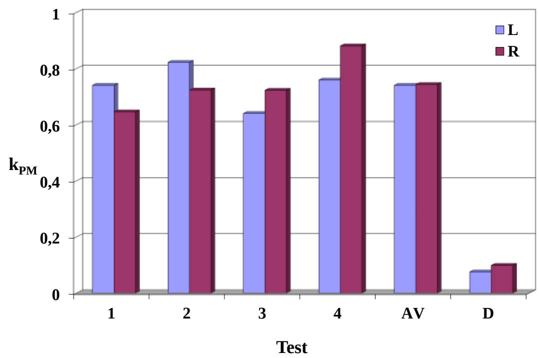

Fig. 5. Coefficient of effectiveness of the reduction of dust emission (k_{PM}) from drum brakes of the car at individual test series: AV – average value of the coefficient; D – standard deviation of the coefficient

The probability density of the averaged diameters of the particles emitted from the braking systems, determined for 32 sample sets under tests, has been presented in Fig. 6.

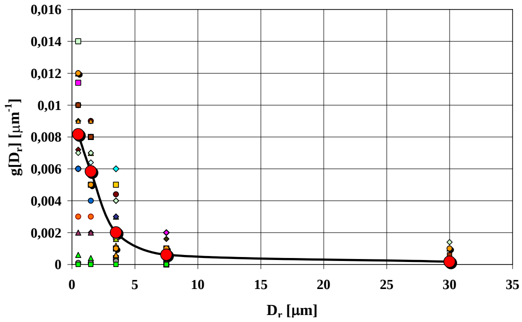

Fig. 6. Probability density (g) of the averaged diameters (D_r) of the particles emitted from the braking systems

It can be clearly seen in the graph that particles of very small diameters, below 1 µm, predominate in the dust emitted from the braking systems. This is even better visible in the graph where the particle diameters are shown in logarithmic scale (Fig. 7). The probability density of the diameters of the particles emitted from braking systems confirms the harmful impact of this pollutant on human health, because the finest dust is known to penetrate into lungs and even into the circulatory system [8, 13, 14].

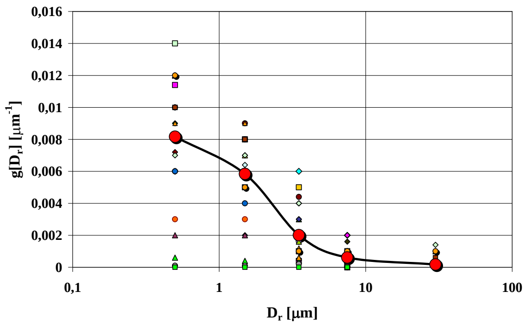

Fig. 7. Probability density (g) of the averaged diameters (D_r) of the particles emitted from the braking systems

In addition to this, the composition of the particulate matter emitted from braking systems causes this dust to be extremely harmful to human health because it contains large quantities of heavy metals. Figs. 8 and 9 show the share of iron grains in all the particulate matter emitted from braking systems, in terms of grain cross–sectional area.

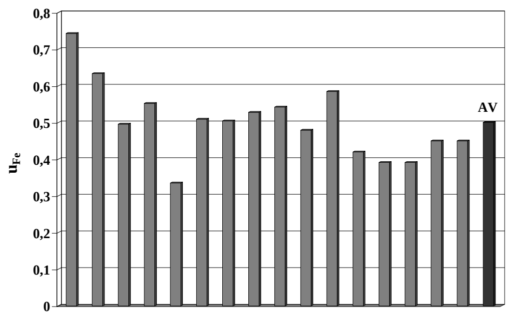

Fig. 8. Share of iron grains in all the particulate matter emitted from disc brakes (u_{Fe}), in terms of grain cross –sectional area: AV – average value

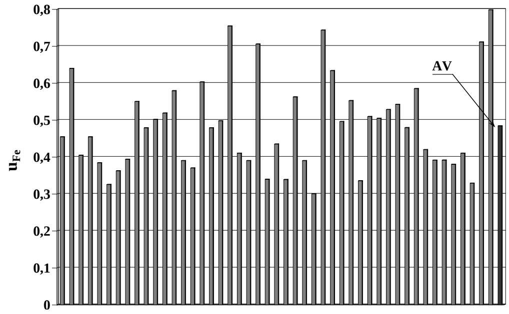

Fig. 9. Share of iron grains in all the particulate matter emitted from drum brakes (u_{Fe}), in terms of grain cross –sectional area: AV – average value

According to the graphs shown above, the average share of iron grains in all the particulate matter emitted from braking systems, in terms of grain cross–sectional area, is about 50%.

3. Conclusions

Based on the test results presented, the following conclusions may be formulated:

1. The motor vehicle braking system is a source of emission of particulate matter whose properties are especially dangerous to human health. Such particles contain heavy metals: in result of investigations carried out, the average share of iron grains in all the particulate matter emitted from braking systems, in terms of grain cross–sectional area, was found to be about 50%. Moreover, the characteristic dimensions of most of the particles emitted from braking systems are smaller than 1 µm; this has been confirmed by the determined values of the probability densities of the averaged particle diameters.
2. In result of experiments carried out, an original test procedure has been developed for evaluation of the effectiveness of operation of a system to reduce particulate matter emission from braking systems in conditions simulating motor vehicle traffic. Such tests are carried out on a vehicle chassis dynamometer in a driving test with constant vehicle speed, where the vehicle under test is driven by the dynamometer roll and the vehicle brakes are cyclically applied. The test procedure having been developed enabled unbiased evaluation of the effectiveness of operation of a system to reduce particulate matter emission from braking systems.
3. The values of the coefficient of effectiveness of the reduction of dust emission from the braking system as determined from rig tests were up to 0.8. The properties of the system developed were confirmed by tests carried out on a vehicle chassis dynamometer, where the coefficient of effectiveness of the reduction of dust emission from the braking system was found to be 0.5 to 0.75.

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The publication was supported with the funds of the National Centre for Research and Development within a development project No. NR10–0050–10/2010 entitled “Development of systems to reduce dust emission from disc brake and drum brake mechanisms of automotive vehicles.”

The scientific work of Jakub Lasocki has been supported by the European Union in the framework of European Social Fund through the Warsaw University of Technology Development Programme.