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Emission Factors of Brake Wear Particles Emitted by Heavy Goods Vehicles in Real-World Driving. New Regulatory Challenge for Road Freight Transport

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Abstract

This paper presents a new study of the measured particles emitted by brake wear of road trucks in real-world driving. Particles were collected, identified and analysed physically and chemically. The results indicate that a highest number of metallic pollutants are associated with high emission factors depending on the brake temperature. Size distributions of the particles are found bi-modal and strongly nanoscale. This study should contribute to the emergence of future regulations of non-exhaust emissions and should help to analyse the exposure-impact relationship for particles from the brake wear.

Keywords: Air pollution; Road transport; Trucks; Non-exhaust emissions; Emission factors; Brake dust

Introduction

Brake wear of road transport emissions contribute to poor air quality in cities and have an impact on human health [1]. So far, there is very little scientific work developing emission factors for the particles emitted by truck brakes in real-world driving. However, there is a fair amount of literature on particulate emissions from light-duty vehicles by brake systems [2]. Effects of road traffic particle emissions on human health and environment have been regularly reported [3]. For instance, between 0.1 µm and 1 µm fine particles can penetrate deep into the respiratory system generating genotoxic damage. Brake particles emissions are generally thermal in nature due to friction. Most brake discs are made from grey cast iron, which is improved by adding various materials. The addition of molybdenum and chrome enhances resistance to thermal cracking and wear. The composition of the brakes trim may include metals such as iron, copper, steel or aluminium combined with bonding agents and other materials such as glass fibres or rubber. Vehicles are generally equipped with metal or semi-metal brakes containing graphite, steel, iron and copper which withstand temperatures of up to 800°C in the case of intense friction. This paper focuses on measurement of the non-exhaust emissions caused by the brake system abrasion in real-world. Emission factors are given using multivariate data analysis to investigate the chemical identification of the measured particles. This research is undoubtedly important as it brings new scientific knowledge.

Materials and Methods

Driving experiments were carried-out in France between the cities of Lyon and Grenoble in the summer period. Particles emitted by truck brakes were collected in real-time driving conditions. The 44 tons truck made five return trips from Lyon to Grenoble (1150 km). A GPS with a sampling of 1 Hz was used to collect speeds and positions of the truck. Half of the tests used RIDEX brake pads and the other half VALEO pads. Analyses of the chemical composition and identification of particles were carried-out by collecting the particles sizes on 45 carbon adhesive tabs (diameters φ of 25, 32 and 47 mm) at 3, 5 and 9 cm from the brake disc to prevent their destruction from the heat of braking. The rough assessment of the temperatures of the brake pads was based on the vehicle parameters and brake application data, and braking behaviour. Temperatures were estimated as mean values and not measured, offering the advantage of being able to explain contact tribology and particle emissions dynamics during braking. The identification of the elemental composition of brake particles was carried-out through an analysis of the collected particles on the carbon membranes with the Scanning Electron Microscopy (SEM) associated with Energy Dispersive X-ray spectroscopy (EDX) (3.0 nm at 30 kV) [4]. The concentrations of particles, ranging in size from 4 nm to 20 µm, were calculated rather than measured, on the basis of the dynamics of these particles collected on the tabs and their chemical and physical parameters determined by the SEM-EDX

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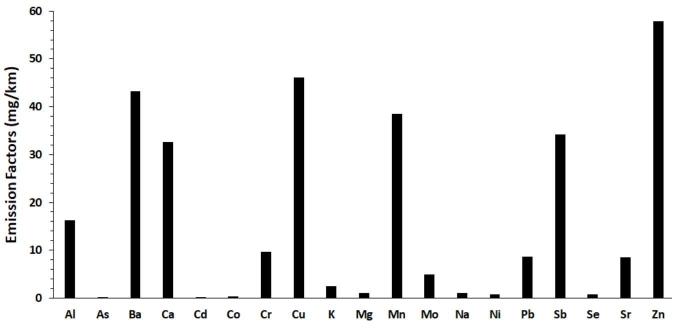

Figure 1: Emission factors of metallic particles emitted by the brakes wear of trucks.

/ INCA (Integrated Calibration and Application Tool - ETAS Company). Based on the pollutant's concentrations identified by a chemical and morphological process, size calculations were made using the total mass collected and the physico-chemical parameters of each element (mass concentrations, densities, Stokes diameters, deposition velocities ...). Individual (per pollutant) and global chemical analyses were carried-out by Minapath Developpement© (MInéralo-NAno-PATHologie). Generated data consisted of spectra showing the chemical elements. The automated INCA software was used to perform particles analyses and identification. The Hierarchical Classification on Principal Components (HCPC) method, combined with a numerical data classification algorithm and optimisation, was used to classify groups of pollutants according to particle size.

Results

- The synthesis of the obtained results provided a general predominance of the brake particles emitted for all experiments in the size: <20 nm for 30% of trips; bi modal distributions between 10 nm and 45 nm for 70% of the trips. Calculated average temperatures during the braking were respectively 265 °C, 353°C and 423°C. The chemical identification of pollutants emitted by brake abrasion was performed and the quantities of dust were evaluated. The chemical inertia of pollutants is found to be consistent and data analysis is significant (v_test ≅ ±2). The application of Pearson and Spearman tests showed that correlations were significant with $p < 0.02$. In addition, the analysis of the inertia of chemical species, which was carried-out, confirms the homogeneity of their identification. Assessment of the heterogeneous mixture of the chemical components reveals that they account for less than 0.5% of the total particles. Analyses showed a variation of the collected particles concentrations on the tabs (calculated average values): from 1.5 10^{+8} to 9 10^{+12} #/cm^3. The quantities of truck brake dust, in particular metallic element, were assessed as follows (mg/kg): Al (5478) – As (29) – Ba (14578) – Ca (11025) – Cd (6) – Co (121) – Cr (3274) – Cu (15560) – K (855) – Mg (373) – Mn (13005) – Mo (1676) – Na (360) – Ni (285) – Pb (2911) – Sb (11548) – Se (270) – Sr (2903) – Zn (19540). Calculation of emission factors EF for metallic pollutants due to truck brake wear shows three groups with EF varying between:0 to 0.8 mg/km: Cd (0.0), As (0.1), Co (0.4), Ni (0.8), Se (0.8)

- 1.1 to 16.2 mg/km: Mg (1.1), Na (1.1), K (2.5), Mo (5.0), Pb (8.6), Sr (8.6), Cr (9.7), Al (16.2)

- 32.7 and 57.9 mg/km: Ca (32.7), Sb (34.2), Mn (38.5), Ba (43.2), Cu (46.1) and Zn (57.9)

The following figure shows the emission factors of the identified metallic elements with the exception of iron, and its oxides, which account for around 53% of the total abraded mass during braking.

Conclusions

This paper thus presents a reliable method combining the evaluation of the dust and the chemical identification of pollutants collected from the truck brake abrasion in real-world driving. The significant findings are as follows:

The brakes particles were smaller than 45 nm. Calculation of their size distributions were found bi-modal.

Average concentrations values for pollutants varied from 1.5 10+8 to 9 10+12 #/cm3. The average quantities of truck brake dust emitted by metallic pollutants were between 6 and 19540 mg/kg.

Emission factors of metallic element of brakes show three different groups: G1 [Cd (0.0 mg/km), As (0.1 mg/km), Co (0.4 mg/km), Ni (0.8 mg/km), Se (0.8 mg/km)]. G2 [Mg (1.1 mg/km), Na (1.1 mg/km), K (2.5 mg/km), Mo (5.0 mg/km), Pb (8.6 mg/km), Sr (8.6 mg/km), Cr (9.7 mg/km), Al (16.2 mg/km)]. G3 [Ca (32.7 mg/km), Sb (34.2 mg/km), Mn (38.5 mg/km), Ba (43.2 mg/km), Cu (46.1 mg/km) and Zn (57.9 mg/km)]. G3 is therefore the group of tracers of this pollution. Iron and its oxides account for around 53% of the total mass of the particles collected during braking.

Author Statements

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