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Emissions factors for fine dust from road traffic

Extract BUWAL-Study/June 1998

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Extract from a study sponsored by the Swiss Environmental Protection Agency BUWAL/Bern, June 1998

The study compiled data on emissions of particulate air pollutants originating from road traffic. The data came from publications (approx. 300), direct inputs from industry, and from the Swiss occupational health project VERT during 1993 and 1997. The emission factors (mg/km) are based on vehicular mileage. The focus was on the health impact of such particulates. In addition to the emitted mass, the goal was to collect information about concentration count, size distribution and chemical composition.
The table on the next page summarizes the results.

A preliminary evaluation indicates:

- Diesel: Fairly consistent information about concentration and size distribution.
- SI 4-stroke: Much scatter and strong dependence on operating state, maintenance and wear. At full load, emissions are comparable to Diesel engines. Scarce information about character and size distribution of these particulates.
- SI 2-stroke: Known for heavy particulate emissions in off-road deployment. No information about character and size distribution of these particulates.
- SI-gas engine: Very little particulate formation during normal operation. However, high concentrations at full load, comparable to Diesel.
- Engine attrition: The heavy metal emissions are no way negligible.
- Tires: Surprisingly high PM10 fraction
  Tires contain 10 - 20% soot with up to 200 µg/g PAH and much Zinc. In the PM10 range, tire emissions are 50% of engine emissions.
- Clutch: Only emits fine particulates; some of the substances are risky; quantity not negligible.
- Breaks: Mostly fine particulates; some of the substances are very risky; not negligible and attaining 10 - 20% of engine emissions.
- Fibers: Mineral fiber fragments from mufflers and catalytic converter canning. Not a negligible contribution compared to other fiber emittants. The industry is aware of the problem.
  The "concentration count" ($1/cm^3$) is already defined legally (Germany TRGS 905).
- Cat. Converters: In contrast to earlier assumptions, the newest investigations detect ultra-fine particulates (crystallite of precious metals). Loss of precious metal attain a few percent of the coating mass.
- Soot filter: No known secondary emissions.
- Corrosion/erosion: No quantitative information.
- Road dust: Extreme scatter in the data.
  Proportionality to tire wear is not confirmed. Road dust is composed of road attrition and fine dust deposited on the road. The traffic re-suspends the dust. The two components have very different particulate sizes and composition. There is insufficient information for a systematic differentiation.

	Sources		PM10-Emission Factors for typical Driving Cycle		Average Particle ∅	Chemical Substances
			mg/km [1)]	$1/cm^3$ [2)]	µm	
Tail Pipe Emissions	Diesel	PW	80 - 160 [3)]	$> 10^6$	0.1	EC/OC/S
		LI	80 - 310	$> 10^6$	0.1	EC/OC/S
		SNF/Bus	380 - 1000	$> 10^6$	0.1	EC/OC/S
	Otto 4T	PW without Kat.	3 - 900	$10^3 - 10^6$	0.08	EC/OC/Pb
	Gasoline	PW with Kat.	5 - 60	$10^3 - 10^6$	0.06	EC/OC
		MR	18		0.08	EC/OC/Pb
	CNG	PW	20	$>10^3 - 10^5$	< 0.08	
	Otto 2T	PW	680	10^6	0.1	EC/OC/Pb
		MF	60	10^6	0.1	EC/OC/Pb
	Engine-wear	PW without Kat.	10-12.3		1	Fe, Cu, Ni, Pb, Zn
		PW with Kat.	0.16 - 1		1	+ many others
		SNF	3			
	Fibres from Silencers	PW	0.1 [4)]	1 [6)]	5	Si, Ca, Mg, Al
		SNF	0.5	1 [6)]	5	K, Na, Fe, Bor
	Diesel Particulate Trap				?	Si, Mg, Fe, Al Ce, V, Pt, Cu
	Catalytic Converter	PW	0.0002 - 0.02		0.005 - 20 [7)]	Pt, Pd, Rh
Vehicle	Clutch	PW	2 - 5 [4)]		5	Fe, Cu, Sn
		SNF	20 - 50		5	ceramic fibres organ. binder
	Breaks	PW	10 - 30		15	Fe, Mn, Ba, Al,
		SNF	50 - 150		15	SiO_2 and v.a.
	Tires	PW	70 - 200		15	EC + OC/PAH
		SNF	400 - 3000		15	Polymeres
		MR	24 - 50		15	S, Zn, Pb, Cd
	Corrosion and Erosion				< 10 ?	Lac particles Fe, Al, Ni, Zn
Road	Road Erosion + Resuspension	PW	600 - 2300 [5)]		< 10	Si, Al, Fe, Cu
		SNF	375 - 11'700		< 10	EC, OC

PW	LD-Vehicle
LI	LD-Truck
MR	Motor Bike
MF	Motor Bicyle
SNF	HD-Truck
EC	Elementary Carbon
OC	Organic Carbon

1. Total Particulate Mass at <52°C, Dilution ca. 1:10
2. Number Concentration per Standard-cm^3-Exhaust Volume and Particle Size Class
3. Lowest/Highest Values from Literature
4. Assumption TTM
5. Typical US-Dates, not transfermable to CH
6. 10^6 F/m^3 a very high Concentration for Fibre Tast
7. Cristallites/Washcoat-Particles

Emission Factors for Traffic Generated Particulates

The available information is generally insufficient, in many aspects, to characterize the particulate emissions from different traffic sources. Particulate emissions are a high priority R&D activity in the automobile industry. The manufacturers presumably have more unpublished information. Hence, this catalog should be enhanced with direct information.

The legal definition of "particulate emissions" only pertains to the Diesel engine. There is an information shortage and very large scatter for some of the other emittants. Comprehensive information is available for Diesel engines under different operating conditions and for all currently deployed technologies. Most of this information, however, pertains to the gravimetric procedure of the CVS dilution tunnel technique. Much less information is available about the tail-pipe composition and size distribution in the aerosol state. The information is also very heterogeneous because various measurement methods were used.

Particulate emissions are rarely measured for SI engines. These are not legally prescribed anywhere. (Particulates from SI engines are usually not visually perceptible). Occasionally (USA, Australia), offensively smoking or stinking vehicles were stopped and sent for examination. The values ascertained are obviously rather extreme. There are other explanations for the big scatter. The fuel composition (additive lead) has a very large influence on the operation. Modern SI engines, too, can have high particulate emissions close to full load. Another factor is the age of the engine (SI engines are less emission stable than Diesel engines). Aging could manifest itself in particulates from the lubricants.

There is still less information for 2-stroke SI engines in 2-wheelers. (Even scarcer is data for off-road equipment engines). The USA now has legislation for off-road deployment. Hence, certification data is available that indicates high particulate emissions. Its parameters are, however, completely unknown.

There is even more uncertainty about the data from non-engine sources. There is statistically very little information available. Further, different technologies are deployed. These strongly influence the parameters of these emissions, i.e. mass, particulate size and the particulate composition.

<u>The main know-how gaps are in the following areas:</u>

1. SI 4-stroke engine: The conventional 4-stroke automobile engine with catalytic converter, obviously can profusely emit fine particulates under certain operating conditions. Thus, the total emissions can be substantial. This conclusion cannot be quantitatively substantiated because of insufficient data. The characteristics of these particulates are largely unknown. Possibly, SI engines can generate more spontaneous condensates of hydrocarbons, if there are few solid particulates onto which such condensates are deposited. It is not impossible that solid particulates are emitted which are even smaller than the Diesel particulates. Lead has a significant influence on particulate formation. The data shows a reduction in particulate mass when the lead content is diminished.
2. Attrition in the engine tires, clutch and brakes can together have a comparable mass to the particulate emissions from combustion. Attrition appears to be the bigger source from vehicular gasoline engines. The abraded particulates contain heavy metals. They should not be incorporated into a single total with the carbon particulates from combustion.

3. Fiber emissions from mufflers and converter packings should be thoroughly investigated. Austria has performed the first immission measurements. Fiber fragments presumably occur in very high concentrations. Their dimensions and material composition are toxic according to the WHO and TRGS 905 criteria.
4. The quantity and quality of road attrition and road dust, according to available data, are very comparable with tail-pipe emissions. The road is a persistent repository for such fine dust. Everybody on the road is subjected to very high concentrations of re-suspended dust. These concentrations (vehicular cabin measurements Munich, London) could be much higher than roadside imission measurements. This emission source requires careful study and investigation of suitable counter-measures (street sweeping machines, dust binding).
5. There is wide size divergence in the particulates originating from traffic. The typical combustion particulates, at the tail-pipe, are in the range of 100 nm. The metal crystallites from catalytic converters are about 5 nm. Many attrition particulates are 5 - 10 µm. The ultra-fine particulates are more hazardous. Hence, gravimetric total criteria should be abandoned. Instead, the concentration count and size distribution are decisive.
6. There is also much variety in the composition of particulates originating from traffic. Conventionally, all countries have legally required summary measurements of these particulate emissions, irrespective of their chemical composition. It is highly doubtful whether such data is adequate to assess the toxic potential.
7. The traffic generated particulates can be solid particulates (with deposited substances, e.g. PAH). They could also be pure condensates. The toxic consequences are presumably different for these two groups. Hence, the measurement technique and the choice of exhaust gas after-treatment must differentiate between solid particulates and condensates. Advances therefore require pertinent research and, possibly, separate legislation for the two types.

<u>The study prompts the following proposals:</u>

- Intensify the investigation of all non-diesel engines.
- Harmonize evaluation criteria (size, substance, consistency) from the emission / imission / toxicology perspective.
- Prepare a more detailed inventory of particulates that reflects the evaluation criteria, using weighting factors.
- Promote particulate measurement techniques, particularly the measurement of size distribution and particulate surface properties, for qualitative characterization, field measurements and online monitoring.

<u>The solution is technically feasible:</u>

Diesel engines with particulate traps:

+ hydrodynamic coupling (automatic transmission)

+ Attrition-free brakes (retarders)

+ Tires without carbon soot

+ Mufflers without fiber fragments (endless fibers, no fibers)