BGN (Employer's Liability Insurance Association for the Food and Hospitality Sector), Germany

The Garage Experiment

Comparison of particle concentrations within a garage caused by
(a) the combustion of three cigarettes
(b) exhausts from a passenger car diesel engine running idle (Euro-III emission norm compliant).

Introduction

In the course of the discussion about the noxious effects of environmental tobacco smoke (ETS), amongst others an Italian study by Invernizzi el al. (1) has been regularly quoted.
According to said study, the combustion of three cigarettes within a self-contained garage has lead to a particle concentration in air many times higher than the concentration measured when a diesel engine (Euro-III emission norm compliant, without soot filter) was running idle for half an hour.

Additionally, the authors regard the composition of ETS to be comparable with that of other combustion products of fossil matter (like diesel fuel), and accordingly deduce that the emissions from only three cigarettes must have a much higher noxious effect than those from the diesel engine running idle for half an hour.

As this result is in blatant contradiction to all reasonable predictions, we have tried to re-create the experiment as true to the original as possible.

Experimental procedure

Our investigations were conducted in a self-contained garage room with a capacity of 130 cubic meters.
The vehicle employed was (like in the original study) a Ford Mondeo TDCi (Common Rail Diesel) with an engine displacement of 2.0 liters, built in 2002, Euro-III emission norm compliant.
The Diesel engine was run with low-sulfur diesel fuel (sulfur contents 10 mg/kg), warmed-up, running idle at 750 rpm. As in the original study, we used „MS“ brand filter tipped cigarettes. Note: The tar yield of 10 mg per cigarette was slightly lower than in the original experiment. The arrangement of cigarette, exhaust pipe and measuring instruments was geared to the arrangements of the original study.

In order to obtain a better characterization of the particles, we not only used the optical aerosol monitor employed in the original study (Aerocet 531, Metone Instruments Inc, USA), but a certain array of additional instruments:

- one pump for collecting of fraction PM4 (particles up to a size of 4 µm) in combination with a 70 mm glass fiber filter
- one 11-step Berner Low Pressure Impactor (BLPI) for particle sizes between 18 nm and 16 µm (with aluminium foil substrates)
- one TSI Scanning Mobility Particle Sizer (SMPS, for particle sizes from 10 nm to 900 nm)
- one portable CPC system (Condensation Particle Counter, TSI Model 3007, for particle sizes from 10 nm upward)

Our experiments were conducted according to the following scheme:

- Ventilation of open garage for 30 minutes
- Closing of garage, recirculation of air within by ventilator for 30 minutes (for background measurement)
- Engine started and run for 30 minutes respectively three cigarettes burnt consecutively in 10-minute cycles
- Both measurements continued with closed garage door for additional 90 minutes
- Opening of garage door and venting

Our evaluation was based on a measuring period of 120 minutes in both cases (30 minutes with emissions, 90 minutes without).

Results

The results of the Metone Aerosol Monitor were consistent with those from Invernizzi et al. In fact, the absolute concentrations in both cases were considerably lower (about one sixth), but this was caused by the bigger garage and obviously different internal air currents. The proportions of emissions from diesel engine (PM 10, average 6,1 µg/m³) and cigarettes (PM 10, average 29,4 µg/m³) were comparable and consequently enabled us to reproduce the quintessence of Invernizzi et al.

However, the results of the other measuring instruments lead to a totally different picture:

- The average particle mass concentrations measured with the Berner Low Pressure Impactor were 348 µg/m³ for the diesel engine, but only a third of that value for the cigarettes: 126 µg/m³.
- The PMSP system showed 490 µg/m³ for the diesel engine and 154 µg/m³ for the cigarettes.
- The average mass of fraction PM4 (particles smaller than 4 µm) was 1280 µg/m³ for the diesel engine, 500 µg/m³ for the cigarettes.
- The mass of elemental carbon (reference value for emissions of diesel engines) was 280 µg/m³ for the engine and 22 µg/m³ for the cigarettes.
- The average particle numbers detected with the Condensation Particle Counter were 214,000 /cm³ for the diesel engine and 45,000 /cm³ for the cigarettes.

Background concentrations without cigarette smoke or diesel emissions were so marginal that they could be disregarded.

Discussion

The measurements made with the Metone Aerosol Monitor enabled us to re-create the findings of Invernizzi et al. with regard to the result that three cigarettes create much higher emissions than a diesel engine running idle for 30 minutes. All other measurement methods lead to a contrary result, insofar as they show much higher emissions from the diesel engine.

What has caused this apparent contradiction?
Viewed by themselves alone, all these measurement methods work unobjectionably.
Yet it is necessary to consider what they actually measured. The Metone Aerosol Monitor

measures the light scattered from particles of 0.5 µm size as calibrated on latex.
Due to the low intensity of light scattered by diesel exhaust particles, this leads to a reduced measurement by the Metone Aerosol Monitor, approximately starting with a particle size over 1.5 µm. In comparison, particles of tobacco smoke are relatively larger condensation droplets, which leads to them being better registered by the aerosol monitor in question.
Therefore, diesel exhaust particulates are a totally different matter: Loose agglomerates of irregular shape, consisting of very small primary particles.
Such agglomerates are still much finer than the condensate droplets of tobacco smoke.
Accordingly, the aerosol monitor is totally blind for diesel exhaust particulates and unsuitable for this application.

Additionally must be noted that the diesel engine's air filter during our experiment has cleaned the air within the garage from coarse particles, that is to say it further reduced the suitability of the Metone device by working as an air cleaner!
In fact, the readings of said device dropped after the start of the diesel engine, and rose when the garage door was re-opened.

Summary

- As they are based on the use of unsuitable measuring equipment, the conclusions of the study by Invernizzi et al. are invalid.
- Particulate matter emissions from the diesel vehicle as measured with the Berne low-pressure impactor were on average three times higher than those from the cigarettes; the SMPS peak value for the diesel emissions even amounted to four times the values for tobacco smoke.
- The results of the optical aerosol monitor used by Invernizzi et al. show the reverse trend – in this case the cigarette smoke's concentration of particulate matter is seemingly five times as high, which is an anomaly caused by the optical properties of the diesel exhaust particulates and by the lower detection limit of the monitor.
- For the measurement of ultrafine aerosols of a size below 300 nm, optical single particle counters cannot be suitable detection devices, and other measuring techniques must be favoured.

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References

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