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High-Volume Combustion Aerosol Sampling using Tandem Atmospheric Samplers

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Introduction

Internal combustion engines, and combustion aerosols in general, are the dominant sources of fine particles in urban air. Fine particles emitted by the internal combustion engines are one of the principal sources of adverse health effects attributed to air pollution. The particles emitted by the engines are rather small, on the order of units to hundreds of nanometers (nm) in diameter, with most prevalent particle size in low tens of nm, and with most particles being smaller than 100 nm. Such small particles have a high deposition rate in human lung alveoli, have the capability to penetrate through cell membranes, and have been known to adversely affect respiratory, circulatory and nervous system. Therefore, total PM mass or PM number are not necessarily a good measure of the effects on human health, and new method for assessment of PM from combustion sources are being sought.

Chemical analyses and toxicological assays can be done on organic extracts of particulate matter, but relatively large quantities of sample are needed, on the order of units to tens of mg, which is two orders of magnitude above the quantities normally sampled for gravimetric analysis to determine total PM mass. Such sampling therefore requires either extensive engine run times, or high sample flows. High sample flows generally possible only with a full-flow dilution tunnel, which is not always available.

The aim of this study is to facilitate collection (dilution and sampling) of large quantities of particulate matter for detailed chemical analyses and for toxicological assays.

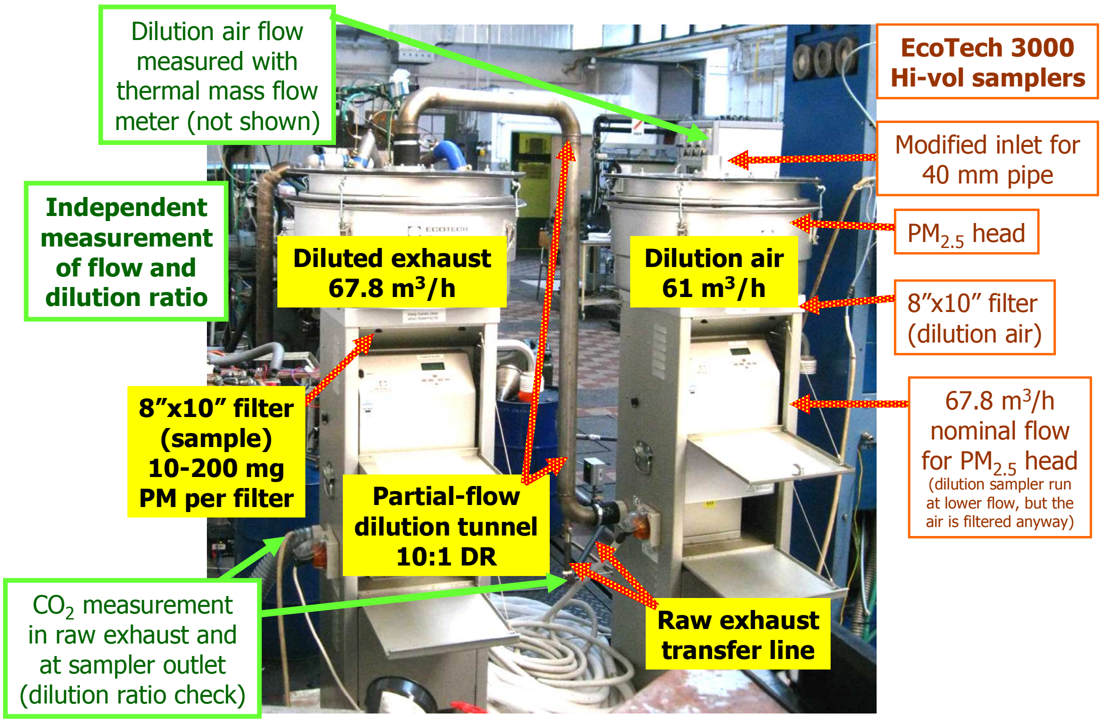
Experimental

The approach described here uses two atmospheric high-volume samplers running in parallel to provide both dilution and sampling of internal combustion engine exhaust.

In the setup described here, two EcoTech 3000 samplers with a $PM_{2.5}$ impactor head were used. One sampler operated at its nominal 67.8 m^3/h rate and was used to sample PM in diluted exhaust. The other sampler was operated at 80-95% of the flow rate of the first one, providing a source of filtered and heated dilution air, with filtering facilitated by a "background" filter (normal use of the sampler), and heating resulting from passing through the blower pump. The outlet of the blower pump is routed to a dilution tunnel extending to the inlet of the other sampler. Raw engine exhaust is routed to the beginning of the dilution tunnel via a stainless steel transfer tube. The degree of insulation of the transfer tube depends on the anticipated exhaust gas temperature.

With this setup, dilution ratios of approximately 5:1 to 20:1 could be facilitated, with 5:1 possible only at low temperatures of the raw exhaust gas, and 20:1 being difficult to achieve due to the raw exhaust flow being controlled as the difference of dilution air and diluted sample flows.

The dilution ratio is verified by independent measurement of CO_2 in raw exhaust and in diluted sample. Also, the flow of the sampler providing the dilution air is verified by a thermal mass flow meter (Sierra Instruments 620S).



Results

With the setup described here, samples of PM were collected on 20x25 cm fluorocarbon coated and quartz filters, with accumulations of ten to several hundreds of mg of PM per filter. The results are reported in a two papers (Vojtisek-Lom et al. and Topinka et al.) presented at this conference.

Due to the slow changes in sampler flows, this setup works in steady-state conditions only.

The independent measurement of flow rates and primarily the dilution ratio was found to be helpful under conditions where the filter reached its capacity within several minutes. Under such conditions, capturing the actual flows of raw exhaust (via dilution ratio data) is necessary as the time to reach steady sampling rates is on the order of tens of seconds to one minute.

Also, as the accumulation of PM filter is such that the sampler is no longer able to maintain the set flow, the flow gradually decreases. With this decrease, however, the amount of the raw exhaust sampled also decreases, until the sampler flow is equal to the flow of the dilution air and the collection of raw exhaust gas ceases.

The system is also suitable for work with low emissions engines. It is estimated that at 0.01 g/kWh PM, 5 m^3/kWh, 10:1 dilution ratio and 67.8 m^3/h diluted sample flow, 10 mg of PM can be collected in 45 minutes.

Conclusions

- **A pair of high-volume samplers used to dilute and to collect large-quantity samples of particulate matter in internal combustion engine exhaust.**
- **Method limited to steady-state conditions.**
- **Dilution ratio of 10:1 generally maintained until filter capacity reached; filter capacity varied by PM properties.**

Acknowledgements

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MEDETOX

Czech Technical University in Prague
Faculty of Mechanical Engineering

TECHNICAL UNIVERSITY OF LIBEREC
Faculty of Mechanical Engineering

Background

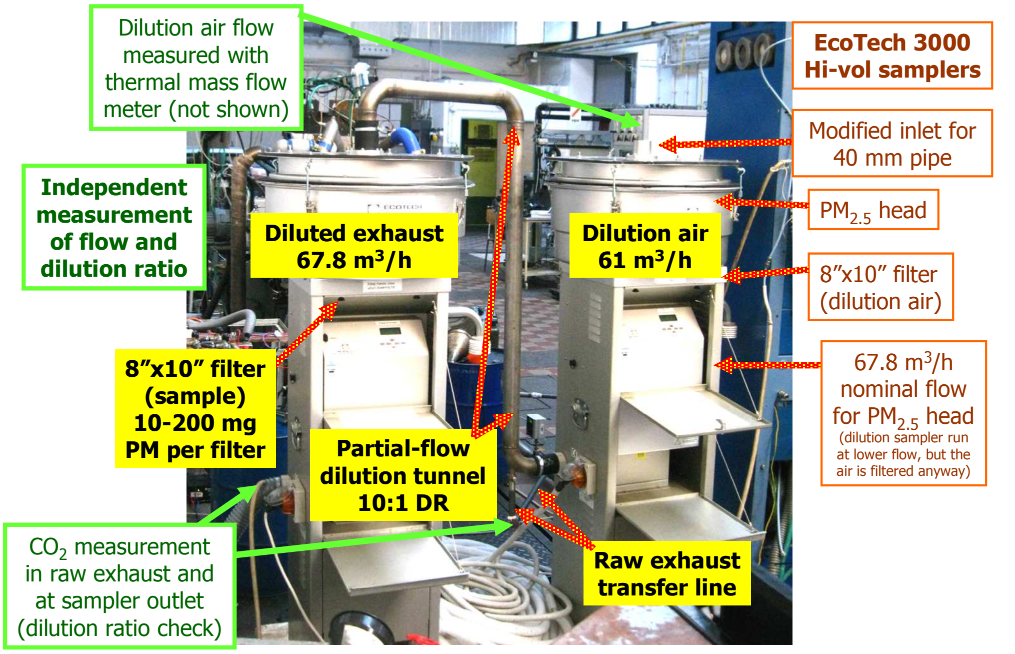
- Internal combustion engines are one of the dominant sources of fine particles in urban air.
- Total PM mass or PM number are not necessarily a good measure of effects on human health – new method are being sought.
- Chemical analyses and toxicological assays can be done on organic extracts of particulate matter, but large quantities of sample are needed.
- This requires either extensive engine run times, or high sample flows.
- High sample flows generally possible only with full-flow dilution tunnel, which is not always available.

Goal

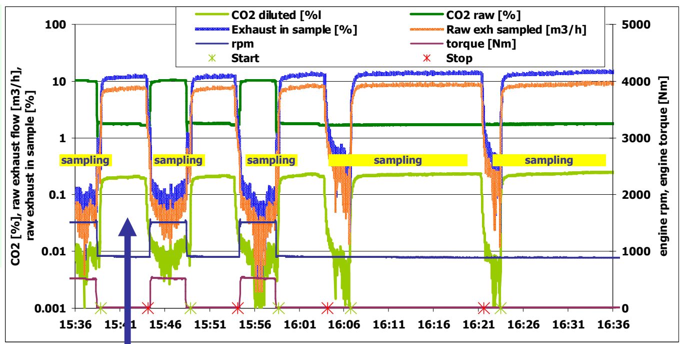
Facilitation of collection (dilution and sampling) of large quantities of particulate matter for detailed chemical analyses and for toxicological assays.

Approach

- Use of atmospheric high-volume samplers (EcoTech 3000, 8″x10″ filters)
- Two samplers are run in tandem:
  -- one to provide filtered dilution air
  -- one to sample the diluted exhaust
- Partial flow dilution tunnel approach, dilution ratio maintained by each sampler automatically maintaining its flow
- Dilution ratio verified by independent measurement of CO2 in raw exhaust and in diluted sample
- Dilution flow verified by thermal mass flow meter
- **Works in steady-state conditions only – high volume samplers not capable of fast changes in air flow**
- At 0.01 g/kWh PM mass, 5 m^3/kWh, 10:1 dilution ratio, 67.8 m^3/h diluted sample flow: 10 mg of PM collected in 45 minutes



Normal operation - filter capacity not reached
Low/moderate loads
Low fraction of EC
~ 100 mg PM per filter (capacity hundreds of mg)
dilution ratio 5:1 to 10:1
(5:1 diesels at low load with high excess air to maximize quantity of sample)

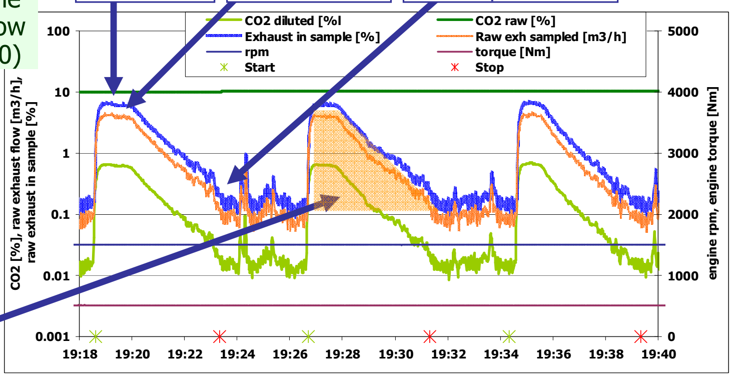


Sampling to the filter capacity
Full load - high share of EC
~ 10 mg PM per filter
dilution ratio 10:1
(difficult to maintain the desired raw exhaust flow at dilution ratios >> 10)

Sampling at nominal rate and nominal dilution ratio

Hi-Vol sampler no longer able to maintain the set flow rate

Flow rate dropped to the dilution flow rate; sampling effectively stops here



Actual amount of raw exhaust sampled determined from integral of raw exhaust flow (calculated from dilution flow and ratio of CO_2 concentrations in raw and diluted exhaust)

Conclusions

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- **Method limited to steady-state conditions.**
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Results of chemical and toxicological assays done on collected samples: See presentation Wednesday morning (Vojtisek-Lom et al., Topinka et al.)

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