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Fine particle emissions from wood and oil fired furnaces

Continuous Measurement of Fine Particles and Gases in the Exhaust of a Chinese Coal Power Plant

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Introduction

China is the world's largest producer and consumer of coal. It satisfies roughly 80% of its energy demand by coal combustion. Currently, China has power plants producing about 250 GW power in total and has plans to double its power-generating capacity until 2010.
Many Chinese coal power plants are old and inefficient, but since China's energy demand is growing continuously, they remain operative. On a global scale, Chinese coal combustion is responsible for 15% of the world's CO_2 emissions, and this percentage is likely to increase in the future in view of the rapidly growing energy demand in China. On a local scale, air pollution is a serious health problem in China. Air-pollution related mortality is approximately three times higher than in Switzerland.
We present particle and exhaust gas measurements done on a small coal power plant in the city of Beijing and propose measures to improve the efficiency and the cleanliness of this power plant.

The Power Plant

Our measurements were performed on the pilot power plant of Tsinghua University, Beijing. The power plant is located just outside the university campus in the northwest of Beijing. It is a pressurized fluidised bed combustor – coal is ground into pieces of a few mm diameter and fed into the combustion zone where the coal pieces are suspended in the strong primary air flow. A secondary air flow is added to adjust the O_2 level in the combustion process. The combustion process is controlled manually by regulating primary and secondary air flows. The power plant has a thermal power of 60MW and burns 20 tons of coal per day.

Sampling System

A schematic overview of the particle sampling system is given in Figure 1.

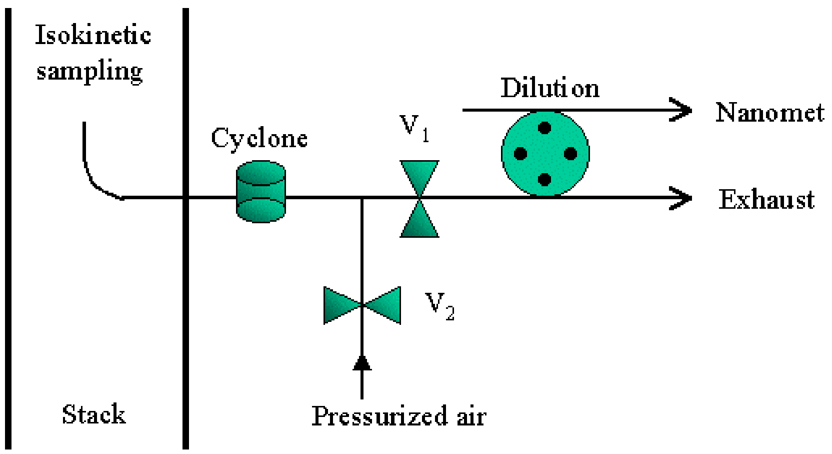


Figure 1: the particle sampling system

Particles are sampled isokinetically in the middle of the stack. A cyclone filters out all particles larger than 5 micron, afterwards the filtered exhaust gas is diluted by a factor 170 with a dilution unit [1] and measured in a Nanomet-System, equipped with PAS and DC (photoelectric charging and diffusion charging of aerosols, see [2] for details) sensors. Two computer-controlled valves, V_1 and V_2 are opened and closed periodically to flush the sampling system with pressurized air for cleaning. This is necessary as dust levels in the flue gas are very high.
The gas sampling system is simpler: the exhaust gas passes through a sinter-metal filter which removes all particles. After this, the gas is cooled in a cooling unit and then O_2, CO_2, CO and NO levels are measured with commercial sensors (Hartmann & Braun).
Additionally we measured some signals characterising the combustion process and the output power from the control room: Combustion temperature, steam temperature, steam pressure and steam flow. The last three can be multiplied together to give a signal proportional to the thermal power of the plant.
Both particle and gas measurement are fully automated and computer controlled. The system remained operative for three months, from March to May 2000.

Results

Figure 2 shows a time series of the two particle signals, PAS and DC. The signals vary rapidly on short timescales – this is an indication that the combustion is not well controlled.

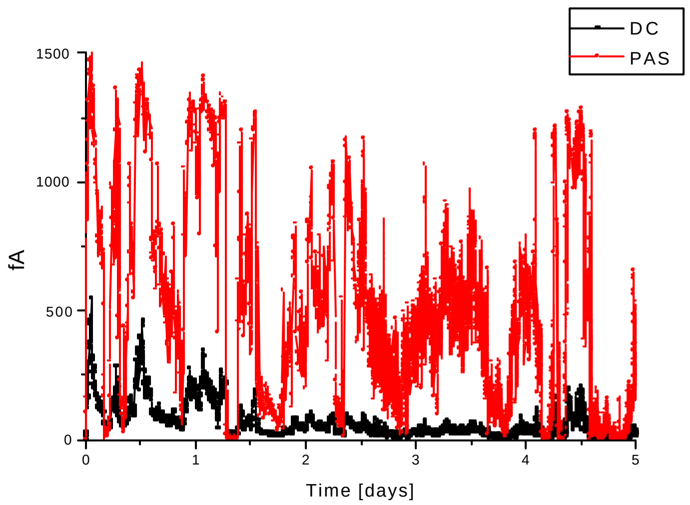
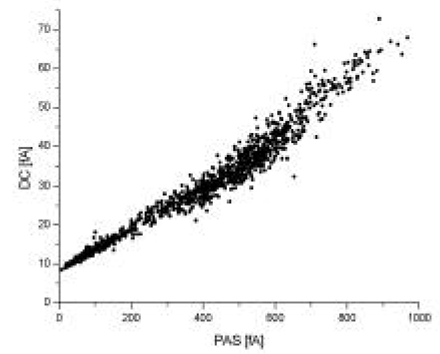


Figure 2: time series of the particle signals from 28th march to 2nd april 2000.

Figure 3 shows a plot of the PAS and the DC signal against each other. The two particle signals correlate very well, the DC signal is offset by a small amount. This small offset is caused by ash particles (mineral dust) which are not seen by the PAS sensor
Figure 4 shows the PAS signal plotted versus CO concentration. The two signals correlate well. This is not too surprising, since both soot particles and CO are indicators for incomplete combustion. However, this correlation is not seen in the exhaust of diesel car engines. Therefore one cannot generalize this result to all combustion processes.



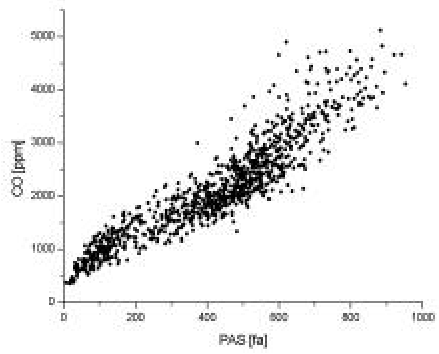


Figure 3: PAS versus DC level (31st march) **Figure 4: PAS versus CO level (31st march)**

Figure 5 shows the thermal power plotted versus the CO_2 level. Once again, the large variation of the data points indicates a bad control of the combustion process. It is obvious that the output power is higher for high CO_2 levels, corresponding to relatively low lambda values, when the heat exchange from the flue gas to the steam is more efficient.

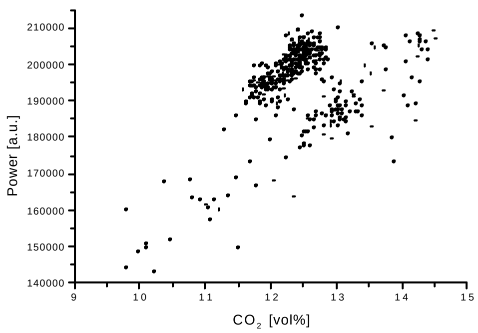


Figure 5: thermal power versus CO_2 level

Conclusions

Our measurements show clear correlations between CO_2 level in the exhaust gas and thermal power, and also between PAS signal and CO level. By fitting this power plant with relatively cheap gas sensors for CO and CO_2 one can keep track of both the cleanliness and the efficiency of the combustion. Regulating the power plant with the help of these sensors could improve the efficiency by about 5% and/or reduce the particulate pollution significantly. Online particle monitoring is also possible but it is much more expensive than gas sensors, and also needs more operator interaction – particle measurements are subject to much more dirt than gas measurements.

References

[1] Hueglin, Ch., Scherrer, L., and Burtscher, H.. (1997), An Accurate, Continuously Adjustable Dilution System (1:10 to 1: 104) for Submicron Aerosols, J. Aerosol Sci., 28/6, 1049 - 1055.

[2] Matter U., Siegmann H.C.,Burtscher H. (1999) Dynamic Field Mesurement of Submicron Particles from Diesel Engines, Environ. Sci. Technol. 33, 1946-1952.

Fine Particle Emissions of Wood and Oil Fired Furnaces

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Introduction

Because of 0their impact on health, particle emissions of various combustion sources have increasingly become a topic for public discussion. Therefore we have started a series of investigations at the EMPA in order to gather information about the emissions of fine particles from different types of heating appliances. We have looked at both, wood and oil fired furnaces. On one hand, oil burners are used in large numbers for domestic heating systems, on the other hand wood fired appliances are becoming increasingly popular for several reasons, one being their contribution in solving the "CO_2-problem".

Experimental

For the determination of number size distributions we are using SMPS and ELPI. Therefore we are able to look at a particle size range from below 10nm to about 10µm. The ELPI allows rather fast measurements of complete spectra (~ 50nm - 10µm) while SMPS spectra (~ 10nm - 1µm) take at least 60s and therefore are only useful during stationary combustion conditions.

With the help of a thermodenuder we had the option to strip the particles off their adsorbates and also make a distinction between condensation and solid particles. The sampling for ELPI measurements was designed to operate under isokinetic conditions.

Furthermore we did gravimetric measurements by exposing different kinds of filters to a defined flow of flue gas. This allowed us to compare those "classical" methods to the results of SMPS or ELPI measurements. For oil burners, we also used the Bacharach method which is commonly used for testing of oil appliances.

In addition to the particle measurements, we also recorded the emissions of NO_x, CO, O_2 and hydrocarbons. This way we were able to determine the quality of the combustion and control the settings of the heating appliance.

Our investigations included five oil burners of different technologies (e.g. "blue" and "yellow" flame burners) but with similar heat output as well as two types of wood boilers, one open fireplace and one boiler with a pellet burner.

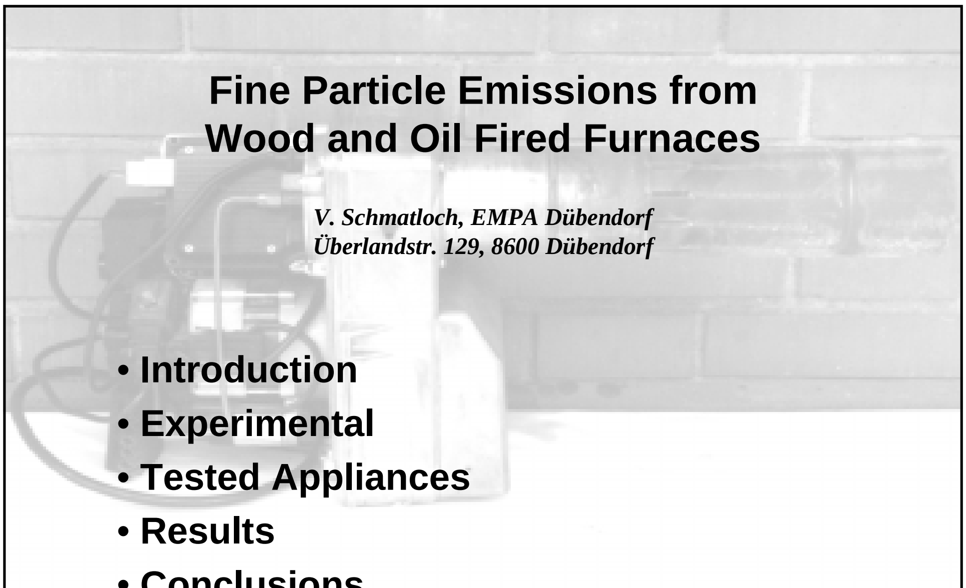
Results

The modes of number size distributions were around 100nm for wood appliances and about 10 to 15nm for the oil burners.

For measuremnets on wood fired appliances, we found a reasonable correlation between gravimetric measurements and ELPI results. Our results also indicate that there is good agreement between SMPS and ELPI results, when the total number concentrations are compared. Modern systems with stepped combustion showed lower emissions.

For the oil burners we did not find significant differences between different technologies. Neither did we find any meaningful influence of the burner adjustements. Only at adjustments that produced extremely high CO concentrations, we observed an increase in particle emissions. The use of low sulfur fuel, however, resulted in a significant reduction of particle emissions.

These projects are funded by the swiss Bundesamt für Umwelt, Wald und Landschaft (BUWAL).



Fine Particle Emissions from Wood and Oil Fired Furnaces

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- **Introduction**
- **Experimental**
- **Tested Appliances**
- **Results**
- **Conclusions**

Introduction

- New legislation concerning particle pollution (PM_{10})
  emissions ⇔ immissions
- various sources:
  industry
  domestic heating
  transportation (vehicle emissions)
  ...
- Particle characterisation:
  size
  mass
  number
  morphology
  composition

Introduction

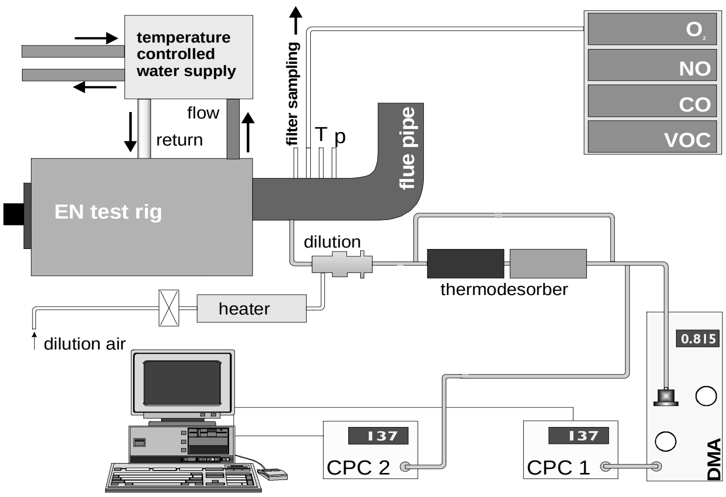
Wood heating increasingly popular

- „CO_2-problem"
- comfort
- ...

Problems

- maintenance
- hydrocarbon emissions („odor")
- particle emissions
- ...

Experimental Setup



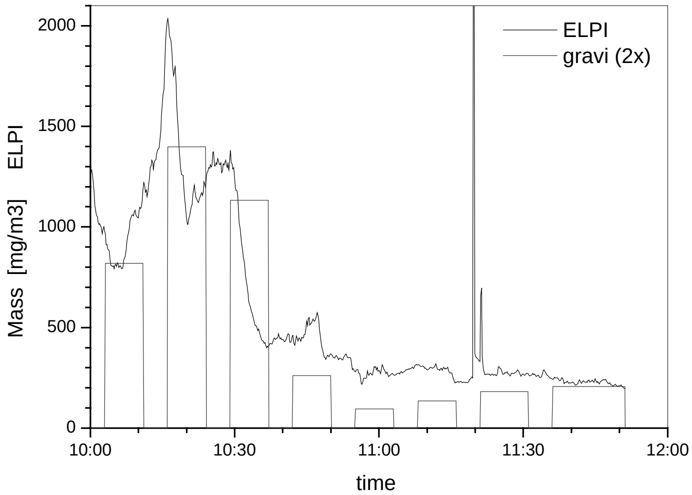
Measurement Techniques

Technique	Information	Time Resolution
Electr. Low Pressure Impactor (ELPI)	Number Size Distribution ($0.04\ \mu m < d_p < 10\ \mu m$)	< 5 s
Scanning Mobility Particle Sizer (SMPS), (resp. DMA & CPC)	Number Size Distribution ($10\ nm < d_p < 700\ nm$)	~ 60 s
Condensation Particle Counter (CPC)	Total Particle Number	< 5 s
Thermodesorber	(Volatiles)	-
Gravimetric Methods (Quartz Filters)	Total Mass	-
Sanning Electron Mikroscopy (SEM)	Morphology, (geometrical Size)	-

Appliances tested

- appliances burning pieces of wood
  - boiler with oberer Abbrand
  - boiler with unterer Abbrand
  - open fireplace
- boiler with pellet burner

Particle Emissions, Total Concentration



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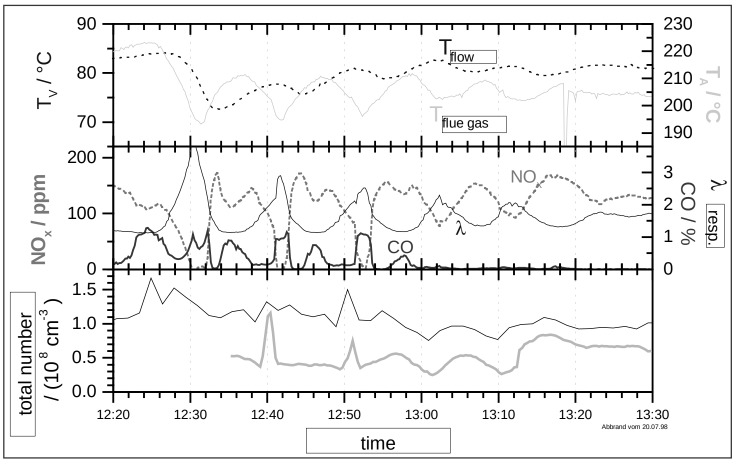
Combustion Cycle



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Conclusions

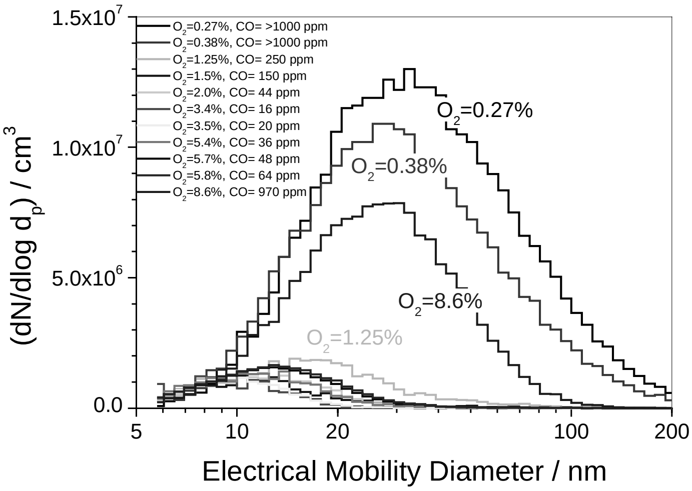
- wood: larger particles than diesel engines
- modern furnaces: lower emissions
- correlation between different particle measurement techiques

This project was funded by the Swiss Environmental Protection Agency (BUWAL).

Burners, technical data

Burner	Y-1	Y-2	B-1	B-2	M-1
type	yellow flame	yellow flame	blue flame	blue flame	blue flame
principle	fan assisted atomising fuel oil burner stabilisation disk	fan assisted atomising fuel oil burner stabilisation disk	fan assisted atomising fuel oil burner diffuser	fan assisted atomising fuel oil burner air nozzles	fan assisted atomising fuel oil burner fuel air mixture
heat output kW	17-38	24-43	18-26	23-33	12-24
Swiss type approval	1987	1998	1992	1998	1993

Fuel / Air Ratio



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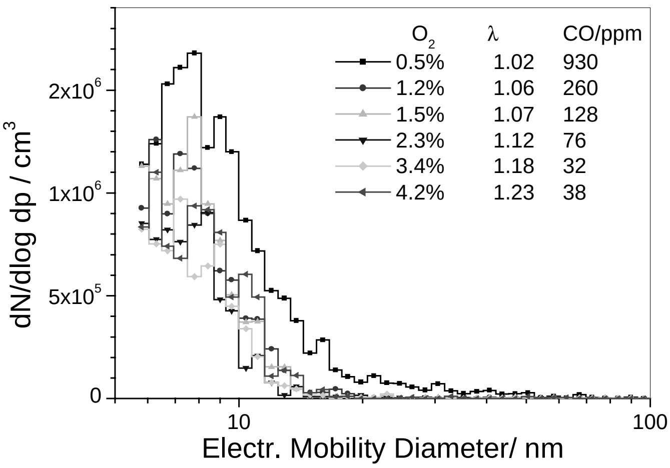
Blue Flame Burner: Fuel / Air Ratio



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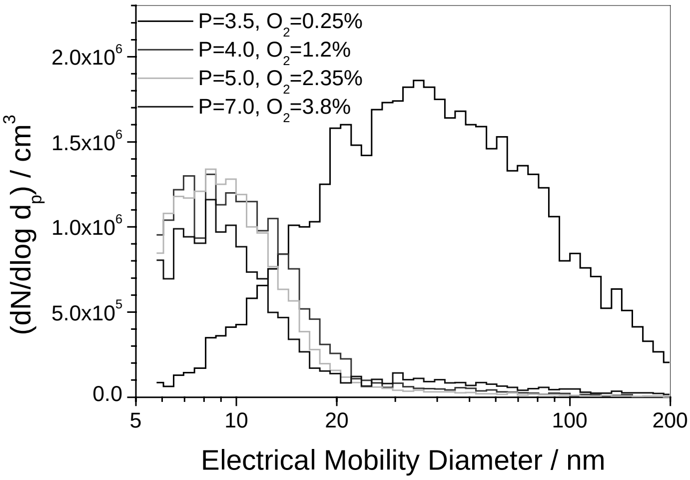
Gap



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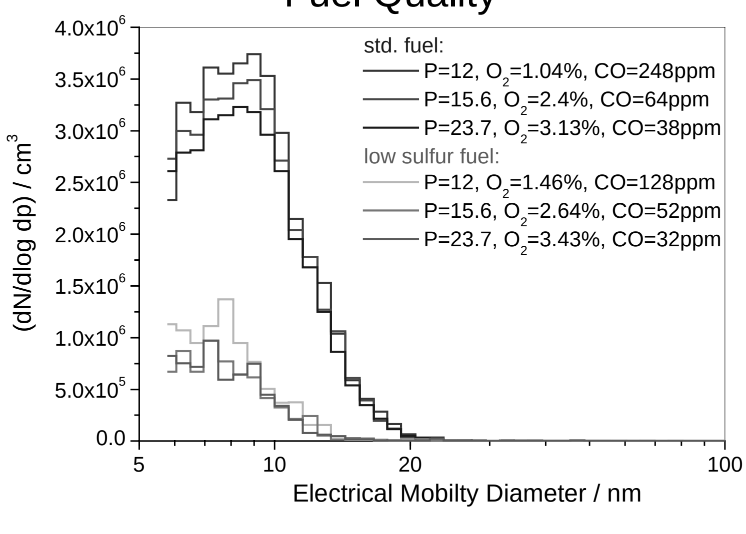
Fuel Quality



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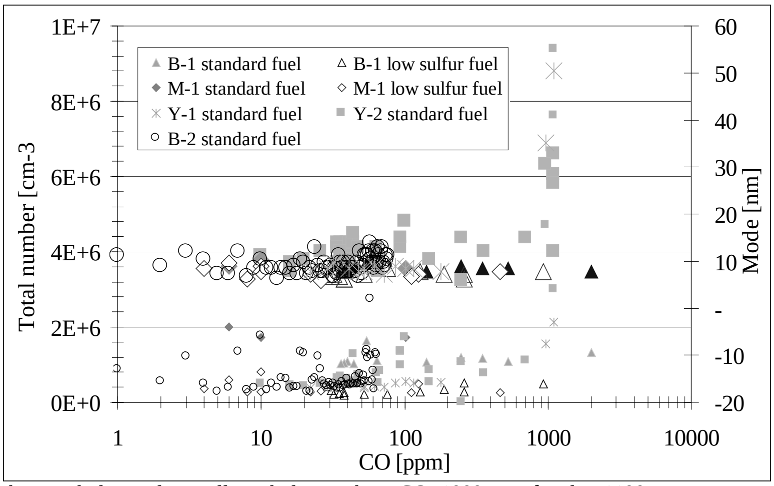
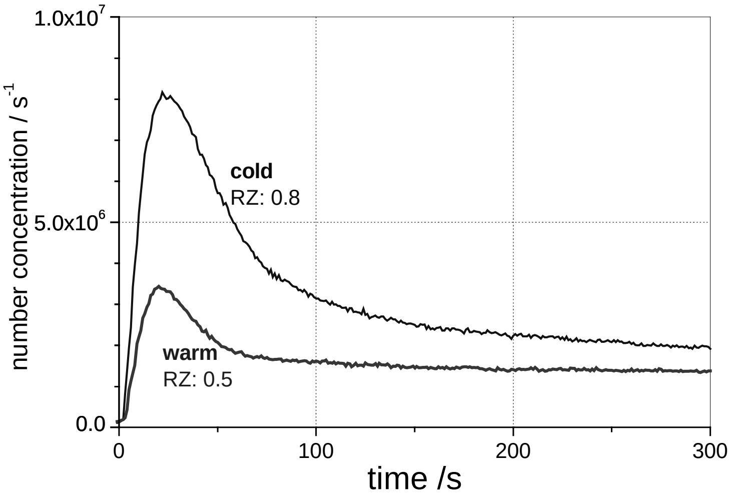
Particle vs. CO Emissions



big symbols: mode, small symbols: number, CO>1000 ppm fixed to 1100 ppm

Start Period



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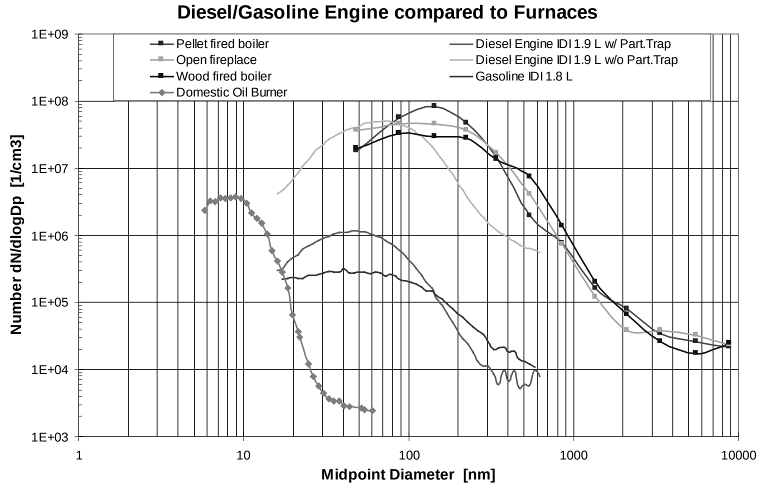
particle emission sources compared



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Oil fired Appliances: Conclusions

- at standard conditions:
  particle number concentrations ~ $1 \cdot 10^6$ 1/cm^3
- no large variation between different burner technologies
- increase of particle emission only at very high CO concentrations
- low sulfur fuel
  ➠ significant reduction of particle emissions
- modes of distributions ~10 - 15 nm
  (much smaller than for i.c. engines)
- higher emissions for cold starts

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