Gas Turbines – Sources or Sinks for Ambient Air Aerosols?

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Introduction

PM10 (particulate matter below 10µm) emission guarantees are requested for modern gas turbines by an increasing amount of customers in the US market and some other countries. The American environmental protection agency (EPA) has established standards for the measurement of PM10 emissions. The standards are based on weighing of filters and the requested guarantees so far are in the region of 10 mg/m^3 and below. Previous tests [1] have shown that the guarantee level is already close to the accuracy limit of the measurement method.

Since the EPA method just weighs the total amount of particles, no information on their origin can be obtained. To measure any type of emissions with high sensitivity and derive some hints on their origin, a test campaign with size classifying instrumentation has been performed. Ultrafine particles were detected with a scanning mobility particle sizer (SMPS), larger particles with optical particle counters. This differentiation detects a fingerprint of the emissions. While combustion aerosols occur primarily in the ultrafine range below roughly 0.5µm, larger particles can be attributed to secondary sources. Within the frame of this conference the present paper concentrates on sub-micron particles.

The Alstom GT26 turbine

All tests were performed at an Alstom GT26 machine located at the test centre in Birr Switzerland. The basic features of this turbine, which is the largest one in Alstom's product range, are given in Figure 1. The turbine is designed for dual fuel operation with alternatively natural gas or oil. Combustion takes place with two subsequent burner arrays. The EV (environmental) burner (Fig. 2) was developed for low emission levels and is used also in other Alstom turbines. After expansion of the gas in the high-pressure turbine, the gas is again reheated with the differently

designed sequential-EV (SEV) burner and than expanded in the 4-stage low-pressure turbine. Ultrafine particle emissions were monitored for all operation conditions from idle to full load.

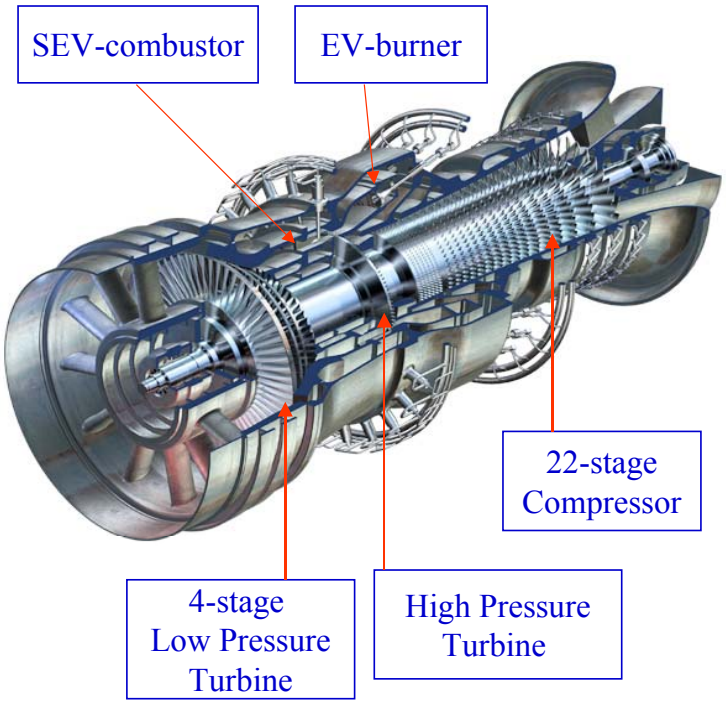

Fig. 1: The GT26 turbine with sequential combustion

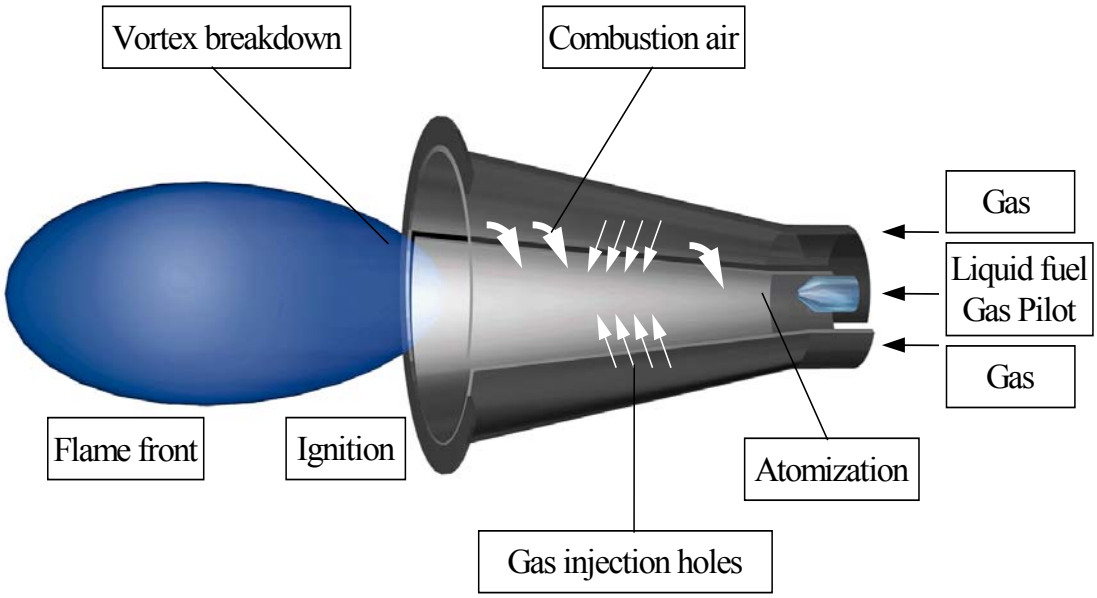

Fig. 2: The EV (environmental) burner

Experimental set-up

A small slipstream of the exhaust gas of 640°C was sampled and diluted with a Nanomet dilution unit. Sampling line and diluter were heated above 120°C to avoid condensation. A dilution factor of 75 was verified after the tests and taken into account for all presented data. The data are also corrected for diffusion losses in the sampling lines. A TSI scanning mobility sizer (SMPS) was used in two alternative modes: Particles between 25nm and 630nm were measured in the low flow mode. For the detection of ultrafines between 6nm and 200nm the instrument was run in the high flow mode.

Results gas operation

The emissions during gas operation were hardly detectable. A summary of several SMPS spectra during full load operation is given in Fig. 3, in which neighboured size channels were averaged to obtain better statistics. The total concentration sums up to $4*10^3$ particles/cm^3. These emissions can be set in relation with an ambient air spectrum recorded at the Birr test centre. The comparison (Fig. 4) shows that the GT emissions are substantially lower than the ambient air background.

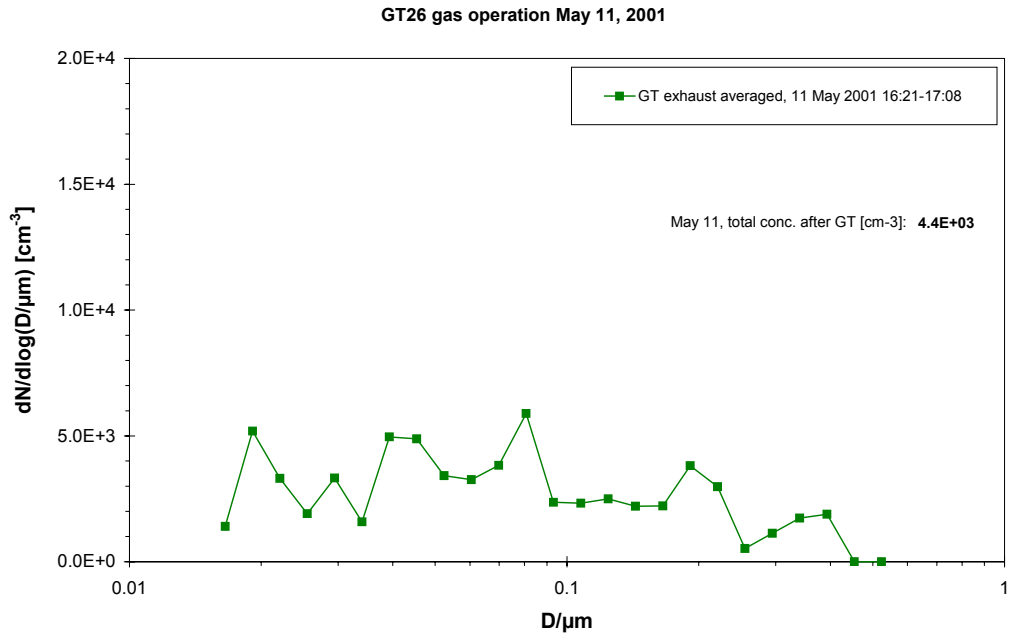

Fig. 3: Particle emissions during gas firing.

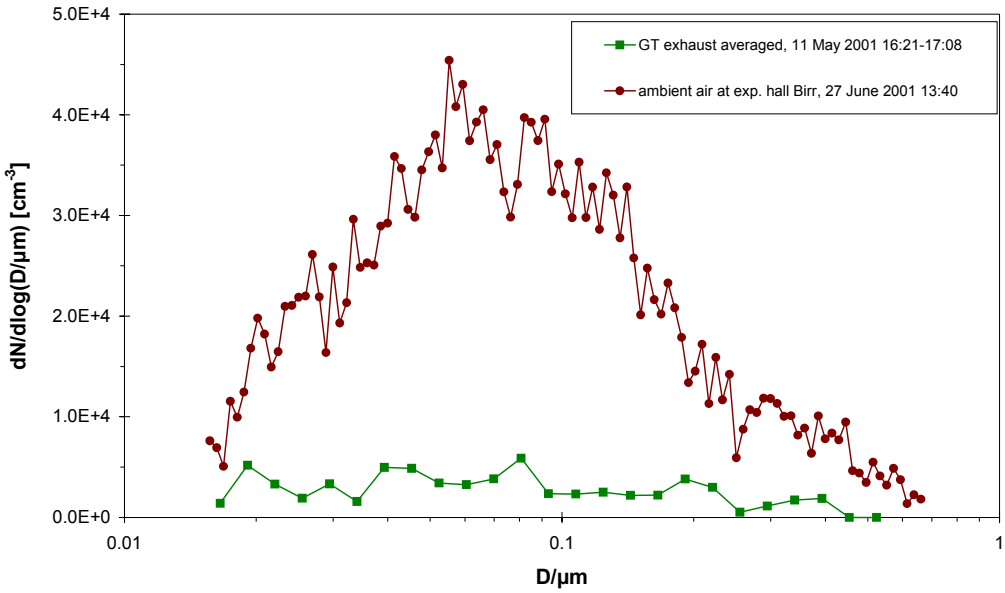

Fig. 4: Comparison of emissions with ambient air at site.

Results oil operation

For particles above 30nm, detected in the low flow mode, this picture does not change significantly when the turbine is run with oil as fuel. Measurements in the high flow mode reveal, however, the emission of ultrafine particles with a peak at about 15nm in the size distribution (Fig. 5). A peak at that size also remains when a thermodenuder is placed in front of the measurement system. Thus the particles in that mode cannot be attributed to condensable matter only. They are more likely primary soot particles, which occur in so low concentrations that agglomeration does not yet take place.

The exact height and size distribution of that peak depends on the operation condition of the gas turbine. Fig. 5 refers to full load operation and NO_x levels within the guarantee limit. During loading-up of the machine the peak is higher than at full load stable conditions. Higher emissions also occur when the machine is idling. The peak for this condition is shifted towards larger sizes, which might be a sign of starting agglomeration of primary soot particles. A comparison for the different operation conditions is given in Fig. 6. It should be noted that the particle concentration never exceeds 10^6 cm^{-3}.

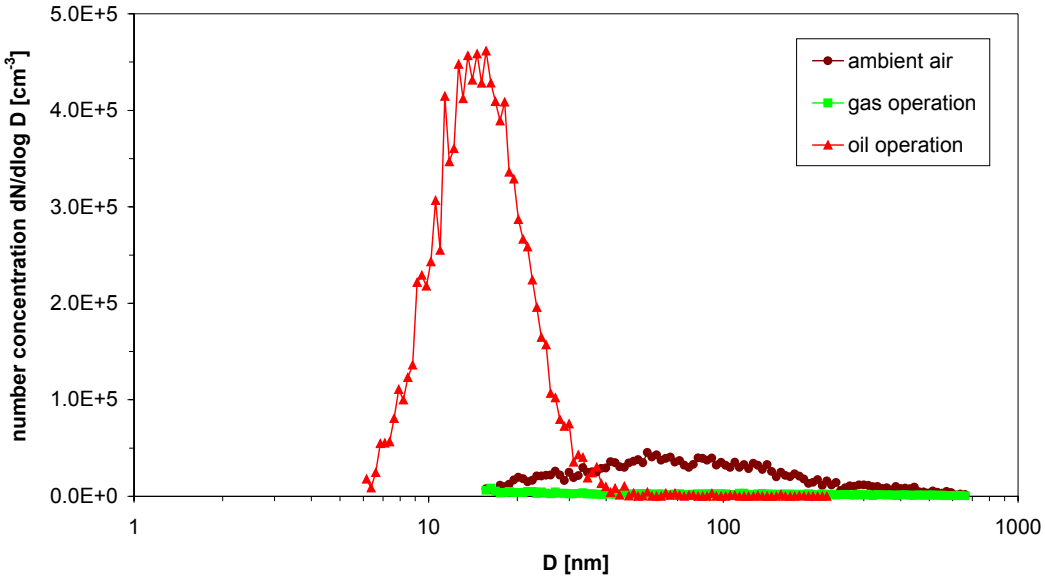

Fig. 5: Particle emissions during oil firing compared to gas and ambient.

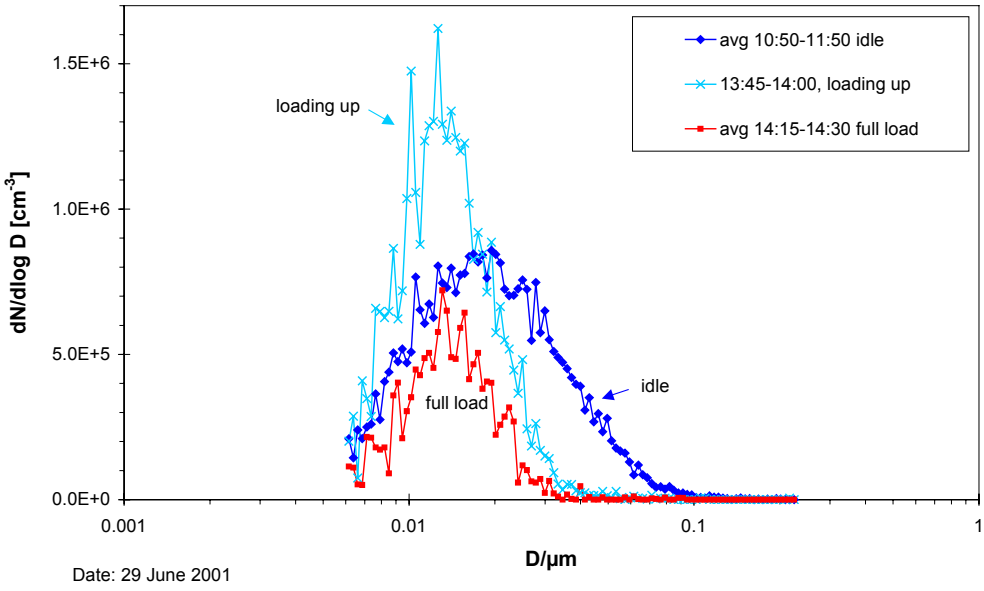

Fig. 6: Influence of operation conditions during oil firing.

Comparison to other sources of combustion aerosols and ambient air

The sub-micron particle concentration after the oil-fired GT26 is significantly lower than for other prominent sources of combustion aerosols, which were summarized in a previous conference contribution of the EMPA [2] and are reprinted in Fig. 7.

Small household burners emit aerosols at the similar size as the oil fired GT26 but roughly one order of magnitude higher in concentration than the oil-fired gas turbine at full load. The by far highest emissions in Switzerland result from Diesel engines without filters and wood firing.

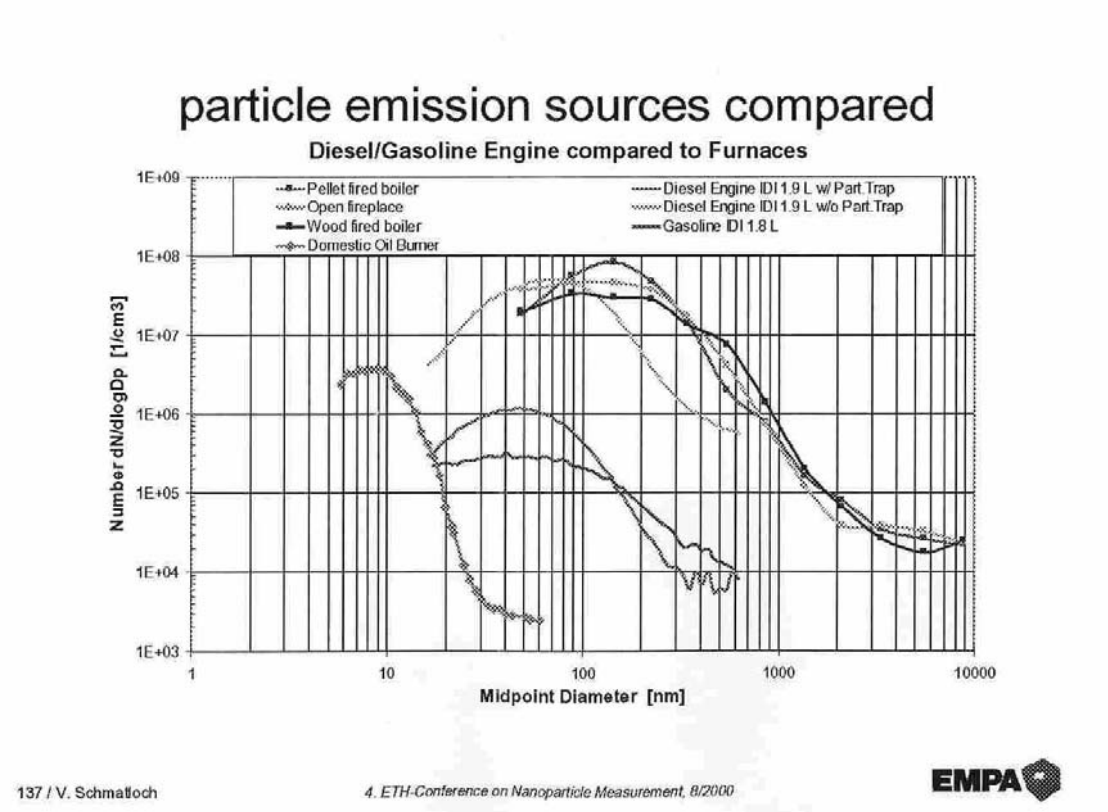

Fig. 7: EMPA data on other sources of combustion aerosols [2].

The size distribution of these predominant sources can also be found in the ambient air spectra, which were recorded, for reasons of comparison. In Fig. 8 the ambient air level measured at the countryside in Wohlen, Switzerland is compared to ambient levels at our test centres in Birr, Switzerland and Lincoln, England, respectively. The peak in the Swiss ambient air is at similar size as Diesel exhaust and wood firing. The spectrum recorded in an industry resort in England is shifted towards smaller sizes and reflects more the particle size distribution of gasoline cars.

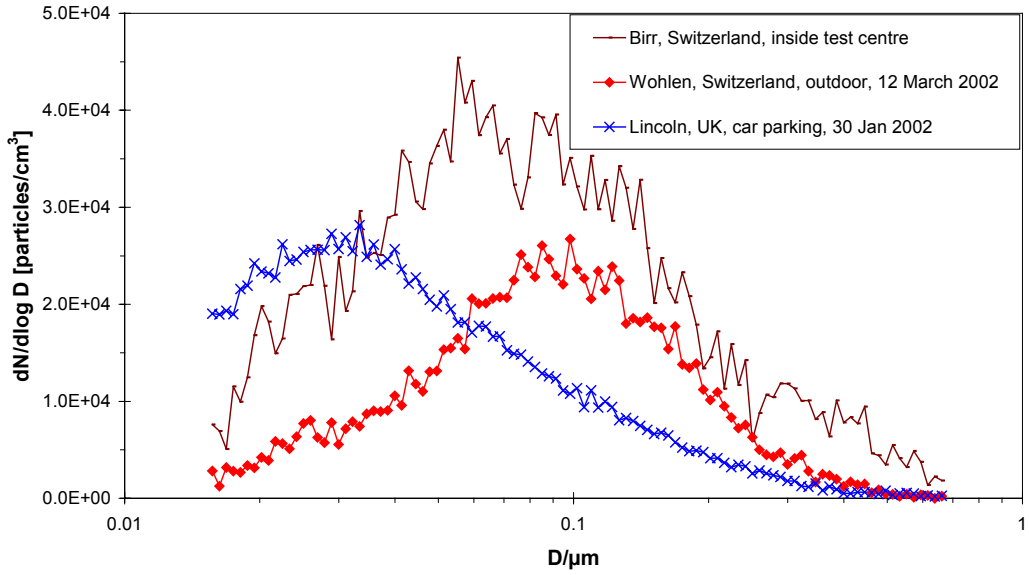

Fig. 8: Ambient air spectra at different sites.

Conversion to mass concentration

These different spectra were converted to mass size distributions and compared to the PM10 measurements of nearby official stations. This comparison is illustrated in Fig. 9, in which the spectrum of coarser particles up to 10µm is also taken into account.

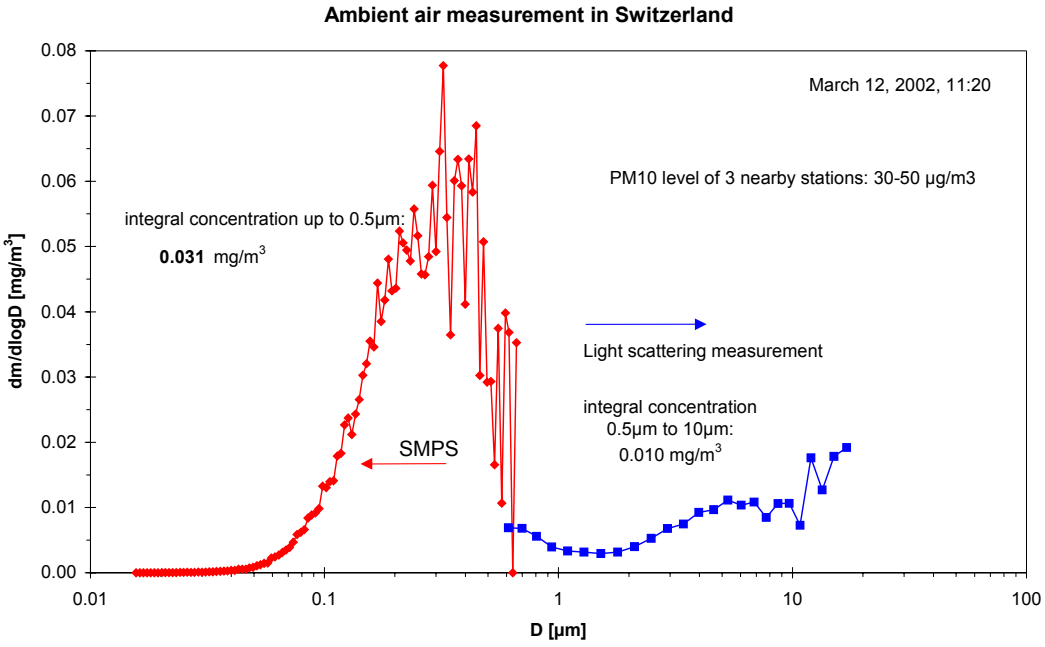

Fig. 9: Mass concentration calculated from simultaneously recorded SMPS and optical particle counter spectra of ambient air.

Particles above 0.6µm were detected with an optical particle counter. The simple assumption of spherical particles of density 1g/cm^3 results in a good agreement of the calculated total mass with the actual PM10 levels measured at three nearby stations: The calculated particle mass is 31µg/m^3 below 0.5µm, and 10µg/m^3 between 0.5µm and 10µm. The sum is 41µg/m3, whereas the neighboured stations measured total PM10 concentrations between 30µg/m^3 and 50µg/m^3.

For the comparison with official PM10 measurements in England only an SMPS spectrum is available. The conversion of the SMPS data to a mass size distribution results in an integral concentration of 15µg/m^3 for particles below 0.5µm. PM10 levels at two nearby stations were 10µg/m^3 hourly average during the tests, and 13µg/m^3 to 15µg/m^3 day average. The latter comparison gives also a reasonable agreement with a slight tendency that the SMPS data conversion overestimates the mass concentration.

Finally, the mass emission of the oil-fired GT26 can be calculated in a similar way as for the imission data. The resulting mass concentration is compared to the measured ambient levels in Switzerland and England in Fig. 10. The ultrafine emissions of the turbine are as low as 0.7µg/m^3 for oil firing.

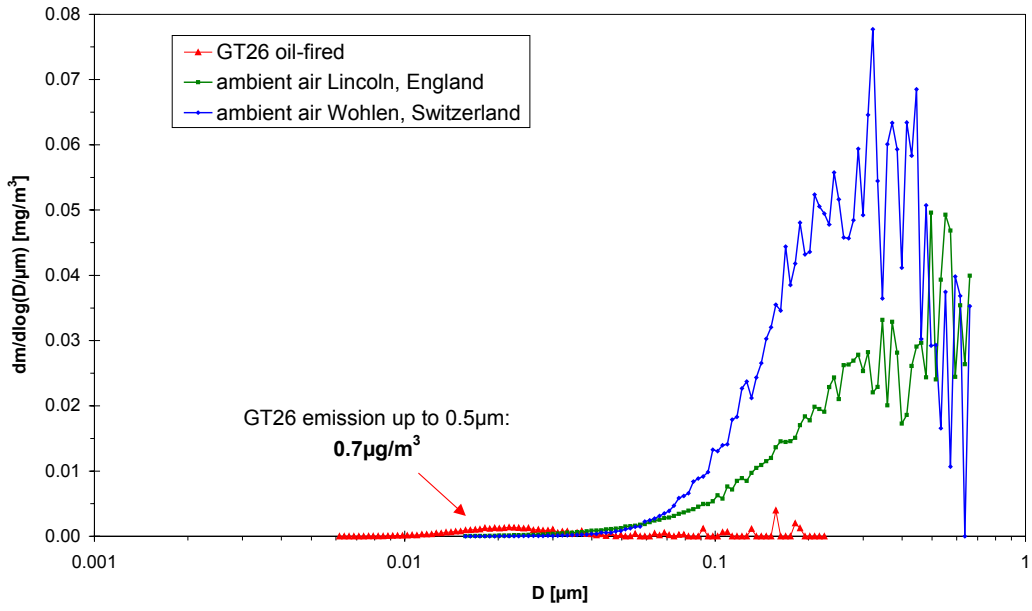

Fig. 10: Mass concentration resulting from the ultrafine peak during oil operation compared to ambient air levels.

Summary and conclusions

The ultrafine particle emissions of the Alstom GT26 turbine were characterized for both oil and gas operation at different load conditions. No noticeable emissions were detected during operation with natural gas. Moreover, the ultrafine particle concentration in the exhaust was significantly lower than in ambient air, measured at different sites. This can be explained, since many ambient aerosols around 100nm in size originate from incomplete combustion in other sources, and consist, therefore, of carbon and hydrocarbons. This material can be post-combusted at the high temperatures inside the turbine. In this way soot is burned-off from the ambient air, and the resulting exhaust gas contains less ultrafine particles than the environment, in densely populated countries. No detectable soot-formation at all takes place during gas operation.

Small amounts of ultrafine particles were emitted during oil firing of the turbine. They form a peak at about 15-20nm in size and can be attributed to primary soot particles. Unlike in many other combustion processes, their concentration is so low, that no larger particles (chains of primaries) are formed by agglomeration. The emissions come closest to small household oil burners, which emit a bit higher concentrations at slightly smaller sizes. The particle mass in the ultrafine peak at GT26 full load can be estimated to be less than 1µg/m^3. This is 4 orders of magnitude below the requested guarantee levels (≈10mg/m^3), and only a minor contribution to the total PM10 particle mass already present in ambient air (typically10-50µg/m^3). The very low levels in the sub-micron range indicate that these particles – which are generally considered as most dangerous for human health – give a negligible contribution to any total PM10 emissions of the GT26.

In an overall comparison between ultrafine particle concentrations of various combustion processes the measured gas turbine emissions are at the lowest end. This is summarized in Fig. 11, which also contains a measurement at a large coal fired power station. Based on a pure number concentration of sub-micron particles, the largest emitters are wood fires, and Diesel engines without particle traps. The emissions of a coal power station are already 1-2 orders of magnitude less, even when a difficult coal for the flue gas cleaning is fired. A further order of magnitude lower is the emission of the GT26 with oil firing. The by far lowest concentrations are reached with the gas fired GT26, with emissions well below ambient concentrations.

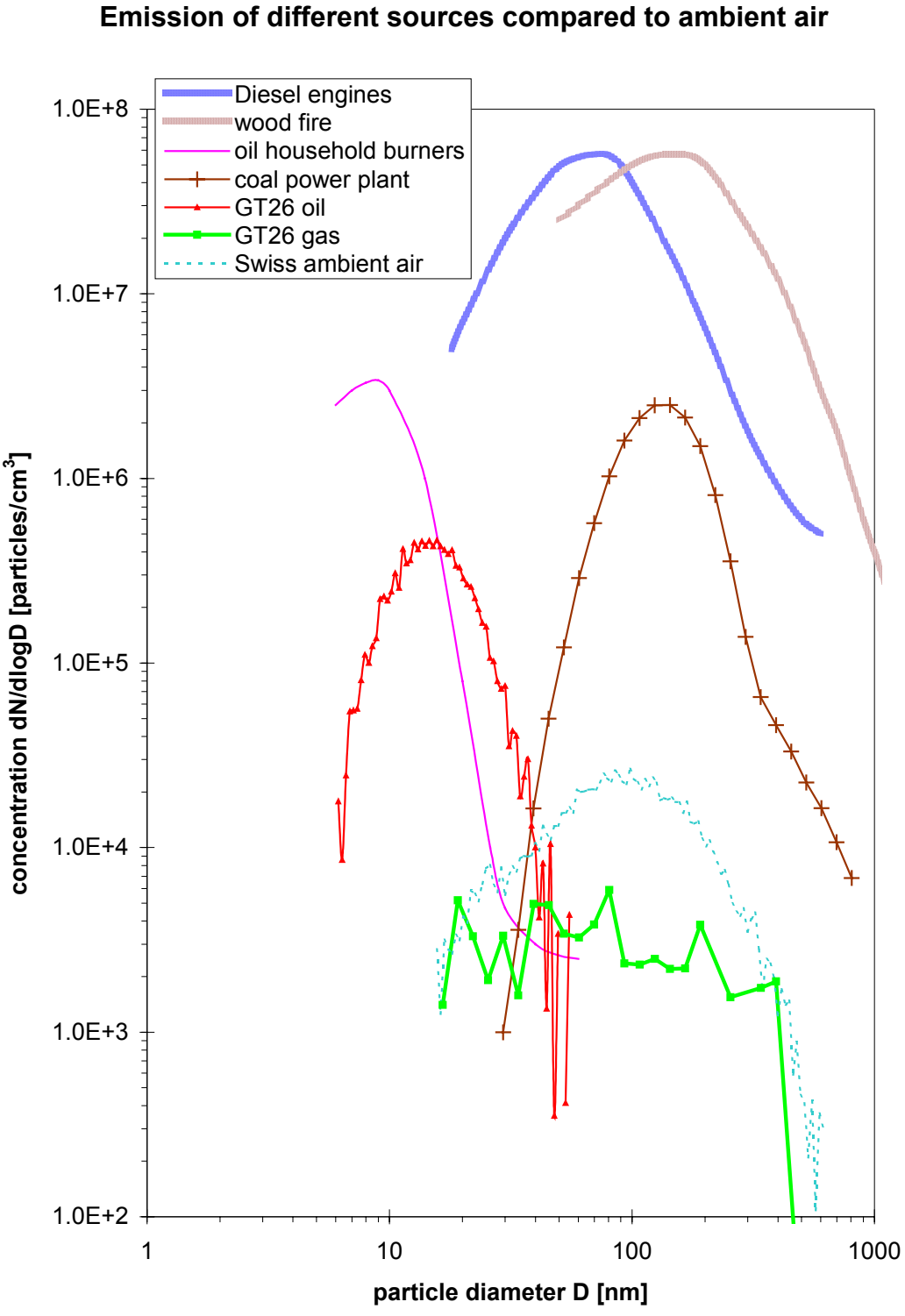

Fig. 11: Comparison of gas turbine emissions (this work) with other sources and ambient air. Data for wood, Diesel and household burners are adopted from Ref. [2], see also Fig. 7. The coal data refer to a large power plant of 600MW and were recorded after the flue gas cleaning (ESP) for a difficult coal [3].

In can be concluded that sub-micron particles do not result in GT26 emissions that are detectable with gravimetrical sampling methods in the exhaust.

A complete comparison between PM10 limits and the measured emissions needs to take the light scattering data (0.5µm to 20µm size range) into account. This subject is beyond the scope of a conference on nanoparticles and will be covered in another forthcoming paper.

References

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Acknowledgement

The contribution of Thomas Mosimann from Matter Engineering in the evaluation phase and the measurement of ambient air spectra is gratefully acknowledged.