ON-LINE PARTICLE EMISSION ANALYSIS OF THE CAST BURNER USING LPME

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ABSTRACT

The soot emission of the CAST (combustion aerosol standard) burner is analyzed and compared to the particle emission of modern diesel engines. The emitted particulate matter is investigated using the multi-wavelength extinction particle analyzer LPME (long path multi-wavelength extinction). The measured data give a better understanding of the CAST burner´s characteristic. Under most operational conditions, the emitted CAST particles are similar to diesel soot emission.

INTRODUCTION

There is a long-standing interest for a soot particle standard for the calibration of particle analyzing instruments. The Jing-CAST burner is intended to serve as a standard soot generator as it is claimed to deliver soot particles similar to those in the exhaust gas of diesel engines. This article presents the systematic aerosol measurements of the CAST emission under different operational points. The data are compared to previously gained data in the exhaust gas of modern diesel engines.

MAIN SECTION

CAST - The Jing-CAST burner, fig. 1, is a co-flow diffusion flame where gaseous fuels are used [1]. The stream of combustion air concentrically surrounds the steady state gaseous fuel flow, which can be pre-diluted by nitrogen. A circular truncated steel cone wraps the diffusion flame. The flame can be quenched by nitrogen at adjustable flame heights thus generating incomplete combustion. The exhaust gas flow may be diluted in the outlet.

LPME - The generated soot aerosol is analyzed in-line/on-line in the untreated, hot exhaust gas by the LPME. The optical spectral attenuation of three wavelengths is simultaneously monitored and the particle diameter and concentration are evaluated by the use of the Mie theory taking into account a log-normal size distribution. A heated, 1.86 m long measurement chamber where the exhaust gas flows, is used for the optical characterization, fig. 2.

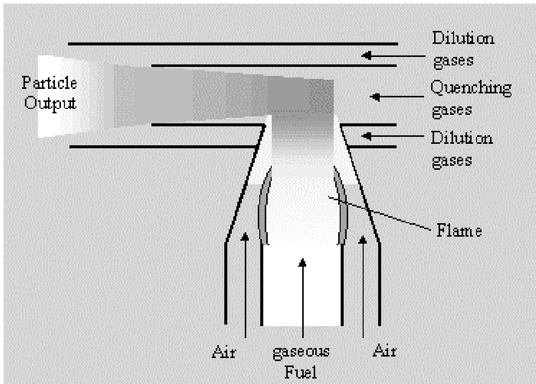

Fig. 1: Schematic of Jing-CAST burner [1]

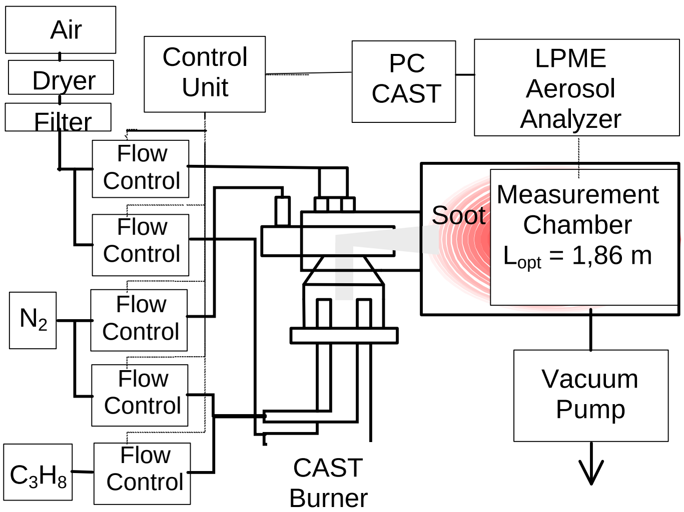

Fig. 2: Schematic of the measurement set up

The diesel soot measurements, which are taken for comparison and the measurement system LPME, are described earlier [2,3] and newest data are presented in the ICE 2003 [4]. Fig. 3 depicts the whole set up with the CAST burner and the LPME.

CAST burner

Measurement tube with flanged sensor heads of LPME

Fig. 3: View of the set up

MEASUREMENTS - The extinction technique measures in good approximation the primary particles of the fractal soot aggregates [2].

Systematic measurements have been performed to study the influence of the different adjustable parameters on the soot aerosol of CAST. A two-level factorial experimental design was used [5], taking into account each influencing factor, i. e. volume flows of N_2 for pre-diluting the fuel, of N_2 as quenching gas, of dilution air and the flame quenching height. Particle mean diameter and particle concentration measured by the optical multi-wavelength extinction are the system responses. With four varying parameters between their low and high levels, a matrix of $2^4 = 16$ experimental conditions had to be studied. Mass flows of propane and oxidation air were fixed for a stable combustion. Table 1 lists the investigated operation conditions of the CAST burner and table 2 the corresponding mean particle sizes and particle concentrations taken by LPME. The CAST operated very stable and repeatable due to the high precision flow controllers for combustion gas, pre-diluting gas nitrogen, quenching gas nitrogen, combustion and dilution air.

Experi-ment	N_2 fuel dilution	N_2 quen-ching	Dilution air	Quen-ching H
Number	l/min	l/min	l/min	mm
1	0	5	20	10
2	0,25	5	20	10
3	0	10	20	10
4	0,25	10	20	10
5	0	5	20	10
6	0,25	5	20	10
7	0	10	20	10
8	0,25	10	20	10

Table 1: Operation conditions of the CAST burner (extract)
Fixed data: Propane 0,06 l/min
Oxidation air 1,5 l/min
(Stochiometric factor l = 1,05)

Experi-ment	Mean particle diameter	Particle vo-lume concen-tration
Number	nm	10^{-6} m^3/m^3
1	17	0.21
2	36	0.09
3	15	0.19
4	15	0.07
5	45	0.20
6	47	0.16
7	48	0.20
8	30	0.18

Table 2: Soot particle emission data of the CAST burner examined by LPME (extract)

The parameters had different influences on the soot particle sizes and concentration. Figs. 4 and 5 show the statistically derived influence of diluting the gaseous fuel by nitrogen on the aerosol parameters (volumetric concentration and mean primary particle size), resulting from the two-level factorial technique [5]. The concentration decreases with a higher fuel dilution – a result, which is expected, fig. 4.

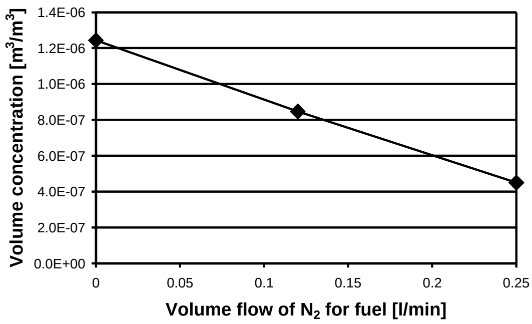

Fig. 4: Influence of fuel dilution by N_2 on particle concentration;
Fixed data: Propane 0,06 l/min
Oxidation air 1,5 l/min

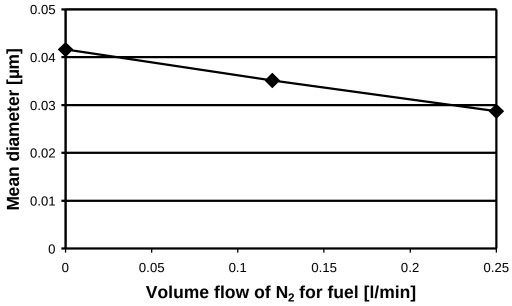

Fig. 5: Influence of fuel dilution by N_2 on mean particle diameter

With increasing dilution of the fuel before combustion, the mean diameter of the primary soot particles decreases slightly, fig. 5. This influence is marginal and may be within the statistical error. The effect will be investigated further. The particle diameters remain typically below 100 nm. This coincides with TEM pictures, fig. 6, gained from simultaneously collected particles in the exhaust gas of the CAST. Similar fractal particles with comparable primary particle sizes are found in the exhaust gas of diesel engines, e.g. [2]. The CAST particle emission, particularly the particle size, seems to react rather sensitive on parameter variations. In contrast, the size variation is much lower in the case of diesel engine emissions at different engine conditions [3, 4]. Typically, the LPME measures slightly lower primary particle sizes in the exhaust gas of diesel engines, e.g. in the range of approx. 20 to 50 nm [4]. Further investigations of the CAST burner are planned to exclude secondary influences and to gain a better understanding of its behavior.

The measured particle sizes by the multi-wavelength extinction technique differ appreciably to the sizes measured by differential mobility analyzer, which are documented in the handbook of the CAST burner [1]. This is also the case for diesel soot particles. The mobility size of the fractal soot is much larger than that of the primary particle. However, a fractal analysis can match the two different size definitions [2].

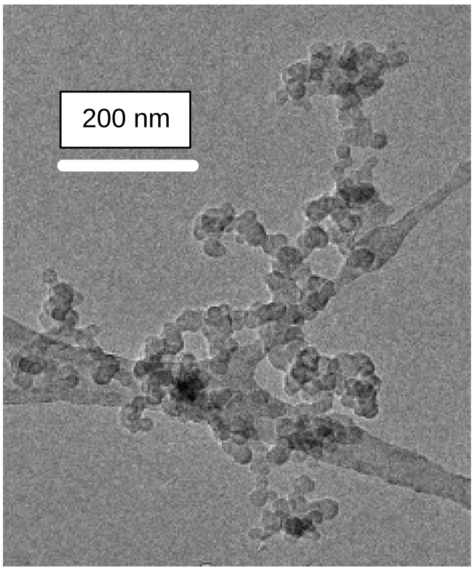

Fig. 6: TEM picture of fractal soot from CAST burner

N_2 fuel dilution	N_2 quen-ching	Dilution air	Quench ing H	Oxida-tion air	Sto-chio-metr.
l/min	l/min	15	mm	l/min	l
0	7,5	20	10	1,0	1,05

Table 3: CAST operation condition yielding soot particles in the size range 150 to 200 nm, measured by LPME
Propane 0,06 l/min

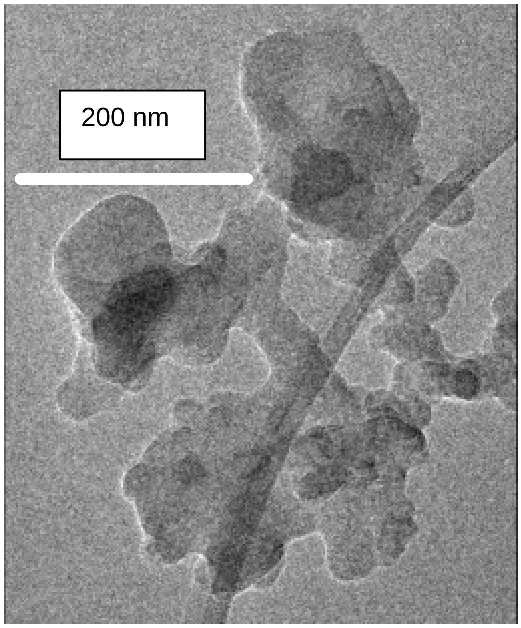

Fig. 7: TEM picture of “solid like” large soot particles from CAST burner

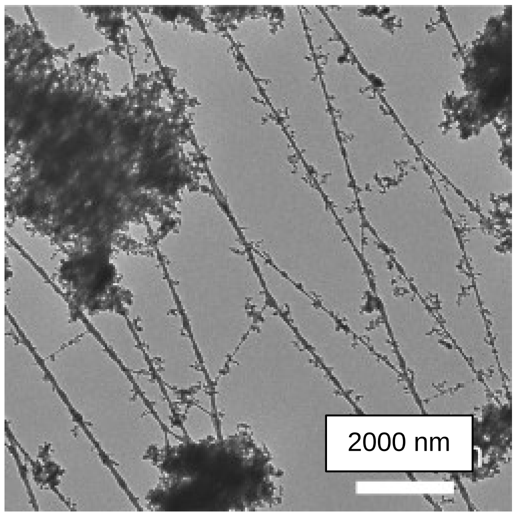

Fig. 8: TEM picture of large agglomerated soot particles from CAST burner

It must be noted that appreciably larger soot particles of 150 to 200 nm mean size were detected in the CAST emission under the operation condition in table 3 with insufficient combustion air by LPME. These large soot particles lost practically their fractal appearance and the individual particles are solid of amorpheous appearance as it can be seen in the TEM picture fig. 7. These particles are not aggregates of primary particles. The formation mechanism will be studied further. It is unlikely that these larger particles are formed by fused primary particles because these grown aggregates are also occasionally found in the aerosol, maybe detached from wall deposits, as shown in fig. 8.

The on-line measurement showed in the case of large solid soot particles unstable particle sizes, i.e. the detected mean sizes fluctuated between 150 and 250 nm during the measurements although the CAST operated in a steady state mode (fig. 9). This was in contrast to the other measurements of fractal soot where the mean diameter (primary particle size) remained rather constantly at approx. 50 nm. The on-line measurement display of fig. 9 depicts this effect: The CAST operation point which delivers large particles of 150 to 200 nm was switched after 200 seconds to the other condition which yield fractal soot particles of 50 nm mean size. The large particles did not appear in CAST operations with sufficient combustion air. Those large soot particles have not yet been detected in the emission of modern diesel engines perhaps due to their different combustion conditions with excess of combustion air.

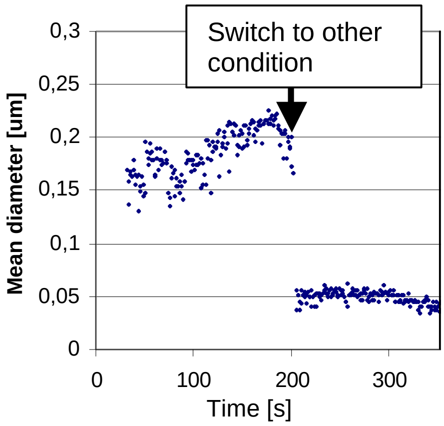

Fig. 9: LPME on-line measurement display of mean soot particle diameter

CONCLUSION

Under most operational conditions, the Jing-CAST burner emits fractal soot particles with primary particle, which are directly comparable to soot particle emissions of modern diesel engines. With insufficient combustion air, different soot morphology with particle sizes of approx. 150 to 200 nm has been detected in the CAST emission. These larger soot particles lost their fractal morphology to a far extend.

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ACRONYMS, ABBREVIATIONS

LPME	Long Path Multi-Wavelength Extinction Particle Analyzer
CAST	Combustion Aerosol Standard
DEXA	Diesel Exhaust Aftertreatment Cluster; EU project