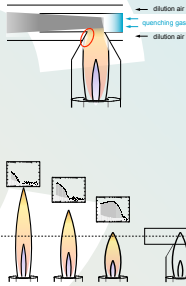


# CAST - Combustion Aerosol Standard: Principle and New Applications

Markus Kasper  
Matter Engineering, Wohlen, Suisse

## Motivation & Principle interrupted laminar diffusion flame

- unlike calibration gases, aerosols cannot be stored because the particle number concentration and average diameter are unstable (due to coagulation, diffusion, sedimentation)
- therefore, a calibration aerosol must be produced instantaneously by a stationary, reproducible process
- produce particles with a laminar diffusion flame
- blow out flame continuously to quench oxidation reactions and extract soot particles
- special burner design prevents soot from being deposited in crucial areas and keeps particle output stable within 5%
- vary virtual height of flame to obtain different particle diameters



## CAST 2 New Features

- closed combustion chamber
  - up to 300 mbar (planned: 500 mbar)
  - constant absolute pressure for calibration applications
- ambient air for combustion/oxidation
  - best defined O<sub>2</sub>/N<sub>2</sub> ratio
  - dried and filtered
- soot output directly or via MD19 diluter
  - MD19: 0–4 L/min at 1:20...1:400 dilution ratio
  - direct: 1–30 L/min against 300 mbar

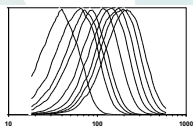
## The Second Generation

- gas flows of fuel and oxidation gas: variable particle size in range 30–200 nm
- carbonaceous soot particles (mainly EC) from fossil fuel combustion
- particle size and concentration stable within 5%
- variable particle size (30 / 60 / 85 / 110 / 140 / 200 nm)
- output up to 400 mg/m<sup>3</sup> or 10<sup>9</sup> prt/cm<sup>3</sup> (depending on particle size)
- output flow 1 – 30 L/min against pressure of up to 300 mbar



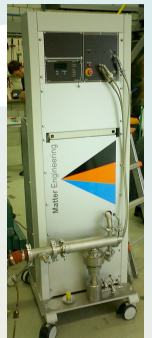
## Influence Parameters

- gas flows of fuel and oxidation gas: variable particle size in range 30–200 nm
- relative humidity of the oxidation air:
  - RH ↗: particle diameter ↘
  - RH ↗: number concentration ↗
- oxygen content of the oxidation air:
  - in compressed air systems, O<sub>2</sub>/N<sub>2</sub> ratio depends on oil content
  - oxidation of oil reduces O<sub>2</sub> content
- barometric pressure in combustion chamber
  - pressure ↗: particle diameter ↘, because flame is "shortened" by pressure



## Derivatives HiVol – LiqF – HiMass

- liqF CAST (lab version)
  - use diesel or gasoline as fuel
  - optional equipment for CAST
- HiMass CAST (concept)
  - high soot mass output (120 g/h)
  - use with liquid fuel, e.g., diesel+additive
- HiVol CAST (prototype)
  - volume flow up to 1500 NL/min
  - mass output up to 2 g/m<sup>3</sup>
  - calibrate entire CVS system



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Markus Kasper, Matter Engineering, Wohlen CH

## Background

The recently much increased interest in particle emissions and ambient particle pollution has led to a widespread use of measurement methods which in the past were operated only in detached laboratory applications. With widespread use the demand for harmonised and traceably calibrated methods grows in order to ensure comparability and reliability of the measurements. This can only be accomplished with a commonly accepted calibration aerosol.

Unlike gases, aerosols cannot be stored. Coagulation and sedimentation of the particles cause losses in terms of particle number, surface and mass, while the mean particle diameter in the aerosol sample increases. Therefore, the calibration procedure known from gas analysers using bottled calibration gases is not a viable route for particle instruments. The solution is to produce particles instantaneously in a continuous process in a well-controlled particle generator with sufficient reproducibility.

Especially for emission measurement a calibration aerosol should have properties very similar to the particles under test. Particles from salt nebulisers have the "wrong" chemistry; mechanically generated particles are at least about 1 micrometer in diameter due to the strong surface forces that make smaller particles stick with each other or with any other surface. On the other hand, flames from carbonaceous fuel combustion are common sources of soot particles that fulfil the most important requirements to a calibration aerosol with near-real properties.

## CAST Principles

CAST is based on the principle of a laminar propane co-flow diffusion flame. A diffusion flame produces a large number of soot particles inside the combustion zone. They are heated to high temperatures by the numerous oxidation reactions in the flame, hence its yellow colour. Outside the flame, little or no soot particles can be found because they are burnt when crossing the oxidising layer at the surface of the flame. The soot particles can only be released from the flame by quenching the combustion process by rapid cooling or with inert gas. The latter corresponds to continuous blowing the flame at a certain height below its tip. Quenching interrupts the chemical reactions in the flame and "freezes" the particles in a certain state that corresponds to the moment in which the combustion process was interrupted.

Particle inception and growth in a diffusion flame occur along the vertical axis of the flame. Early in the combustion process - i.e. low in the flame -, small soot nuclei are formed, which quickly grow to larger primary particles. As the number density of the primary particles is very high in that zone, particles growth additionally by coagulating with other primaries. If the cut-point of the quenching process is chosen at a low position in the flame, the resulting particles have small diameters; accordingly, a high quenching position will produce large particles. Thus the size of the soot particles extracted from the flame can be varied by changing the quenching position along the flame axis.

The CAST burner has a fixed geometry, and changing the quenching position would imply moving mechanical parts. Alternatively, the gas flows producing the flame - i.e. the fuel gas and the oxidation air - can be varied to simulate flames of varying total height that are each quenched at the same geometric position. In CAST, high gas volume flows will produce a high flame which will yield small particles, while low gas flows and a small flame will produce large particles.

A common problem with flame based particle generators is the uncontrolled deposition of soot in places that disturb the flow field of the flame. Such accumulations gradually alter the combustion pattern and result in a drift of the particle propert-

ies and thus limit stability and repeatability of particle generation. The CAST burner circumvents this problem by ensuring a sheath air flow along each sensitive wall element of the burner, such that no soot particles reach the walls and precipitate there.

## Influence Parameters

Due to its rigid and precise control elements, CAST is able to provide a particle output that is stable and reproducible within 5% both in terms of particle mobility diameter and number concentration. Developed in cooperation with the Swiss Federal Office of Metrology and Accreditation (METAS), CAST has the potential to become a primary calibration instrument for particles.

Stability of CAST has been demonstrated in connection with a number of instruments such as AVL Smoke-Meter, Dekati Mass Monitor (DMM), Esytec Laser Induced Incandescence Soot Analyser (LI<sup>2</sup>SA) and numerous other methods (e.g., within PMP).

In some cases, problems have been reported concerning the particle diameter which at some operation points deviated by several 10 nm from the value calibrated by METAS. In a subsequent evaluation programme, all possible influence parameters were varied to quantify their effect on particle properties:

- relative humidity of the oxidation air
- oil content of the oxidation air (when taken from a compressed air system)
- oxygen content of the oxidation air
- barometric pressure at which the flame is operated

The findings of this evaluation programme have led to a redesign of CAST with some major improvements.

## New Features and Outlook

The main novelty of the second generation CAST is a closed combustion chamber that can be operated at elevated relative pressure. For calibration applications, the combustion chamber will be operated at constant absolute pressure which will exclude barometric pressure as a potential error source and will thereby make CAST a transportable particle standard. Furthermore, CAST can now be used in filter development and testing applications where soot production against the back-pressure of a DPF is required.

Oxidation air for fuel combustion is now taken from ambient air. Synthetic air was found to vary too strongly in O<sub>2</sub> content to ensure stable combustion conditions; and when using compressed air, the oil that is fed into the supply system tends to reduce the O<sub>2</sub> content to a rather unpredictable extent, again compromising flame stability. In ambient air the N<sub>2</sub>/O<sub>2</sub> ratio is most stable, and if filtered and dried, it provides the most reliable and reproducible oxidation gas and thus constant and reproducible particle output.

The CAST principle is being extended to new applications. A long-standing wish has been the use of liquid fuels, especially gasoline and diesel, and also diesel containing additives/FBCs (fuel borne catalysts); this is realised in the liqF-CAST prototype. The HiVol-CAST is an up-scaled version with soot emissions and exhaust gas flow comparable to a passenger car; the first unit will be used to calibrate an entire CVS system. Finally, a HiMass version with soot output of 120 g/h is under consideration.

## Contact / More Information

Matter Engineering, Wohlen, Switzerland  
www.matter-engineering.com  
T +41 56 618 66 30  
info@matter-engineering.com

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