Measurement of soot in atmospheric and low pressure flames with a novel particle mass spectrometer

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The formation and growth of soot particles in flames are difficult to measure since the surrounding gas is highly reactive, the particle size is in the range of a few nanometers and the particle concentrations are higher than 10^{10} cm^{-3}.

Soot particle sizing methods involve (a) sampling and off-line analysis like transmission electron microscopy (TEM), (b) sampling and on-line analysis like mobility analyzers (SMPS) which require high sample dilution or, (c) non-intrusive methods like light scattering and extinction or laser-induced incandescence (LII). Often, preference is given to the non-intrusive optical methods, but they are associated with averaging over the particle size distribution rather than resolving it.

In this study, soot formation was measured in low and atmospheric pressure flames with a novel particle mass spectrometer (PMS).

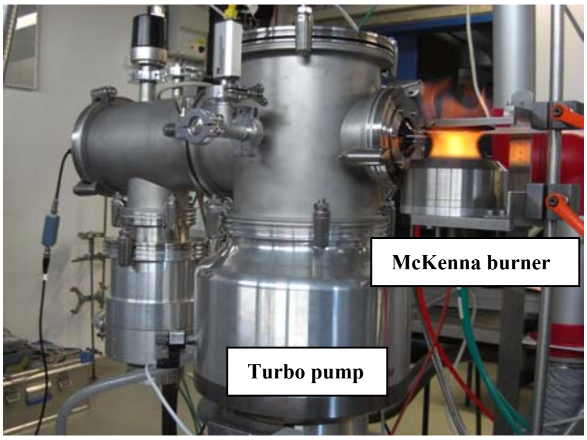

Figure 1. Particle mass spectrometer (ATMO-PMS)

The PMS has a two stage molecular beam sampling system which allows a probing inside of the flame. Due to the supercritical expansion in the molecular beam, the incoming gas is quenched down very quickly and all interactions between the particles or between particles and gas molecules are blocked within the shortest possible time. Behind the two stage inlet system, the particles pass a capacitor with variable electric field and the charged particle fraction is separated according to the polarity and to the ratio of kinetic energy to charge. The charged particles are collected at faraday cups and the resulting intensity is proportional to the number concentration. The particle velocity is measured simultaneously and allows to derive the mass and size spectra from the m/z spectrum with the assumption of single charge (z = 1) and with the known material density.

Soot particles were generated in laminar, flat premixed acetylene or ethylene / air flames burning at low (25 mbar) and ambient pressure. The McKenna burner consists of an inner cylindrical chamber of 7.5 cm in diameter with a water-cooled sintered bronze plate and around this plate there is an outer concentric annulus for sheet gas to stabilise the flame. Both positively and negatively charged soot particles with diameters between 2 and 10 nm were detected and their growth along the flame axis for different C/O ratios was measured. At low pressure, the soot particles show charge distributions with three peaks, while at ambient pressure four to five peaks appear which are partly overlap (Fig. 2). Under the assumption that peak 1 is induced from single charged and the other peaks from higher charged particles, we calculate a mean particle diameter of 7 nm which is comparable to Maricq (2003) measured with SMPS.

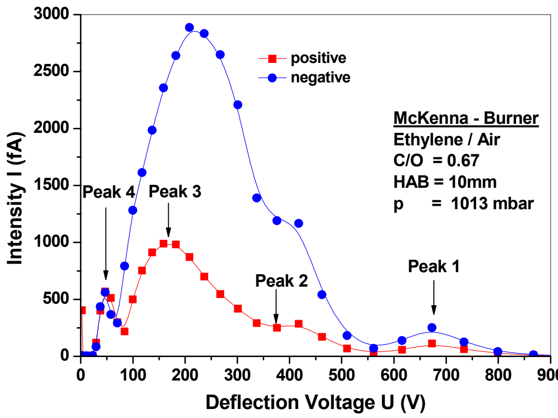

Figure 2. Charge distribution of soot particles in ambient ethylene / air flame

The absolute particle mass was detected with a quartz crystal microbalance (QCM) installed in the molecular beam and by deflection of the charged particles with a capacitor it is possible to measure the ratio of charged to uncharged particles. The results of measurements in the atmospheric flames show that up to 40 % of the soot particles are charged.

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