Laserinduced photofragmentation fluorescence of alkali-chlorides in flames

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Abstract

Environmental issues and overall efforts to achieve a sustainable energy supply require power plant operators to increasingly consider utilization of biomass fuels. However, many such fuels result in production of alkali chlorides such as potassium- and sodium-chloride (KCl and NaCl) during combustion in power plant boilers. Alkali chlorides are key components for slagging and fouling in power plant boilers and also affect heat exchange surfaces. In addition, chlorine exposure increases the risk of corrosion on furnace walls, super heaters, and economizers. Minimizing alakali-cloride problems will thus increase operational time, improve steam data, and reduce maintenance costs.

While problems related to alkali chlorides can be avoided using fuels with low content of alkali and chlorine, addition of sulphur compounds allows for reduction of the gas-phase alkali to potassium sulphate (K_2SO_4), which is less harmful. This can be achieved either by co-combustion with a sulphur-containing fuel or injection of sulphate-containing additives to the flue gas. Optimum reduction of alkali-chlorides requires detailed understanding of this process which can be achieved from studies in laboratory flames under well-controlled conditions.

Laser-based techniques provide non-invasive species-specific probing with high temporal and spatial resolution for detailed studies of combustion processes. The laserinduced fluorescence technique also permits for two-dimensional imaging of species distributions. Alkali chlorides can be detected by means of photo-fragmentation fluorescence based on photodissciation of alakali compounds into atomic fragments and detection of fluorescence from the excited alkali metal atom.

Potassium chloride has been monitored using photo-fragmentation fluorescence imaging during combustion in the post-flame region of premixed laminar one-dimensional methane-air flames. An ArF Excimer laser (Lambda Physik) provided pulses at wavelength 193 nm for photodissociation of KCl. The laser had 50 ns pulse duration and output pulse energy achieved was 50 mJ. The 532 nm second harmonic of a Nd:YAG laser (Brilliant B, Quantel)

was used for Rayleigh scattering thermometry. The Nd:YAG laser had a pulse duration of 7 ns and the pulse energy at 532 nm was 120 mJ.

The 193 nm laser beam was focused into a 30 mm vertical sheet using cylindrical lenses of focal lengths f=+1000 mm and f=+500 mm. For Rayleigh scattering measurements the 532 nm beam was aligned into the beam path using a dichroic mirror and focused using cylindrical lenses of focal lengths f=-40 mm, f=+200 mm and f=+500 mm. The signals were detected with an intensified CCD camera (Princeton Instruments, PI-MAX I) equipped with an f=50 mm objective (Nikkor f/1.4). A bandpass filter transmitting 766 nm was used for measurements of K atom fluorescence and suppression of scattered laser radiation.

A modified absorption spectroscopy burner (Perkin Elmer) was used for measurements in alkali-seeded CH4-air flames. The burner consists of a water-cooled bronze mesh which allows for stabilization of flat laminar premixed flames on the burner. Premixed CH4 and air are supplied to the burner and a fraction of the air is led through a reservoir containing liquid KCl solution. The air and droplets are led to a nebulizer in which the droplets are reduced into a fine spray and then mixed with the CH4 and the rest of the air before the burner mesh. A nitrogen co-flow was supplied to the porous ring surrounding the burner mesh to shield the flame. A steel cylinder was mounted 30 mm above the burner for flame stabilization. The total gas flow to the burner was 5 l/min and the individual flows were controlled by mass flow controllers. Premixed CH4-air flames of equivalence ratios 0.8-1.3 were investigated and the KCl concentration in the seeding solution varied from 0.01 to 1.0 M.

Laser-induced photofragmentation fluorescence allows for imaging detection of alkali chlorides such as KCl with high sensitivity. The method can be employed for detailed studies of akalichloride formation in well-defined alkali-seeded laboratory flames, providing valuable information for understanding these processes and necessary for efficient use of biomass fuels in combustion. This has been exemplified in studies of flames seeded with KCl for which the impact of stoichiometry and ammonium sulphate additive has been investigated.