LII MEASUREMENTS OF SOOT PARTICLES PRODUCED BY FLUIDIZED BED COMBUSTION OF WOOD PELLETS

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Abstract

Soot formation is investigated at the exhaust of the fluidized bed combustor fed with wood pellets in different conditions of oxygen excess. Laser- Induced Incandescence measurements have been carried out at the exhaust and after at 0.5 μm filter. Particulate sampling has been performed for TEM analyses. The residual powder collected on the filter has been investigated by SEM technique.

Introduction

Biomass- and waste-derived fuels are considered as an attractive and sustainable energy source. In particular, the use of pelletized biomass has gained interest over recent years as it may enhance utilization of biogenic fuels from the standpoints of fuel storage, transportation and handling. However biomass furnaces exhibit relatively high emission of NO_x and particulates in comparison to furnaces with natural gas or oil. Measurements indicate that emissions of particulates is well above 50 $\mu g/m^3$ [1] containing both ash particles (>1 μm) and fine particles (<1 μm) [2]. Biomass combustion is a complex process and improvements in the combustion technologies are necessary. Fluidized bed combustion (FBC) represents one of the most viable technologies for the use of biogenic fuels, because nearly homogeneous conditions of temperature and concentrations can be achieved, thus enabling high burnout quality at excess air. In this work we present an investigation of the influence of the excess air on soot concentration and size at the exhaust of a fluidized bed combustor fed by wood pellets. The facility is available at the CNR-IRC laboratory in Naples. Two-colour time-resolved Laser-Induced Incandescence (LII) measurements have been carried out both directly at the chimney and after a 0.5 μm filter by using the optical device for LII measurements developed in the CNR-IENI laboratory in Milano. Parallel to the optical measurements, particle sampling has been performed for TEM analysis. Finally the residual powder collected on the filter has been also investigated with SEM technique.

Fluidized bed combustor apparatus

The experimental apparatus, Fig.1, consists of a cylindrical wind-box, a fluidized bed, an upper cylindrical section, a heat recovery system, a fuel particle feeding device, a particulate collection system, a set of gas analyzers and a data acquisition system. A detailed description of the apparatus is reported elsewhere [1].

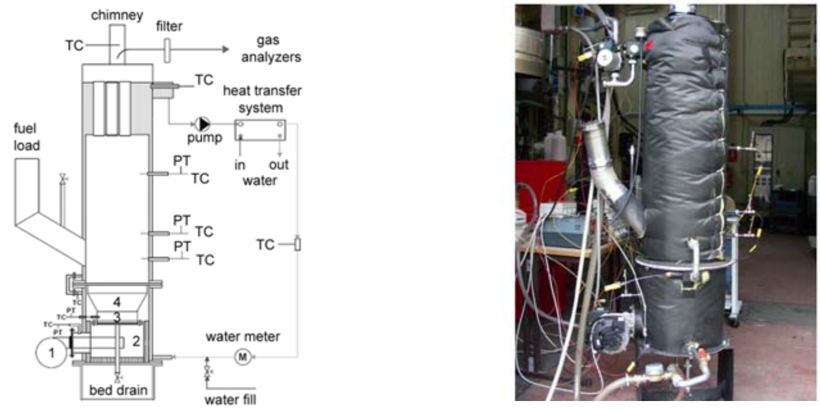


Figure 1. Schematic representation and an image of the fluidized bed boiler. 1) gas burner; 2) wind-box; 3) fluidizing gas distributor plate; 4) fluidized bed. PT: pressure transducer, TC: Thermocouple.

Composition of the exhaust gas is measured by on-line sampling carried out with a heated probe connected to a set of continuous gas analyzers for measuring O_2, CO, CO_2, NOx, SO_2 and Total Organic Carbon. Thermocouples, typically K-type, and high-precision piezo-resistive gas pressure transducers have been adopted to measure the temperature and the gas pressure along the fluidization column. The data acquisition system consists of a PC equipped with an A/D converter (National Instruments cDAQ 9172). The system is able to acquire the electrical signals coming from pressure transducers, thermocouples and gas analyzers.

Table 1. Proximate and ultimate analysis of wood pellets.

Fuel	Wood Pellets
Proximate Analysis, wt % (as received)	
Moisture	8.0
Volatile Matter	74.2
Ash	0.4
Fixed Carbon	17.4
Ultimate Analysis, wt % (dry basis)	
Carbon	50.4
Hydrogen	6.1
Nitrogen	0.1
Sulphur	0.1
Ash	0.4
Oxygen (by difference)	42.7
Lower Heating Value (MJ/kg)	18.24

Quartzite sand sieved in size range 600-850 μm (Umf=0.455m/s @ 293 K and 101 kPa) has been used in the experiments with a bed inventory kept constant at a value of 4 kg. The fuel consists of wood pellets (cylindrical shape, 6 mm OD) whose proprieties are reported in Table 1.

Laser-Induced Incandescence experimental set-up

For LII measurements, soot is sampled at the exhaust of the fluidized bed combustor and piped in the test cell for the analysis. The test cell consists of a 20 cm long (6.75 mm ID) pyrex tube having proper accesses for gases and two windows for the laser beam. The IR beam of a Nd:YAG laser (Quantel, Big Sky CFR 200, 30 Hz) is steered by two prisms and coaxially aligned within the tube. A diaphragm (4.5 mm diameter) limits the laser-beam diameter in order to avoid scattering from the tube walls along the whole tube length. A Gentec Beamage Focus I is used to check the beam intensity distribution. The LII signal is properly detected through a rectangular to circular fused silica fiber bundle (Oriel 77539). The circular aperture is coupled by a small collimating lens (Oriel 77644) to a system of optical blocks (Hamamatsu) containing a short pass filter (CVI, $\lambda < 850$ nm), a dichroic mirror (660 nm) and two optical arms. In each arm a bandpass filter and a PMT module (Hamamatsu H5783-20) are allocated. The investigated spectral regions are: 530nm with $\Delta\lambda = 40$ nm (FWHM) and 700 nm with $\Delta\lambda = 60$ nm (FWHM). A digital oscilloscope (Agilent Technologies, MS06104A, 1 GHz, 4 GSa/s), triggered by the laser Q-switch pulse, is used for data acquisition and storage. Each signal results from an average of 128 laser pulses. The two-color LII digital signals are processed by MATHCAD in order to determine the temporal decay and the “prompt” value, defined as the average value on a 4 ns interval around the maximum of the LII curve [3].

Soot sampling has been carried out directly at the chimney and after a 0.5 μm filter in the following experimental conditions: 5%, 6.5%, 7% and 8% excess oxygen.

As for TEM measurements, sampling are performed soon after and before the particulate filter. To this purpose the typical TEM grid (Cu with carbon film, ϕ = 3 mm, TAAB) is used and properly positioned along the probing tube. Particulate samples are then analyzed with a Transmission Electron Microscope (TEM, Jeol Jem 2000 FXII).

As a further investigation, the residual powder collected inside the filter after one set of measurements is analyzed in terms of morphology by using a Scanning Electron Microscope STEREOSCAN 430 (LEO).

Results

Each time-decay incandescence signal is obtained with an average over 128 curves. Being the laser running at 6 Hz, this means that each acquisition is taken every 20 s. The resulting signal is then subtracted for the background, that is evaluated with nitrogen flowing in the sampling probe. According to the LII modeling, the

peak of the incandescence signal is proportional to the soot volume fraction and the signal decay time to the primary particle diameter.
In order to derive quantitative measurements, as for the soot concentration a calibration procedure has been performed by using a calibrated lamp. The evaluation of the particle size is obtained by using LII modeling to fit the time-resolved incandescence signal [4]. To this purpose, LII modeling available at a web interface (http://www.liisim.com) has been applied.
In Fig. 2 the trend of soot concentration (ppb) versus the oxygen excess is reported for the two wavelengths for measurements at the exhaust (on the left) and after the filter (on the right). Error bars are also shown on the curves.

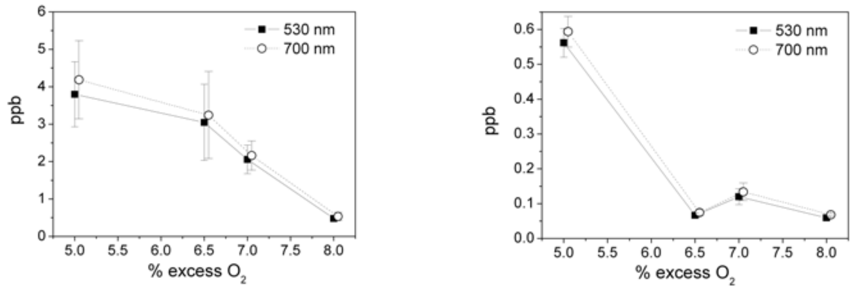


Figure 2. Soot particle concentration in ppb as a function of the oxygen excess. Measurements carried out at the exhaust (left) and after the filter (right).

Comparing the graphs, it can be observed that soot concentration at the exhaust results to be about an order of magnitude higher than the values after the filter.
Moreover, in both cases, by decreasing the percentage of oxygen excess a significant increase of the soot concentration is observed.
In Fig. 3 the primary particle diameter (dp) are reported as a function of the oxygen excess again for sampling at the exhaust and after the filter. The two sets of curves refer to measurements obtained with the two wavelengths. Even in this case error bars are reported.

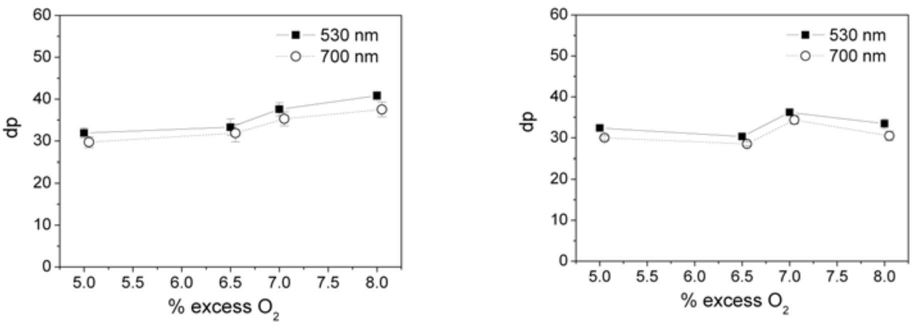


Figure 3. Soot particle diameter versus oxygen excess. Measurements carried out at the exhaust (left) and after the filter (right).

While for measurements after the filter the values of dp are independent of the oxygen content, for measurements at the exhaust a slight increase of soot size with oxygen excess is detected. Anyway, in both cases (at the exhaust and after the filter) almost the same values of the particle diameter are obtained. These observation allow to infer that, while soot volume fraction decreases using the filter, no substantial differences are observed for the primary particle diameter. In order to gain more insight in the morphology of soot particulate at the exhaust of the fluidized bed combustor, particle sampling and subsequent TEM analysis have been carried out both directly at the exhaust and after the 0.5 μm filter. In Fig. 4 typical micrographs of the soot particulate collected in the two positions are shown. By comparing the two structures reported in the figure, no substantial differences are evident: soot aggregate is almost ramified, with similar primary particle diameter.

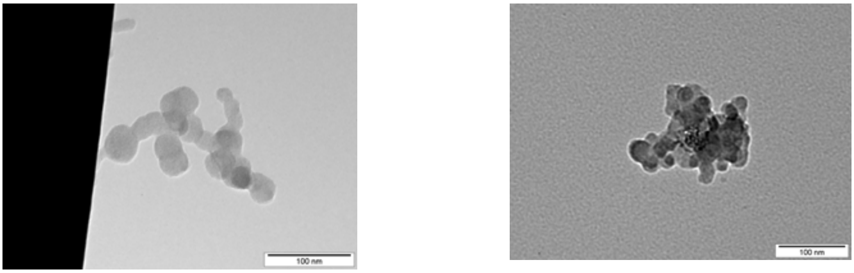


Figure 4. TEM images of sampling collected at the exhaust (left) and after the filter (right).

Concerning the analysis performed at the exhaust, looking more in detail the grid, several non defined complex structures have been observed as shown in Fig. 5. These structures are large, very dense and seem to be completely covered by spherical particles that are very similar to soot particles in term of dimension and shape.

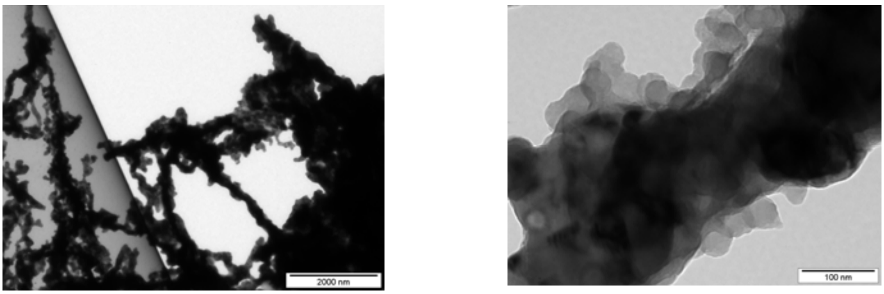
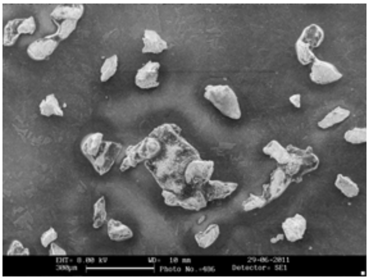


Figure 5. TEM images of sampling collected at the exhaust.

From the 0.5 μm filter some powder has been collected and analyzed in term of morphology by SEM analysis. As can be seen in Fig. 6 the size of the powder varies from 100 to 200 μm. The structure is very irregular and it can been observed a fibrous matrix that is similar to that of wooden material probably related to unburned pellets.



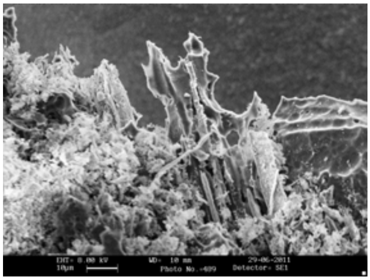


Figure 6. SEM images of powder collected on the 0.5 μm filter.

LII measurements and TEM/SEM analyses allow to derive a consistent description of soot formation at the exhaust of the fluidized bed combustor under study. Clusters of soot particles with 30 nm diameter are formed. The effect of the filter is only to reduce the total soot concentration as residues of unburned pellet stop particles even with small diameter.

Conclusions

Soot formation at the exhaust of a fluidized bed combustor has been investigated by applying LII measurements and ex-situ TEM/SEM analyses. Increasing oxygen content a decrease of soot concentration is detected while the particles diameter remains almost constant. Due to the presence in the filter of the unburned pellets, the effect of the filter at the exhaust is only the reduction of the soot concentration.

Acknowledgements

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