Light Absorbing Aerosols within Intense Laser Beams: Optical Effects, Morphology, and Composition

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Summary

Aerosols exist everywhere in Earth's atmosphere; they have unique composition, morphology, and exhibit special physical properties. This series of experiments measures the effects of laser illumination on different types of light absorbing aerosols, including particles from burning incense and soot. Ammonium sulfate is tested as a comparative measurement. Size distribution of aerosols with and without laser illumination are measured through use of an electrostatic classifier and particle counter. When illuminated by a laser, both soot and incense samples showed a significant drop in particle diameter, while ammonium sulfate particles remained unchanged. Thermogravimetric analysis (TGA) was used to measure the volatility of the samples with temperature. It was found the soot produced by a kerosene lamp was relatively non-volatile until approx. 550 deg. Celsius when a rapid decrease in mass was noted. We believe the combustion of soot began to occur at this temperature. The incense aerosol appeared more liquid-like, with a gradual loss of mass at temperatures above 100 C.

This initial data suggests the liquid-like incense aerosol undergoes a gradual vaporization within the laser beam, while the fresh soot particles may split into primary spheres during irradiation. However, this has not been confirmed via electron microscopy analysis. These initial experiments also suggest removal of volatile materials through laser heating should be possible.

Instrument Setup

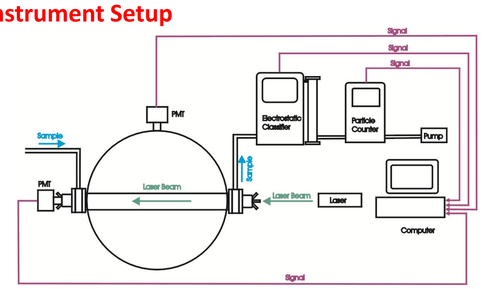
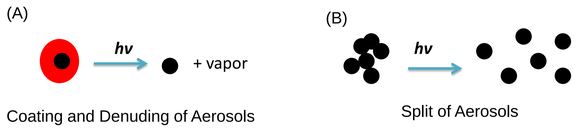


Figure 1. Instrument setup for size distribution and optical measurement.

Aerosol samples were generated by different methods. Three samples were measured: soot, incense aerosols and ammonium sulfate. Soot was generated by burning a kerosene lamp, while Incense aerosols were made by burning an incense stick in a chamber. Ammonium sulfate was generated from aqueous solution with an atomizer.

The laser beams were composed of both 532 and 1064nm wavelengths (Nd:YAG laser). Optical filters were used to select for a single wavelength when desired. The outlet of the illumination tube was connected to an electrostatic classifier and condensation particle counter. The electrostatic classifier selected particle sizes while the counter measured particle concentration.

Two Models for Particle Behavior During Laser Illumination



In model (A), absorbing aerosols are initially coated. Light absorption may cause coating evaporation, but particle number concentration should remain the same. In model (B), aerosols consist of primary particles linked to form aggregates; these particles break up during laser illumination. Particle number concentration will be significantly increased.

Light Absorbing Aerosols: Kerosene Soot

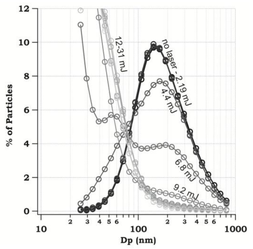


Figure 2. Size distribution of soot with and without laser illumination. This plot describes the percentage of particles (%) vs. particle diameter (Dp) for several laser powers. A clear shift to smaller diameters is noted.

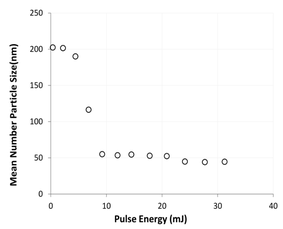


Figure 3. Mean number particle size vs. laser pulse energy. Pulse energy is the average energy emitted by the laser in one pulse.

Particle size distributions of illuminated soot for different laser powers is shown in figure 2. No difference among the curves can be observed when laser pulse energy was smaller than 2 mJ. The distribution started to change at 4.4 mJ indicating a decrease in diameter and a large increase in number concentration. When energy was larger than 12mJ, the distribution was shifted to almost exclusively <100 nm particles. Figure 3 shows a plot of the mean number diameter vs. laser pulse power. It is clear that particle size dropped quickly and then reached a steady value.

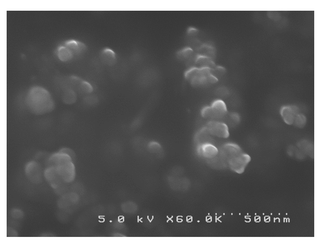


Figure 4. Scanning electron micrograph of kerosene soot without laser illumination. Aggregates of primary spheres are apparent.

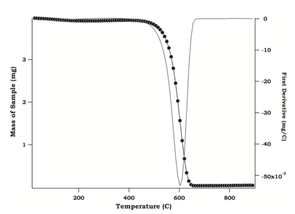


Figure 5. Thermogravimetric analysis (TGA) of soot. Operating temperature was set from 25 to 900℃. Analysis was conducted in air.

Scanning electron micrograph of kerosene soot without laser illumination is shown is figure 4. Soot is made up of small primary soot particles combining together. Size of these smaller primary particles is often about 50 nm.

TGA experiment in figure 5 show there was very little loss of mass before 550℃. Then mass of sample dropped quickly between 550 and 650 ℃. After this period, it was found that there was nothing left in crucible. The reaction between 550 and 650 ℃ may come from combustion of soot. Since there was very little mass loss prior to 550℃, the soot generated by the kerosene lamp appears to be almost completely uncoated.

Light Absorbing Aerosols: Incense Burning Aerosols

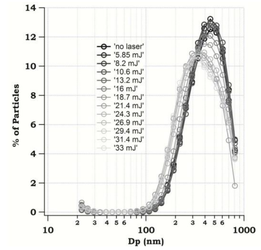


Figure 6. Size distribution of incense burning aerosols with and without laser illumination. This plot describes the percentage of concentration (%) vs. particle diameter (Dp) at several laser powers.

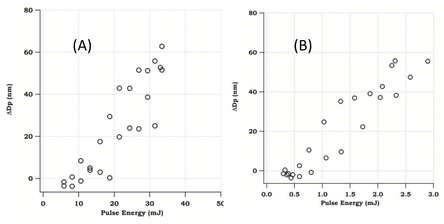


Figure 7. Decrease of mean number diameter (ΔDp) vs. pulse energy. (A) is illumination by 1064nm wavelength and (B) is illumination by 532nm wavelength. A and B are plots of change in particle size, a larger number refers to a more significant change and thus a smaller diameter.

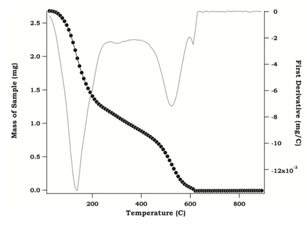


Figure 8. TGA of incense burning aerosols. Mass of sample changing with temperature is shown is this plot. Operating temperature is set from 25 to 900℃. Reactive gas is air.

Incense burning aerosols exhibited different behavior compared to soot. The size distribution of incense burning aerosols drifted to smaller size gradually when pulse energy increased from 0 to 33 mJ. Meanwhile, total change of diameter was much smaller than that of soot. Two different wavelengths (532 and 1064 nm) illustrated similar trends, but at differing pulse energies.

The number concentration of incense burning aerosols were unaffected by laser illumination. TGA experiments shown in figure 8 indicated incense aerosol began to lose mass through volatilization very early in the heating cycle (approx. 100 C). There are three significant peaks in the first derivative data. The first two peaks may result from evaporation of volatile compounds in incense. The third peak at around 650 ℃ appears to correspond to combustion of the refractory material in the crucible.

Comparative Analysis: Ammonium Sulfate

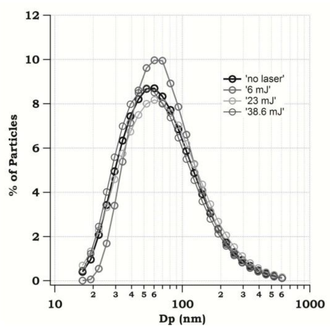


Figure 9. Size distribution of ammonium sulfate with and without laser illumination. This plot describes percentage of concentration (%) vs. particle diameter (Dp) for several laser powers ranging from 0 to 38.6 mJ.

Ammonium sulfate does not absorb light at either 532 or 1064 nm, so it is used as comparative analysis. Ammonium sulfate aerosol was produced with an atomizer and passed through a diffusion dryer. The relative humidity of the sample was kept at about 10%. The pulse energy of the laser was increased from 0 to 38.6 mJ. However, no patterns or differences were observed in size distribution data. These size distribution curves indicated that ammonium sulfate aerosols showed no change in particle diameter.

Conclusion

Three samples were measured in these experiments: soot, incense burning aerosols and ammonium sulfate. Both the soot and incense aerosols showed change of size distribution during laser illumination. Soot is generally composed of smaller primary particles, we believe these primary particles may break apart in the laser beam. Compared to soot, incense aerosols are composed of semi-volatile materials and a portion of this material seems to evaporate when illuminated by a laser beam. As a comparative test, ammonium sulfate did not absorb light and showed no change of particle size distribution when in laser beam.

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