Measurement of the Optical Properties of Volcanic Ash

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1 Abstract

We have just commenced a laboratory project, the "Optical Properties of Volcanic Ash". This project will measure volcanic ash aerosol extinction spectra and the aerosol particle size distribution. These measurements will allow the calculation of the aerosol cross section which is required in the analysis of IR satellite observations of ash clouds. Dry, water ice and sulphuric acid coated ash are to be measured. The temperature range will represent that of the troposphere to the lower stratosphere. To facilitate these measurements the project extends the capability of the Molecular Spectroscopy Facility at the Rutherford Appleton laboratory. The project has been funded by Natural Environment Research Council (NERC), under its Core-Strategic Measurements for Atmospheric Science (COSMAS) program. In this poster presentation we describe the current status of the project.

2 Motivation

The project has a number of end aims. One of which is to allow further assessment of the role of volcanic ash in atmospheric chemistry, and radiative transfer. Applications of the measurements:

- For radiative transfer from:
  - Scattering solar radiation.
  - Absorption in the infrared.
- For chemical reactions:
  - Particles become coated in sulphuric acid, after an eruption causing an increase in the surface area and volume of sulphuric acid aerosol in the stratosphere. These act as a surface or volume for chemical reactions, and reservoirs of reactive species through the uptake of trace gases.

Uncertainties in satellite instruments retrieval schemes of aerosol parameters are currently limited by our knowledge of the optical properties of several aerosol types including volcanic ash. Thus high quality reference measurements of the optical properties of volcanic ash aerosols will add value to satellite instruments (for example ATSR/2, AATSR, MIPAS, MSG, HIRDLS, TOMS).

Volcanic ash clouds are also potentially damaging to aircraft, causing the malfunction of aircraft systems [1]. Silicate particles in the ash clouds can enter the engines and melt. In the past two decades two commercial passenger aircraft have had all engines fail after flying into an unanticipated volcanic ash cloud. Timely satellite detection of these clouds would help to reduce this hazard.

3 Method

The extinction cross section is related to the optical transmission by:

$$T(\lambda) = \exp^{-\beta(\lambda)x}$$

Where:

T Transmission.
β Volume extinction coefficient.
x Measurement path length.

The volume extinction coefficient is given by:

$$\beta(\lambda) = \int_0^\infty \sigma_{ext}(r, m, \lambda) n(r) dr$$

Where:

σ_{ext} Extinction coefficient.
r Particle radii.
m Particle complex refractive index.
λ Wavelength.
$n(r)dr$ Number of particles between radii r and $r + dr$.

Hence to obtain the extinction coefficient, σ_{ext} we require the measurements of the optical transmission, T as well as the particle distribution, $n(r)$.

4 Samples

Figure 1 The Aso bomb-shelters.

At present we have one volcanic ash sample, collected from the Aso volcanic eruptions in 1993. This sample has been collected from a "bomb-shelter" where 1 m to 2 m of ash accumulated (see Figure 1). This is thought to be in a "fresh" state because of the environmental protection of the bomb shelter.

In addition to the volcanic ash we also hope to characterize Saharan dust samples. Figure 2 summarizes out proposed measurement conditions. Also shown is the current measurement priorities.

Conditions	Ash	Saharan dust
Dry	$\surd\surd\surd$	$\surd$
$0\% < RH < 100\%$	$\surd\surd$	$\surd$
Ice	$\surd\surd$	$\surd$
H_2SO_4 coated	$\surd\surd$	$\surd$

$\surd\surd\surd$ = primary aim.
$\surd\surd$ = secondary aim.
$\surd$ = tertiary aim.

Figure 2 Summary of the samples to be measured.

We also intended to collect and characterize additional samples from other eruptions.

5 Experimental design

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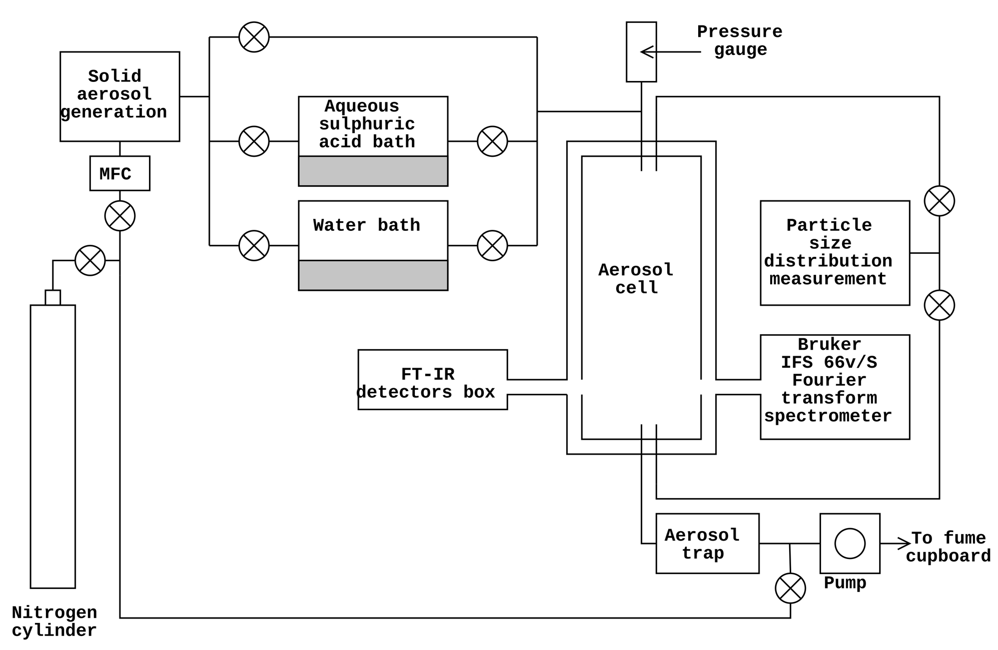

Figure 3 Baseline experiment configuration.

The experimental design is currently being developed. A base line configuration is shown in Figure 3.

A temperature controlled aerosol cell at the Rutherford Appleton Laboratory, Molecular Spectroscopy Facility will be used [3]. The optical transmission, $T(\lambda)$, will be measured in an aerosol cell, by using a high resolution Fourier Transform (FT) spectrometer.

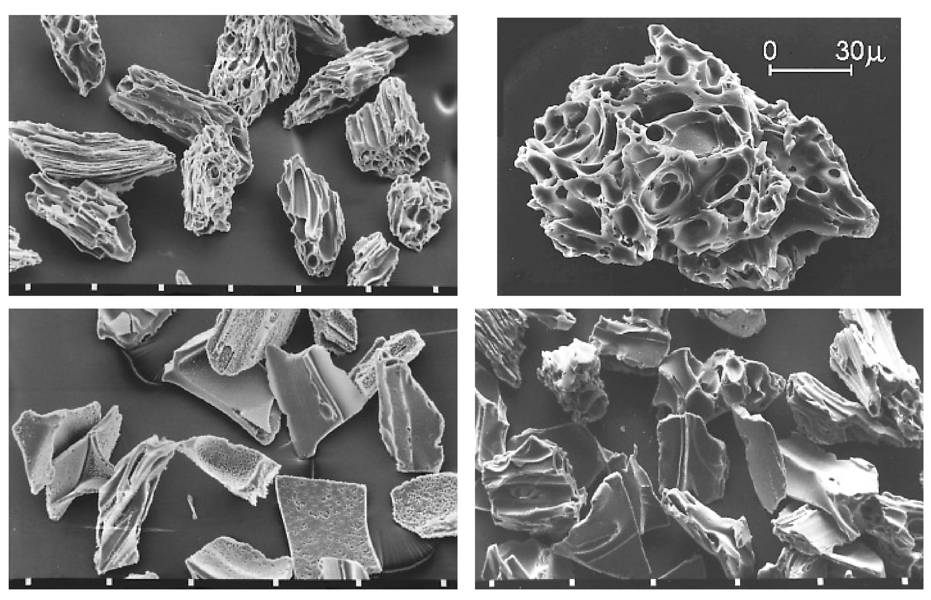

Figure 4 Example SEM images of a volcanic ash sample [2].

We will obtain information on the morphology and basic particle size distribution of our sample by using microscopy. This will also allow the sample type to be identified. For the submicron particle sizes electron microscopy will be used. Figures 4 and 5 show examples particle fields.

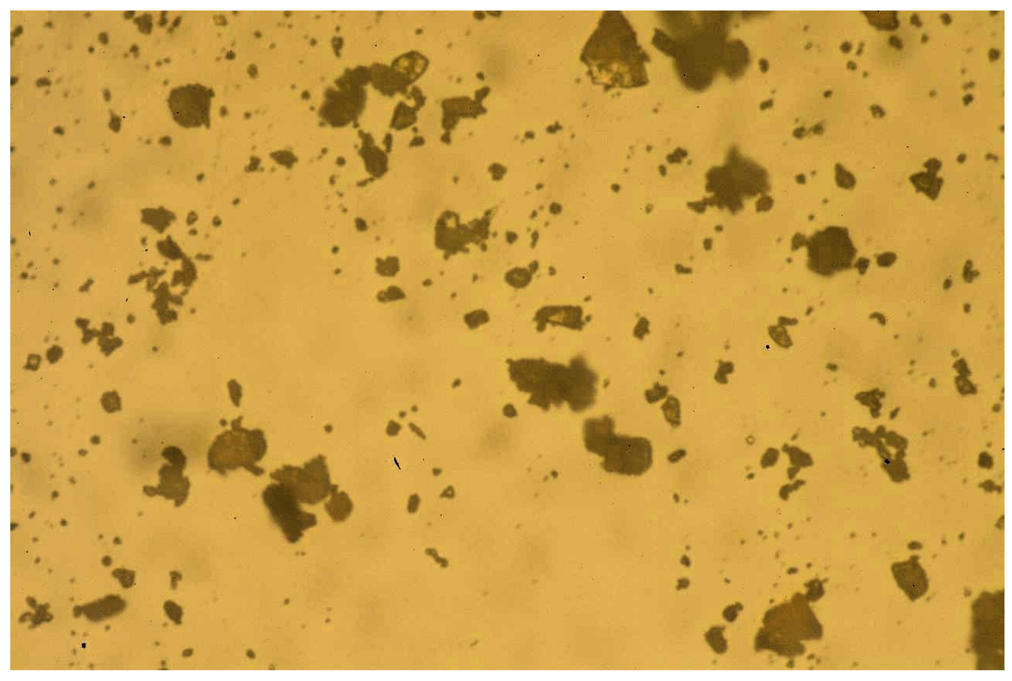

Figure 5 Optical microscopy of the volcanic ash sample. The width across the frame is aproximatly 450 μm.

5.1 Aerosol generation

Several aerosol generation techniques have been identified:

- Suspending the solid aerosol in a volatile fluid, that is nebulized and then dried.
- Using a fluidized bed generation technique.

The final chosen generation method will be required to generate a steady controlled aerosol from our solid sample.

To generate the ice/water and sulphuric coated aerosols, the solid aerosol will be passed though over either a sulphuric acid or water bath (see Figure 3).

In addition to these generation techniques, if the particles generated are <1 μm in radius it would be possible to use a Differential Mobility Analyser (DMA) to obtain a particle size "slice", of the generated aerosol. This would have the advantage of neatly separating the size distribution, $n(r)$ from the extinction spectra, σ_{ext}.

5.2 Particle evolution

During an experimental run the possibilities of particle evolution needs to be addressed. This can be from the following effects:

- Sedimentation. Smaller particles have a lower terminal velocity, hence the larger particles will be preferentially removed from the cell.
- Coagulation.
- Wall loses.

To quantify these effects it is planed to measure the particle size distribution both on the inlet and outlet of the cell (see Figure 3).

These effects are also to be included as part of the experimental design. For example the aerosol generation should not introduce particles with a radius that would cause significant sedimentation during a spectral measurement cycle.

5.3 Particle size measurement

We need to measure the particle size distribution, $n(r)$, in the aerosol. Several techniques have been identified so far:

- Scanning Mobility Particle Sizer (SMPS). In situ measurements, over a size range of 0.001 μm to 1 μm.
- Aerodynamic Particle Sizer (APS). Measurements in situ from 0.5 μm to 20 μm.

The choice of measurement method will depend on the particle sizes available in our samples.

For the dry aerosol, the particle size measurements may be checked by particle collection using "impactors", on the inlet and outlet of the aerosol cell. These samples would be latter analysed by microscopy confirm the in situ particle size measurements.

References

[1] Danger to aircraft from volcanic eruption clouds, http://volcanoes.usgs.gov/hazards/effects/ash+aircraft.html.

[2] Photo glossary of volcano terms , http://volcanoes.usgs.gov/products/pglossary/ash.html.

[3] R. A. McPheat, S. F. Bass, D. A. Newnham, J. Ballard, and J. J. Remedios. Comparison of aerosol and thin film spectra of supercooled ternary solution aerosol. *Journal of geophysical research*, 107(D19), 2002.