# Measurement of the Optical Properties of Volcanic Ash: Current status.


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## 1 Abstract

This poster gives the current status of the COSMAS funded laboratory project "Optical Properties of Volcanic ash". This project sets out to measure the extinction spectra and size distribution of volcanic ash aerosol. The measurements will allow the calculation of aerosol cross section required for IR satellite observations of ash clouds. Dry, water ice and sulphuric acid coated aerosol are to be measured over a temperature range representative of the troposphere to lower stratosphere. The latest results, as measured at the Molecular Spectroscopy Facility at the Rutherford Appleton laboratory, are outlined.


## 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 include:

- 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, MERIS).

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.
- $\beta$ 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:

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

Hence to obtain the extinction coefficient, $\sigma_{ext}$ 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 setup

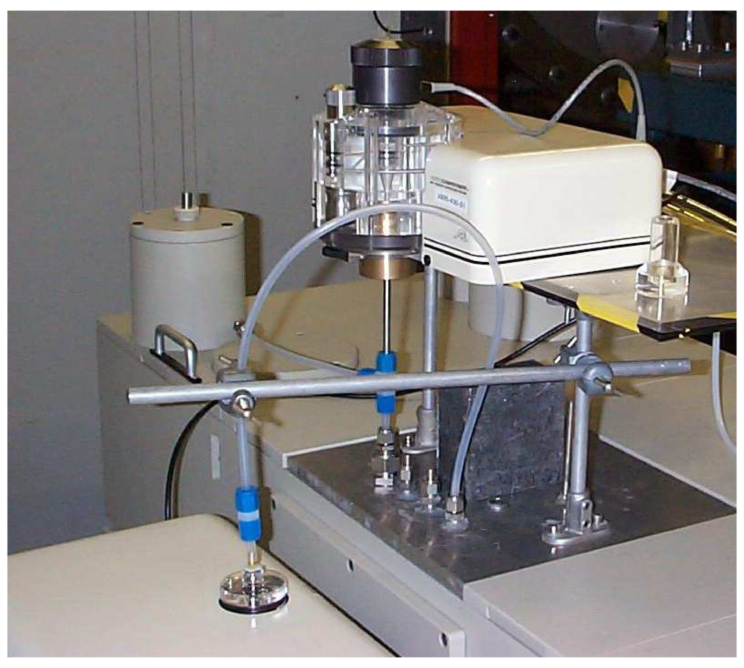

Figure 3 Experimental configuration.

Figure 4 outlines the basic configuration of the experiments undertaken so far. The aerosol is generated from a powder sample and then introduced to the small aerosol cell. The aerosol cell has optical windows fitted, allowing the aerosol absorption to be measured via the Fourier Transform Spectrometer, FTS. Particle size distribution of the aerosol is then determined and the aerosol then exhausted into a fume cupboard.

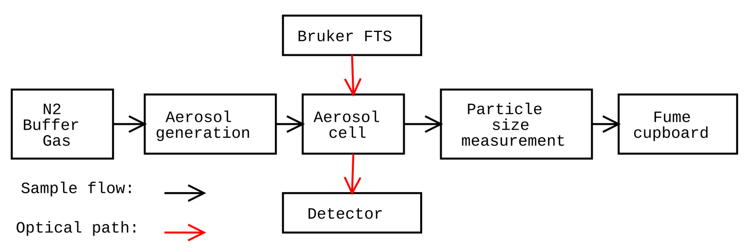


Figure 4 Simplified diagram of experimental configuration.

### 5.1 Aerosol Generation

The aerosol is generated by an AeroDisperser head, manufactured by Amherst Process Instruments. The unit is designed to be used in with the AeroSizer particle sizing instrument, to obtain particle size distribution of powders. It uses a high pressure gas pulse jet, to entrain the powder sample which is contained in a small sample cup. Once the sample is entrained it enters an impaction region and a high shear force region, this ensures a high degree of de-agglomeration. We used $N_2$ as the carrier gas.

### 5.2 Aerosol Cell

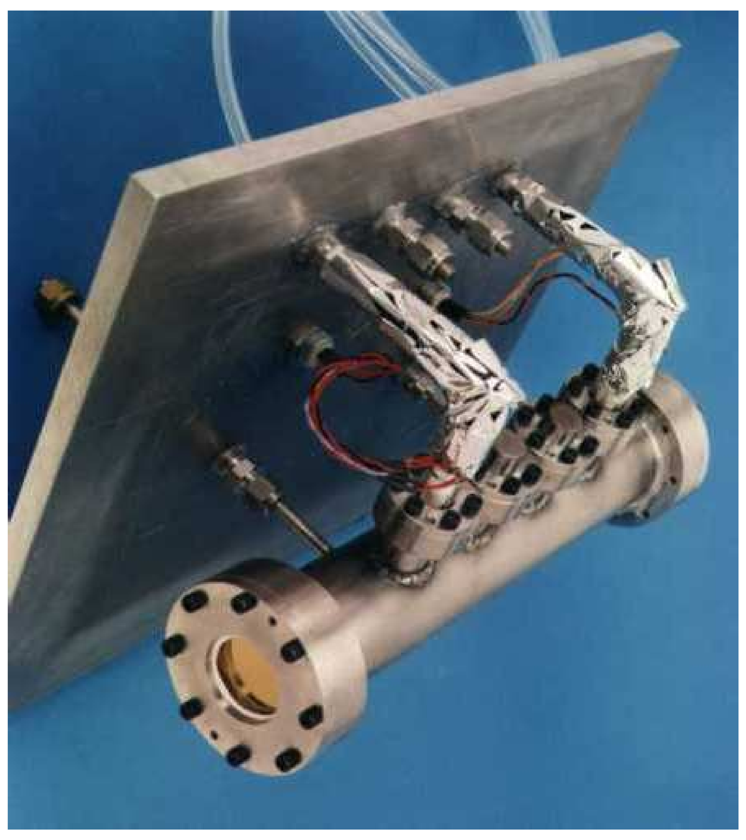

Figure 5 The small aerosol cell.

The MSF small aerosol cell has an optical path length of 30 cm. The small AeroDisperser cup volume (0.5 $cm^3$) allows the aerosol to be generated for a few minutes. This means that we are limited to using an aerosol cell with a small volume.

Spectral intensity measurements are made using a Bruker FTS. Measurements of the detected intensity are obtained with and without the aerosol to calculate the transmission spectrum, $T(\lambda)$.

### 5.3 Size distribution measurements

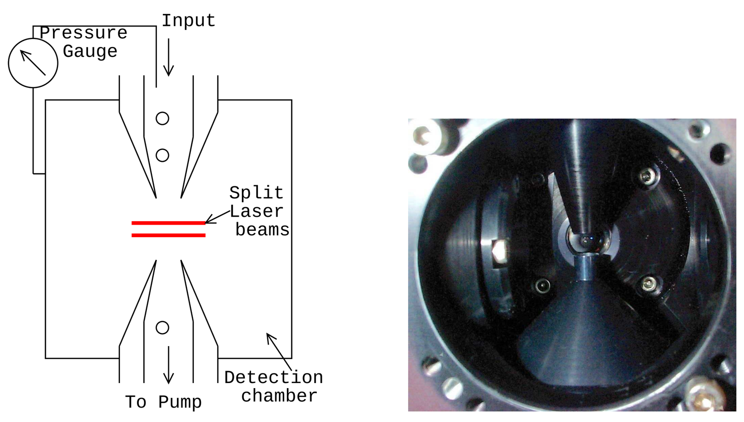


Figure 6 The Aerosizer.

The particle size distribution is measured by an AeroSizer LD manufactured by Amherst Process Instruments. It is able to measure the particles aerodynamic diameter in the range 0.5$\mu$m, to 700 $\mu$m. The technique is independent of the particles refractive index, but we do need to know the particles density. This particle sizer is available to other users of the MSF on request (depending on the chemical compatibility of the AeroSizer LD to the aerosol).

## 6 Results

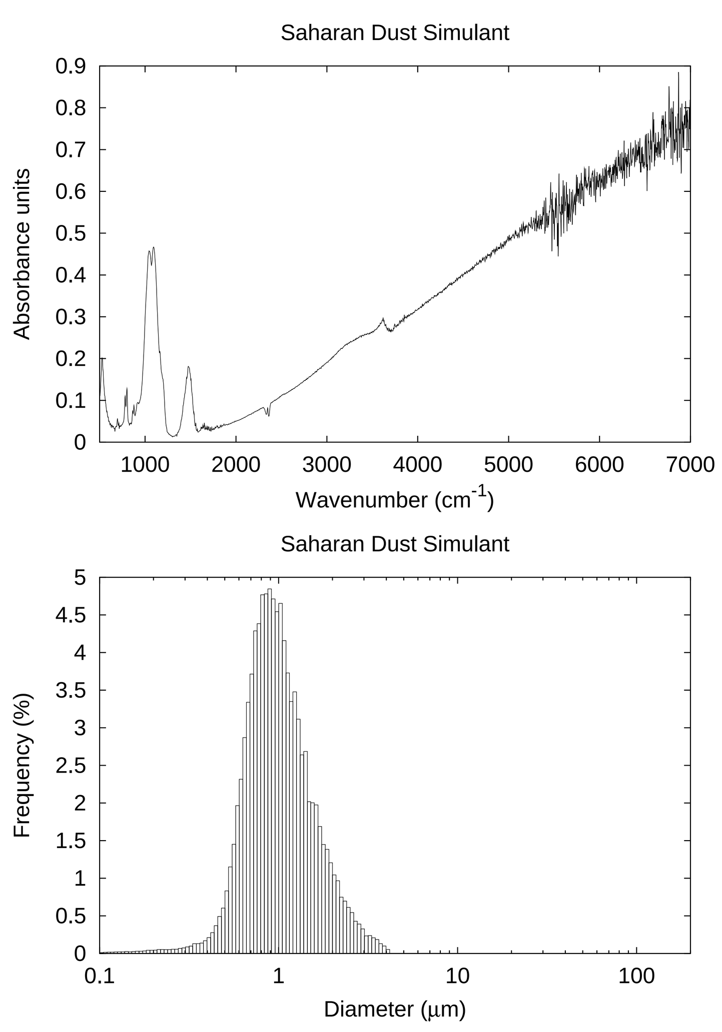


Figure 7 Example of a measured size distribution and absorption spectrum.

To ensure that the actual samples are not wasted, the experiment has first been run using a Saharan dust simulant (crushed sand). Problems have been found in the repeatability of the number density of the aerosol. This has caused poor signal to noise in most of the collected absorption spectra. An example of a low noise spectra from the simulant is shown in Figure 7. This clearly shows scattering and absorption features.

Figure 7 also shows the measured aerosol size distribution, for the spectra shown. The lower size limit of the AeroSizer LD is around 0.5 $\mu$m and is a function of the instruments Photo Multipliers Tube (PMT) voltage. In the size distribution shown it is 850V. Increasing this to 1100V reveals that we are only detecting the start of the distribution, most of the particles were smaller than the 0.5 $\mu$m.

## 7 Further work

The method describe by Thomas [3][4] will be used to retrieval the refractive index of the aerosol from the measured absorption spectra and size distribution. We hope to attempt this for all the aerosol types given in Figure 2.

The dispersal method will be improved to allow a continuous aerosol flow for much longer periods (hours). The improved method will also aim in increase the dispersion repeatability and number density. The longer dispersal period will allow the use of the large aerosol cell at the MSF [2]. The large aerosol cell has a longer path length (50 cm) and better homogeneity.

The addition of water and a sulphuric acid bath to allow the creation of water ice, hydrated and sulphuric acid coated volcanic ash aerosols.

To allow measurements of particle size for particles less than 0.5 $\mu$m we have purchased a GRIMM SMPS+C from Quantitech. This instrument measures particles size in the range 10 to 875 nm in diameter.


## References

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

[2] 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.

[3] G. E. Thomas, S. F. Bass, R. G. Grainger, and A. Lambert. Retrieval of aerosol refractive index from extinction spectra using a damped harmonic oscillator band model. *submitted to Applied Optics*, 2004.

[4] G. E. Thomas, R. G. Grainger, and R. A. McPheat. A new method of retrieving aerosol optical properties form IR extinction measurements. *COSMAS annual meeting Bristol*, 2004.