

Laboratory simulation of Martian atmospheric chemistry

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Abstract

Measurements of the yield of important trace gas species such as ozone, evolved during photolytic reactions have been made under Martian environmental conditions in one of the The Open University's Mars simulation chambers. The simulation chamber can mimic Martian temperatures and pressures and a UV solar simulator can be added to irradiate a Mars-like gas mixture within the chamber to drive chemical reactions. The concentration of trace gases is measured in situ using a Fourier Transform Infrared spectrometer (FTIR). The data obtained will be invaluable in improving the qualitative and quantitative representation of chemical species calculated using Mars global circulation models (MGCMs) and in interpreting a new suite of observational data such as from ExoMars Trace Gas Orbiter (TGO).

1. Introduction

Measuring the gas composition of the Martian atmosphere gives vital clues about active processes occurring in the Martian system. The current composition of the atmosphere of Mars is approximately 95.3% CO₂, 2.7% N₂, 1.8% Ar, 0.13% O₂ and 0.08% CO. Chemistry within the atmosphere is driven by photolytic reactions and varies according to location, altitude and season on Mars.

The reactions contributing to this chemistry have been modelled both in 1D and 3D [1, 2, 3] to build up a picture of the seasonal behaviour of species such as ozone [3]. However, these models are only as good as the reaction schemes included in them. Many of these reactions have been taken from studies of terrestrial atmospheric chemistry and have not been observed under Martian conditions. The current study seeks to take the first steps at simulating this complex system in the laboratory.

1.1. Heterogeneous reactions

The rates and mechanisms of photolytic chemical reactions occurring within the Martian atmosphere are

controlled by many environmental factors. One such factor is the total surface area of ice crystals and dust particles. Both these components have been observed within the Martian atmosphere and vary considerably [4]. Heterogeneous reactions occurring on the surface of ice crystals have been modelled previously [5], in this case they improved the quantitative agreement between model calculation of seasonal ozone abundance and observations of ozone taken by SPICAM a UV/IR spectrometer aboard Mars Express.

The dust in the Martian atmosphere is thought to be derived from the basalt regolith present on the majority of the planet's surface. Heterogeneous reactions can occur on the surface of dust particles. These reactions can have a net effect to produce or destroy species such as ozone and so modelling their behaviour is a complex problem. Heterogeneous reactions have long been proposed as an important mechanism of generating stability for Martian CO₂ [6, 7].

The focus of the current study is to characterise the effect of basalt powder on the yields of certain trace gas species under Martian environmental conditions. This data is to be used to improve the reaction scheme of the MGCM used at The Open University [8].

2. Method

The simulation chamber consists of a stainless steel vacuum chamber, approximately 5L in volume, attached to a backing pump and a turbo pump. When cooling to low temperatures, liquid nitrogen is flowed through a separate chamber adjoining the main one, generating temperatures of -50°C. The pressure is controlled by a solenoid valve and can operate between 1×10⁻⁵ and 100 mbar. Both temperature and pressure are logged.

The main chamber has a gas inlet pipe that allows the sample gas to enter the chamber. During a run a Mars-like gas mixture consisting of 95% CO₂ and 5% N₂ are pumped inside the chamber. The top of the chamber has a magnesium fluoride window that transmits UV light in the VUV region. A deuterium UV lamp is mounted onto the window to allow irradiation

of the chamber.

At the base of the main chamber there is a stainless steel heating plate that can heat the chamber to 200°C. When running with a regolith sample, a glass petri dish, 5 cm in diameter, is placed on top of the heating plate.

There are two side ports, both containing germanium windows for IR transmission. These windows allow measurement of the gases within the chamber using a Thermo-Nicolet FTIR spectrometer combined with an MCT-A external detector. Absorption spectra are recorded every two minutes using OMNIC software and analysed using a combination of OMNIC and python scripts.

The experimental set-up can be seen in Figure 1.

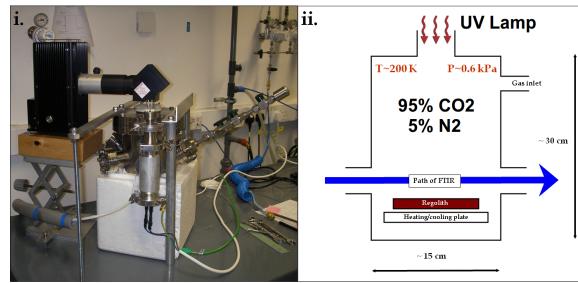


Figure 1: The simulation chamber and a schematic of the set-up.

2.1. Mars analogue regolith

Three different Mars regolith samples have been introduced into the chamber. Two of the regolith samples are powdered flood basalt from a Deccan tholeiite deposit in India. The third is a sample of NASA JSC Mars-1. All three samples have been compositionally characterized using XRD and XRF. The samples were chosen to be representative of the general composition of Martian basalt proposed in [9].

The regolith samples are each dried and weighed before emplacement in the chamber. A control sample of glass beads with the same approximate surface area as the regolith samples will also be used.

3. Summary

Laboratory simulations of Martian atmospheric chemistry are vital to improve the accuracy of numerical modelling work. If we are to identify sources and sinks of particular gases we must observe the behaviour of those gases under Martian conditions.

The work presented here represents a preliminary investigation into how basalt powders may alter the atmospheric chemistry of Mars by providing a surface for heterogeneous reactions. This work will be extended in the future to add more trace gas species into the chamber.

Acknowledgements

This work is funded by the Science and Technology Facilities Council and The Open University Charter Studentship Fund. The authors would like to thank Dr Tim Ringrose and Martin Percy for their support.

References

- [1] Nair H., Allen M., Anbar A. D., Yung Y. L and Clancy R. T.: A photochemical model of the martian atmosphere, *Icarus*, 111, pp. 124-50, 1994.
- [2] Krasnopolsky, V. A.: Photochemistry of the martian atmosphere: Seasonal, latitudinal, and diurnal variations, *Icarus*, 185, pp. 153 - 170, 2006.
- [3] Lefèvre, F., Lebonnois, S., Montmessin, F. and Forget, F.: Three-dimensional modeling of ozone on Mars, *Journal of Geophysical Research*, 109, E07004, 2004.
- [4] Smith, M. D.: Interannual variability in TES atmospheric observations of Mars during 1999-2003, *Icarus*, Vol. 167, 1, 2004.
- [5] Lefèvre, F., Bertaux, J-L, Clancy, R. T., Encrenaz, T., Fast, K., Forget, F., Lebonnois, S., Montmessin, F. and Perrier, S.: Heterogeneous chemistry in the atmosphere of Mars, *Nature*, 454, pp. 971-975, 2008.
- [6] Atreya, S. K. and Gu, Z. G.: Photochemistry and stability of the atmosphere of Mars, *Advances in Space Research*, 16, pp. 57 - 68, 1995.
- [7] Atreya, S. K. and Gu, Z. G.: Stability of the Martian atmosphere: Is heterogeneous catalysis essential?, *Journal of Geophysical Research*, 99, pp. 13133-13145, 1994.
- [8] Duffy, M. K. D., Mason, N. J. and Lewis, S. R.: Modelling trace gas chemistry in the Martian atmosphere, *European Planetary Science Congress*, 23-28 September 2012, Madrid, Spain, 2012.
- [9] Seiferlin, K., Ehrenfreund, P., Garry, J., Gunderson, K., Hütter, E., Kargl, G., Maturilli, A. and Merriison, J. P.: Simulating Martian regolith in the laboratory, *Planetary and Space Science*, 56, pp. 2009-2025, 2008.