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Thermogravimetry: a technique for planetary in-situ missions

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Abstract

The thermogravimetry technique allows to study desorption and sublimation processes of volatile compounds in different environments. This technique shows a large range of applications for planetary in-situ mission, e.g. the measurement of water and organics in a planetary environment.
The capability of a thermogravimeter to study water desorption from clay has been verified. Another experiment which can find application in a planetary mission concerns the measurement of enthalpy of sublimation of a particular volatile compound.

1. Introduction

Thermogravimetric analysis (TGA) is a widely used technique to investigate deposition/sublimation and absorption/desorption processes of volatile compounds in different environments: outgassing contamination in space, dehydration and organic decomposition in minerals, as well as to measure moisture content in foods or develop temperature profiles for firing ceramics (e.g. [1, 2]). It measures the change in mass of a sample as a function of temperature and time. The technique can characterize materials that exhibit weight loss or gain due to kinetic processes, mainly: decomposition, oxidation or dehydration.
The thermogravimeter core is a Piezoelectric Crystal Microbalance (PCM), whose oscillation frequency linearly depends on the mass deposited on it, according to the Sauerbrey equation [3]. The PCM temperature can be increased by means of an appropriate heater, in order to allow the most volatile component of the analysed sample to desorb. The abundance of the volatile component will be given by the mass variation during the desorption process, while its composition can be inferred by the desorption temperature. The volatile compound is also characterised by its enthalpy of evaporation/sublimation, which can be obtained by thermogravimetric measures [4].

2. Planetary applications

Instruments based on TGA have been studied for space applications and proposed for planetary in-situ missions. For instance, the VISTA instrument (Volatile In Situ Thermogravimetry Analyser) is under study for Phase A of the proposed mission MarcoPoloR-ESA, addressed to a primitive Near Earth Asteroid, and has been also studied for JUICE (JUpiter ICy moon Explorer)-ESA [5] and for DREAMS, the scientific package of the Entry and Descent Module of ExoMars 2016-ESA [6].
The thermogravimeter is a very versatile instrument, that can accomplish the following tasks, depending on the planetary scenario:

- Measurement of abundance of volatiles of scientific interest (e.g. water, organics) in the planetary/asteroidal regolith;
- Detection of cometary-like activity of asteroids (by measuring the gas-dust abundance ratio);
- Discrimination between water ice and clathrate hydrates (basing on their different sublimation temperature) on icy satellite surfaces;
- Determination of composition of non-ice materials on icy satellite surfaces;
- Discrimination between condensable and refractory component in cloud aerosols;
- Measurements of humidity (which can be inferred by water frost point);

3.Thermogravimetry measurements

3.1 Water desorption

Desorption of water from clay is a common process in planetary environment (for example, it occurs on Mars). We demonstrated the capability of a thermogravimeter with an integrate micro-heater to perform measurements of water desorption [7]. A clay sample has been hydrated in a controlled hydration chamber and then heated on the PCM. Finally, the correspondence between the amount of water collected and released has been verified (Figure 1).

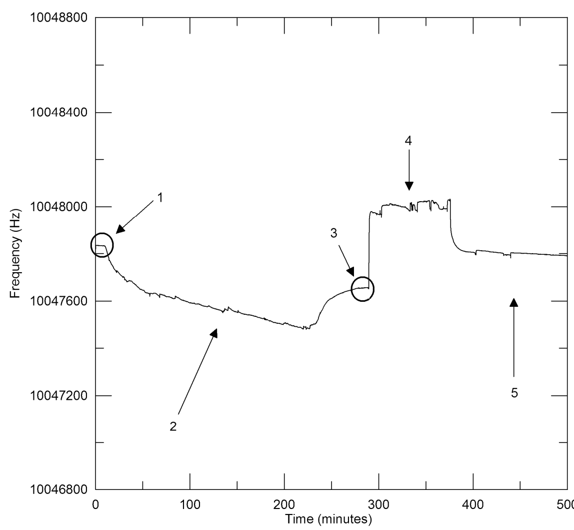

Figure 1 (adapted from [7]). PCM resonance frequency as function of time in the experiment performed by [7]. The numbers refer to: 1) original frequency; 2) hydration process; 3) frequency after hydration; 4) heating process; 5) final frequency. Original and final frequency are similar.

3.2 Enthalpy of sublimation

The retrieval of the enthalpy of sublimation of the analysed compound can help to determine its composition. A laboratory test is planned to verify the capability of our device to perform this kind of measurement.

The sample and the PCM are placed inside a vacuum chamber, which would simulate an asteroidal environment. Then, the sample is heated and degassed, while the PCM is cooled down to about -50°C by a cold finger, in order to allow the deposition of the gas molecules produced by the sublimation process (Figure 2). By measuring the rates of deposition on the PCM R_1 and R_2 at two different sample temperatures T_1 and T_2, it would be possible to infer the enthalpy of sublimation ΔH of the sample from the Van't Hoff relation [8]:

$$\Delta H = R\left(\frac{T_2 T_1}{T_2 - T_1}\right) \ln\left(\frac{R_2}{R_1}\right),$$

where R is the gas constant.

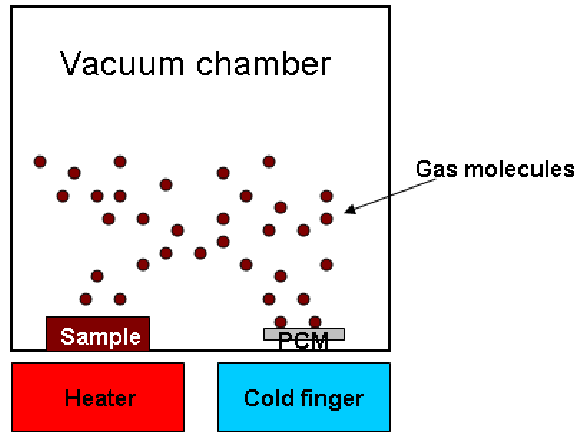

Figure 2. Schematic representation of the experiment for the measurement of enthalpy of sublimation.

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