A Quantitative Comparison Between Theory And Experiment for CO_2 Sublimation on a Granular Surface under Terrestrial and Martian Conditions and Morphological Results.

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Introduction: Many currently active geomorphic processes on the surface of Mars are believed to be caused by the CO_2 cycle. CO_2 is Mars' primary atmospheric constituent and during the winter around half of the atmosphere is deposited as CO_2 snow and ice. During the spring this sublimates and can cause a variety of behaviours and features such as avalanches, spiders, furrows [1] and linear gullies [3, 6]. Furrows frequently occur on dune faces and are narrow negative topography features with a range of planforms and patterns. Linear gullies are long narrow channels on dune lee slopes with terminal pits. Both of these features have no Earth analogs. Our previous experiments under ambient Earth conditions were indicative of CO_2 formation mechanisms for both of these active features [5]. However, this activity has not been observed under the lower atmospheric pressure and gravity experienced on Mars.

C. J. Hansen first proposed the hypothesis that linear gullies form when a block of solid CO_2 ice falls from a dune brink onto a relatively hot granular surface and then sublimates sufficiently vigorously to support itself on a gas layer like that engendered by the *Leidenfrost Effect*. This gaseous lubrication layer then allows the blocks to slide down even gentle slopes since solid friction is eliminated or reduced. This hypothesis was investigated in [3] where a detailed comparison with HiRISE images was performed, proof of concept was demonstrated in field experiments and a mathematical model developed. However, though this showed qualitatively that the Leidenfrost process can be highly effective for CO_2 blocks on Earth, there was no quantitative test of the model under either Terrestrial or Martian conditions. In fact, despite the wide range of phenomena attributed to CO_2 on Mars, there has been almost no experimental work and little detailed mathematical modelling and there is a dearth of quantitative evidence to support models of CO_2 sublimation [7, 5, 4].

We report the first quantitative experiments under Earth and Martian conditions to test the CO_2 block sublimation model using a variety of grain sizes. We report unusual vigorous sublimation activity for fine to medium grain sizes and consequent burrowing of CO_2. We also report the first physical observations of pit and furrow morphologies formed by sublimating CO_2 under Martian conditions.

Methods: Experiments were performed in the Mars Simulation Chamber at the Open University at a temperature of 293 K and a pressure of either $\approx 10^5$ Pa or 600 Pa. In both cases the chamber was first filled with pure CO_2 primarily to remove any water vapour from the system, but also to make the conditions as similar as possible between the two ambient pressures. A block of CO_2 ice of approximately $20 \times 10 \times 2$ cm was suspended by a harness above a granular bed (figure 1a).

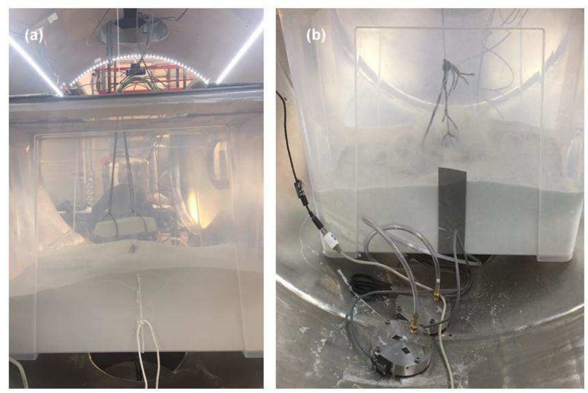

Figure 1: (a) CO_2 block suspended above a granular bed (75–150 μm) before lowering ambient pressure to 6 mbar and backfilling the Mars Simulation Chamber with gaseous CO_2. (b) Vigorous sublimation observed at 6 mbar when a block was gently placed on the granular surface (75–150 μm).

Once the desired pressure was achieved the block was lowered gently onto the surface, which consisted of dried, sieved and levelled Guyson Honite Glass Spheres. Three different coarse grain sizes (250–425 μm, 425–600 μm and 600–850 μm) were used as the theory predicts a very strong (quadratic) dependence of lift force on particle diameter. Finer grain sizes could not be used to quantitatively test the model as under Martian pressure these were readily mobilised and the block burrowed. Within the bed a rake of thermocouples was used to track the temperature in time. In addition, tubes were placed at various depths and connected to highly sensitive ($\pm$35 Pa) differential pressure transducers. These effectively measure the lift force since this is the integrated differential pressure under the block.

A further set of experiments was conducted specifically to investigate the range of morphologies sublimating CO_2 could form under Martian conditions. For this, CO_2 blocks were lowered onto a range of grain sizes from 75–850 μm to investigate the role of reduced ambient pressure on (i) pit and (ii) furrow morphologies and morphometries.

Results: The pressure under the block for one experiment is shown in figure 2 compared to the model prediction. The excellent agreement is clear. The data show that the simple model combining 1D heat transport and 3D Darcy flow captures the essential physics of the problem under both Terrestrial and Martian conditions. This provides evidence that the model for pit formation via CO_2 sublimation will also be valid under Martian gravity and with the much larger (meter sized) blocks that are expected.

Furrows were observed to form on coarser grains (> 206 μm) under Martian conditions, whereas coarse grains were not mobilised in such a manner under Earth conditions. In the case of finer grain sizes (< 250 μm), highly unusual activity was observed (figure 1b) where blocks burrowed rapidly beneath the bed surface to form pit morphologies. Mass flux sublimation rate under Martian pressure was up to 12 times greater than under Earth conditions for grain sizes similar to those detected on the Bagnold dunes [2], indicating that CO_2 phase change on Mars is a highly effective agent of surface modification on Martian aeolian landforms.

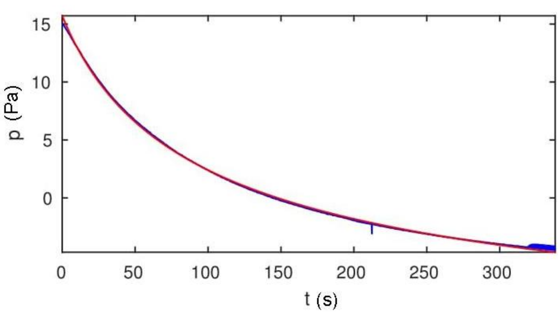

Figure 2: Trace of pressure (Pa) against time (s) under a CO_2 block. Blue is experimental data, red is theoretical prediction.

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