EPSC Abstracts
Vol. 12, EPSC2018-1153-1, 2018
European Planetary Science Congress 2018


# Methane transport in the subsurface of Mars

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## Abstract

The detection and characterization of trace gases such as methane is among the main objectives of ExoMars Trace Gas Orbiter (TGO). The interpretation of the TGO measurements and the study of methane outgassing scenarios require an understanding of gas transport in the martian subsurface. Here, we model the $CH_4$ transport through the porous martian regolith using the dusty gas model (DGM) [1] for the binary $CH_4$-$CO_2$ mixture. The effects of different parameters on the transport are also investigated.

## 1. Introduction

The multiple detections of $CH_4$ in the martian atmosphere have raised numerous questions about its potential sources. It has been suggested that methane on Mars could have a biological origin and be generated by organisms living in the subsurface where conditions are more hospitable [2]. Methane could also be produced through several abiologic processes, including Fischer-Tropsch Type (FTT) reactions where $H_2$ reacts with $CO_2$ in the presence of a metal catalyst [3]. The $H_2$ necessary for the FTT reactions can be produced by several processes and notably by serpentinization [4]. Many of the proposed generation mechanisms for $CH_4$ would take place hundreds of metres to several kilometres deep in the crust of Mars, while subsurface reservoirs such as clathrate hydrates [5] could release methane from shallower depths. Once produced, $CH_4$ has to be transported from its source through the martian subsurface.

Gas transport through porous media can be divided in different mechanisms [1]:

- Free molecule or Knudsen flow occurs when the pore radius is less than one tenth of the gas mean free path, and molecule-wall collisions dominate.
- Viscous or advective flow, in which the gas acts as a continuum fluid under the influence of a pressure gradient. In this mode, molecule-molecule collisions dominate.
- Continuum or molecular diffusion refers to the relative motion of the different gas species under the influence of concentration gradients, temperature gradients or external forces. In this regime, the pore radius is larger than 10x the gas mean free path and collisions between gas molecules dominate.
- Surface flow or diffusion in which molecules move along a solid surface in an adsorbed layer.

Methane transport through the porous martian regolith has been modelled using the DGM [1] for the binary $CH_4$-$CO_2$ mixture and neglecting thermal transpiration, baro-diffusion and surface diffusion.

## 2. The model

The dusty gas model is based on the full Chapman Enskog kinetic theory of gases. In this model, the porous medium is considered as one component of the mixture and is treated as a collection of giant spherical molecules (dust particles) kept in space by external force. The total flux of a gas mixture is represented as the sum of the diffusive flux (molecular and Knudsen diffusion) and the viscous flux. The flux equation of a binary gas mixture may be written as:

$$\frac{N_1}{D_{1K}} + \frac{y_2 N_1 - y_1 N_2}{D_{12}} = - c_T \frac{dy_1}{dz} - y_1 \frac{dc_T}{dz} \left(1 + \frac{B_0 P}{\mu D_{1K}}\right) \quad (1)$$

where subscripts 1 and 2 refer to components 1 and 2 of the gas mixture repectively, $N$ is the total molar flux, $D_{1K}$ is the effective Knudsen diffusion coefficient of component 1, $y$ is the mole fraction, $D_{12}$ is the effective molecular diffusion coefficient of the binary mixture, $c_T$ is the total molar concentration, $B_0$ is the permeability, $P$ is the pressure and $\mu$ is the gas mixture viscosity.

## 3. Preliminary results

In a first time, methane transport was studied taking into account only the diffusion process and different parameters were varied to investigate their effect on the $CH_4$ transport. Results showed that the flux is strongly dependent on the pressure gradient. On the other hand, it is less sensitive to temperature changes even if it increases slightly during warmer seasons. Similarly to what was found by [6], diffusion is not an efficient process to generate short-lived methane plume from deep sources. Indeed, when diffusion is the only transport mechanism considered, the methane source has to be located at very shallow depth (on the order of few meters) to observe temporal variations in surface flux. Even though near-surface metastable reservoirs could provide long-term release of atmospheric methane, it is very likely that $CH_4$ is produced at depth in the martian crust. Methane generated at depth should move preferably via advection following pathways along faults and fractures [3]. Results regarding this last process and their implications will be presented.

Finally, it is important to note that methane outgassing scenarios are strongly dependent on the subsurface environment and new constrains could be provided by current and future missions such as InSight and ExoMars.

## Acknowledgements

This work was financially supported by the Belgian Science Policy Office (BELSPO) through the BRAIN-be SCOOP project and the ESA/PRODEX Program. This research was performed as part of the “Excellence of Science” project “Evolution and Tracers of Habitability on Mars and the Earth” (FNRS 30442502).

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