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Characterizing Evaporites on Titan Using an Experimental Chamber

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Abstract

Titan has an abundance of lakes and seas, as confirmed by Cassini. Major components of these liquid bodies include methane (CH_4) and ethane (C_2H_6), however, evidence indicates that minor components may also exist in the lakes. Here, we provide saturation values, evaporation rates, and constraints on evaporite formation by using a Titan simulation chamber that produces Titan surface conditions (89-94 K, 1.5 bar). Experimental samples were analyzed using FTIR spectroscopy, mass, temperature, and visual readings. Our experiments show that ethylene evaporites formed more quickly in a methane solvent than an ethane solvent, or a mixture of methane/ethane. Additionally, we observed red shifts in ethylene absorption bands at 1.630 and 2.121 μm and the persistence of a methane band at 1.666 μm. Understanding the details of evaporite formation aids in better understanding the chemical composition of Titan's lakes and surface materials, and the exchange processes between them.

1. Introduction

Evaporites form when dissolved solids (solutes) precipitate out of a saturated solution as that liquid (solvent) evaporates [3]. Evaporation of a solvent causes the solute to deposit as an evaporite either onto the surface (if all liquid has evaporated), or at the bottom of the saturated liquid (if not all liquid has evaporated) [7]. Cassini's Visual Infrared Mapping Spectrometer (VIMS), identified probable evaporites on Titan with a "5-μm-bright" signature in many dry lakebeds near Ligeia Mare at the north pole [3,5], Tui and Hotei Regios at the midlatitudes [1] and Ontario Lacus at the south pole [2,4]. In-depth studies of these 5-μm-bright regions have concluded that they are non-water ice materials. We therefore sought to study Titan-relevant evaporite materials in the laboratory to better constrain the processes that may be occurring in and around Titan's lakes.

2. Methods

The University of Arkansas owns a specialized Titan simulation chamber that reproduces Titan surface conditions [9]. This chamber is unique in that it provides real-time experimental data on the composition of simulated hydrocarbon samples. We maintain a 1.5 bar atmosphere with pressurized N_2 and sustain temperatures of 89 K – 94 K with liquid nitrogen (LN_2).

After the compounds were added to the condenser and given time to condense and dissolve into the solvent, a solenoid valve was turned on, which allowed the liquid sample to transfer from the condenser to the sample dish at the bottom of the chamber while a balance continuously weighed the sample. A layer of Spectralon®, which serves as a background for two-way transmission IR spectroscopic measurements, covers the sample dish. Here, the sample was analyzed via Fourier transform infrared (FTIR) spectroscopy probes connected to a Nicolet 6700 FTIR (wavelength 1–2.5 μm) using a TEC InGaAs detector, CaF_2 beamsplitter, and white light source.

The mole fractions of each compound were calculated from the experimental spectra using a spectral unmixing model. Each sample's spectrum was fitted with a linear combination of pure component spectra, with a least-squares calculation leading to the best fit. Additionally, the balance data was used to measure the evaporation rate of CH_4 and C_2H_6. The evaporation rate was assumed to be directly proportional to the surface area in contact with the nitrogen atmosphere. Errors were measured through Markov Chain Monte Carlo simulations.

3. Results and Discussion

Three types of experiments were repeatedly analyzed for C_2H_4 evaporites: CH_4/C_2H_4 (Fig. 1), C_2H_6/C_2H_4, and $CH_4/C_2H_6/C_2H_4$. Through band depth measurements (Fig. 2), mass data, and spectral data analysis, we determined that a C_2H_4 evaporite only formed in the CH_4/C_2H_4 experiment (Fig. 1). These results imply that on Titan, C_2H_4 evaporites may form in CH_4-dominated lakes on short timescales, but may also form with C_2H_6 on longer timescales. We observed red shifts in C_2H_4 bands at 1.64 μm ($\nu_5 + \nu_9$) and 2.12 μm ($\nu_9 + \nu_2$). These red shifts represent a phase change from dissolved C_2H_4 to solid C_2H_4. Additionally, we observed the persistence of a band at 1.666 μm. This band was unusual in the fact that it was present in pure CH_4, however band depth measurements and our spectral unmixing model confirmed complete CH_4 evaporation by the end of the experiment. The persistence of the 1.666 μm band may be explained by CH_4 remaining in contact with the C_2H_4 evaporite layer.

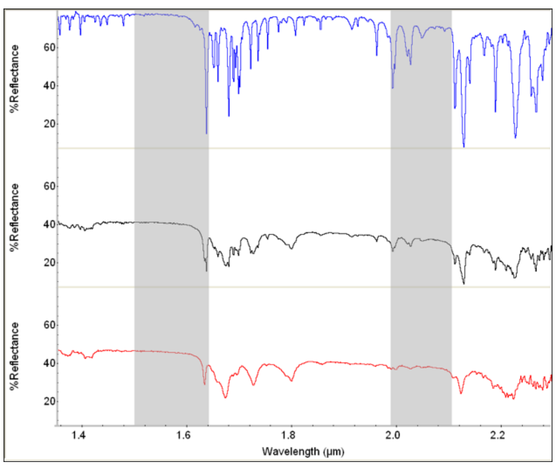

Figure 1: Spectra from a C_2H_4/CH_4 experiment showing initial (red, bottom), intermediate (black, center), and final (blue, top) spectral samples. Gray rectangles highlight VIMS atmospheric windows.

The final CH_4 evaporation occurred between t = 146 and 185 minutes (Fig. 2). During evaporation (t = 165 minutes), the mole fraction of C_2H_4 was measured at 0.59 mole fraction. This value is comparable to 0.56 mole fraction of C_2H_4 calculated in a previous study [8]. From the mass data, we calculated an average methane evaporation rate of $(2.80 \pm 0.63) \times 10^{-4}$ kg s^{-1} m^{-2}, which is consistent with the value calculated for pure CH_4 in a previous study [6].

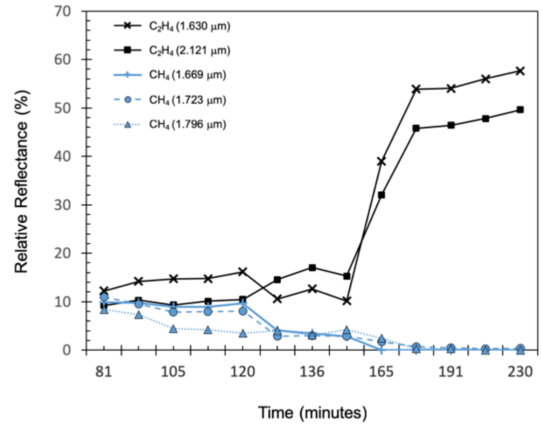

Figure 2: Band depth values from a C_2H_4/CH_4 experiment showing saturation of the sample at t = 165 minutes.

4. Summary and Conclusions

Under Titan conditions, we experimentally formed C_2H_4 evaporites in a solution of CH_4 and derived saturation and evaporation values for these samples based on spectral and mass data. We also observed red shifts of C_2H_4 bands and the persistence of a CH_4 band that may remain in contact with the evaporite. Future experiments will include additional evaporite compounds (e.g. C_6H_6, C_2H_2, CH_3CN, C_2H_3CN) and mixtures with multiple solutes. Enhanced sample analysis will be provided by a new Raman spectral probe and other updates to the Titan chamber. Our results insinuate interesting chemistry is occurring in Titan's lakes, and understanding the laboratory context of Titan's evaporites can help unlock these mysteries for future exploration.

Acknowledgements

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