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The hydrostatic effects on the phase equilibria involving liquid on Titan

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Abstract

Liquid bodies in Titan's lakes/seas are subject to hydrostatic effects that in turn introduce a pressure gradient from the surface to the bottom of the bodies. Incorporating the effects makes the thermodynamic modeling more realistic and tells whether another phase may appear at some depth, thus explain phenomena such as the transient features, also known as "magic islands", observed in Cassini's flybys.

1. Introduction

The properties and behavior of chemical systems with components in multiple phases are often keys to physicochemical processes in the atmosphere, surface, and subsurface in planetary geochemistry and climate studies. Until in-situ measurements can be made regularly, thermodynamic modeling, in which an equation of state (EOS) is developed to represent the systems, is the best way for analyses.

Conventional EOS, e.g. virial and cubic EOS, cannot deal with condensed phases and are handicapped by limiting assumptions that hinder their applicability to the non-ideal systems on planetary bodies. A recently developed EOS, referred to as CRYOCHEM, has been successfully applied to model Titan's lower troposphere [1] and then extended up to the tropopause after including solid phases [2], where Huygens data of methane mole fraction is well reproduced. The description of complex phase equilibria in Ref [2] is verified by observations in lab experiments [3]. The model also made predictions on surface-liquid compositions that are consistent with related observations, i.e. Titan's northern lakes were correctly predicted to be rich with methane instead of ethane [4] as also derived from observations by Cassini [5]. In further applications, with its ability to represent solid solutions, CRYOCHEM has successfully described solid-phase equilibria on Pluto's surface [6] that are consistent with recent work derived from observations by New Horizons, for example, Cthulhu Regio, the temperature of which never falls below 42.5 K [7], does not show volatile abundances as solid phase on the surface [8], and Tombaugh Regio, temperature of which never rises above 37.0 K [7], has solid that is rich with nitrogen on the surface [8].

While liquid phase on Titan's surface may be commonly assumed to be in equilibrium with the atmosphere, it aggregates into liquid bodies in lakes or seas with some depths from the surface. The current model of the phase equilibrium does not account for the hydrostatic effect arising from the gravity that effectively introduces a vertical pressure gradient in the liquid body. Recalling that the phase equilibria are very sensitive to temperature and pressure [2], the pressure gradient would likely play an important role in determining the phase(s) that physically exist in the liquid-atmosphere system.

This work will show the phase equilibria that may appear due to the pressure gradient in the liquid body, which is a step forward in improving the model for sea/lake liquids on Titan. The results can be used in evaluating, for example, whether the transient features seen on Ligeia Mare [9] are phase-equilibrium phenomena; specifically, the appearance of another phase, either a second liquid [2,3,10] or even a floating solid, both rich in ethane [2,3].

2. Approach

To a first approximation, temperature gradient that may be introduced by the surrounding crusts is assumed to be negligible, so that the effects will come solely from the pressure gradient, thus the hydrostatic effects. The temperature is consequently considered uniform as an average from the surface to the bottom of the liquid bodies.

This investigation can be carried out by incorporating the gravitational potential into the framework of CRYOCHEM, which is based on statistical molecular thermodynamics with the Helmholtz energy as the main building block [1]. When a multicomponent mixture is in a stable phase in a gravitational field at a fixed temperature, the sum of chemical potential of each component and its gravitational potential is constant throughout the column of the mixture.

As before [2], Titan's fluid is modeled as a mixture of three most abundant chemical species on Titan, i.e. nitrogen, methane, and ethane. The liquid surface is assumed to be in equilibrium with the atmosphere. Two average temperatures will be presented: 90 K and 85 K. The overall composition used for the phase-equilibrium calculations is 5.65% methane, 0.0038% ethane, and nitrogen as the balance [2].

3. Results

The results will be presented in ternary phase diagrams, such as that in Figure 1 for the phase equilibria on the surface at 85 K and 1.7 bar. It has four two-phase regions LV, S_3L, LS_2, and S_3V as well as one three-phase region S_3LV.

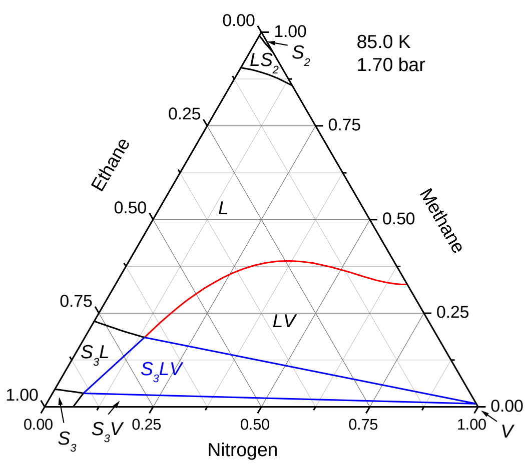

Figure 1: The phase diagram of nitrogen(1)/ methane(2)/ethane(3) at 85 K and 1.7 bar. V is the vapor region, L is the liquid region, and two solid regions S_2 and S_3, which are rich with methane and ethane, respectively.

Conditions along the depth in liquid at 90 K and 85 K will be investigated. They will tell whether another phase appears at some depth. Phase diagrams at some interesting conditions will be displayed. Densities and compositions of phases will also be presented.

4. Conclusions

By taking the hydrostatic effects into account, the phase equilibria predicted using CRYOCHEM are more realistic as the compositional grading due to the gravitational segregation is included. It is a preliminary step towards a more complete model. Further improvement of this modification can be done by also accounting for the thermo-gravitational effects that introduce a vertical temperature gradient in addition to the hydrostatic pressure gradient.

Acknowledgements

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