EFFECT OF SEDIMENT CONCENTRATION ON TITAN FLUID DYNAMICS. Benjamin Brophy[1,2], Sandeep Singh[1], Vincent Chevrier[1], [1]Arkansas Center for Space and Planetary Sciences, University of Arkansas, [2]Department of Physics and Astronomy, Michigan State University (brophyb1@msu.edu)

Introduction:

Understanding the viscosity of fluids on the surface of Titan can tell us about the nature of flow on the surface, what size boulders can be transported, and whether waves form in Titan's methane lakes. The viscosity of any fluid is dependent on the temperature of the fluid and the concentration of sediments in the fluid [1,2]. Because of the narrow temperature range on Titan (90 K – 94 K) [3] the concentration of sediments within a fluid should be the dominating factor in viscosity variation [1,2]. Sediments expected to be dissolved in Titan fluids are tholins, nanophase particulates formed by irradiation of organic compounds in Titan's atmosphere [4].

The main objective of this study is to determine a model for the dependence of viscosity on the concentration of sediments in polar and non-polar solvents, and use the results to predict the flow of liquids on the surface of Titan.

Methods:

For prelimary investigation of sediment concentration effect on fluids, two polar solvents, acetone and ether, and two non-polar solvents, pentane and hexane were selected. The sediment used was silicon dioxide nanoparticles. This sediment was selected as an analogue to tholins due to similar structure properties (Fig. 1), non-reactivity in the solvents, and being on the same scale of density.

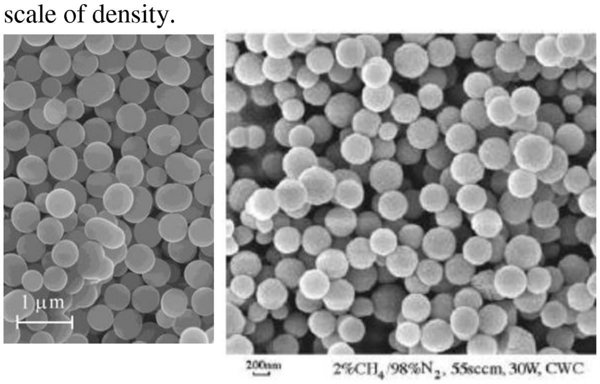

Figure 1: SEM images of Silicon Nanoparticles on left, tholins on right. (Img. credit [6,7])

Viscosity Measurement. EZ Viscosity Cups provide a quick method of measuring the viscosity of true liquids. The time it takes for a full cup of fluid to drain correlates to the kinematic viscosity of the fluid. The set of cups has different sized drainage holes to measure fluids of varying viscosities.

For the 10%, 20%, and 25% silica in acetone mixtures, the cup was filled from the top with a new batch for each measurement. For 12%, 14%, 16%, 18%, 22%, and 24% silica in acetone mixtures, one batch was made, and the cup was repeatedly filled by dipping in to the mixture. While this is the process recommended for viscosity cups, it turned out inappropriate for these mixtures which were not true liquids. The silica settled quickly out of the mixtures and clogged the drainage hole in the thickest mixtures, but in any case left residue in the cup. In addition, the acetone evaporated causing the proportion of silica in the mixture to increase over time.

Results:

The EZ viscosity cup manual provides a table to convert drainage time measurements to obtain kinematic viscosities. The density of each mixture was calculated from the the known density of the liquid and silicone dioxide nanoparticles (50 kg/m^3). Dynamic viscosity is then the mixture's kinematic viscosity multiplied by its density.

Acetone and silica. 10% and 12% mixtures were too thin to register on the viscosity cup scale, so they must have kinematic viscosities less than 10 centistokes.

In the case of data taken by repeated dipping, only the first several data points for each mixture were used. For example, in the 16% silica in acetone mixture, a trend in increase in flow time for each measurement is observed after791 kg/m^3 the third measurement, so only the first three measurements were used to determine the model.

At a fixed temperature, the relationship between dynamic viscosity and concentration is [1]

$$\eta = A * e^{\beta C \frac{\rho_b}{\rho_f}}$$

where η is dynamic viscosity, A is a constant with units of Pa-s which includes temperature dependence (temperature is fixed) and is theoretically the viscosity of the pure liquid, β is dimensionless constant, C is the concentration of sediment in the fluid, ρ_b is the density of silicon dioxide nanoparticles, 50 kg/m^3, and ρ_f is the density of the fluid.

$$\rho_f = C * \rho_b + (1 - C) * \rho_a$$

where ρ_a is the density of acetone, 791 kg/m^3.

The relation was fit to the following mean viscosity data for each concentration.

The final fit was found to be

$$\eta = 5.26 * 10^{-4} * e^{350C\frac{\rho_b}{C*\rho_b+(1-C)*\rho_a}}$$

and is plotted in Fig. 2.

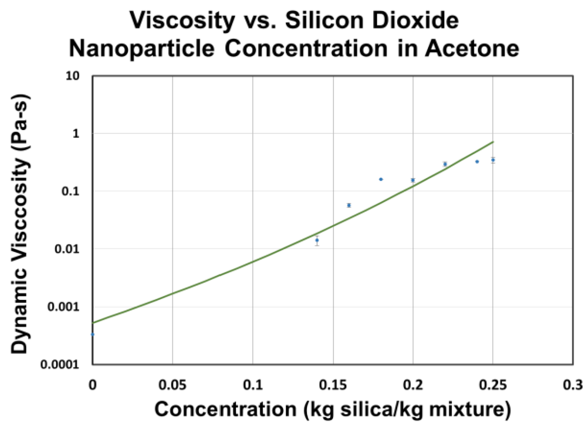

Figure 2

Ether, Pentane, Hexanes and Silica: All mixtures with these liquids were either not viscous enough to be registered on the scale of the viscosity cups, or the sediments settled too quickly to allow the liquid to completely flow through.

Numerical Model:

This relation between concentration and viscosity of a fluid was used in the numerical model of Titan fluvial features by Singh et al. 2013 [5]. We can use the β calculated from the acetone viscosity model to predict the behavior of methane viscosity on Titan. Then let A be the viscosity of pure methane at Titan conditions, $1.84*10^{-4}$ Pa-s, and density of liquid at Titan conditions be

$$\rho_f = C * \rho_b + (1-C) * \rho_m$$

where ρ_m is the density of methane at Titan conditions, 450 kg/m^3. Thus the final equation is

$$\eta = 1.84 * 10^{-4} * e^{350C\frac{\rho_b}{C*\rho_b+(1-C)*\rho_m}}$$

Figure 3 displays how various flow parameters are affected by concentration for different slopes under this model in a trapezoidal channel with width of 5 m and depth 1 m. The transition from turbulent to laminar flow at near 20% concentration is apparent, and a spike in both the average velocity and critical diameter appears at this point.

To move a boulder of 15 cm diameter, as observed at the Huygens landing site, at a slope of 0.1 deg, would require a sediment concentration of 3.7% and a fluid velocity of 1.16 m/s (Fig 3 a ,b).

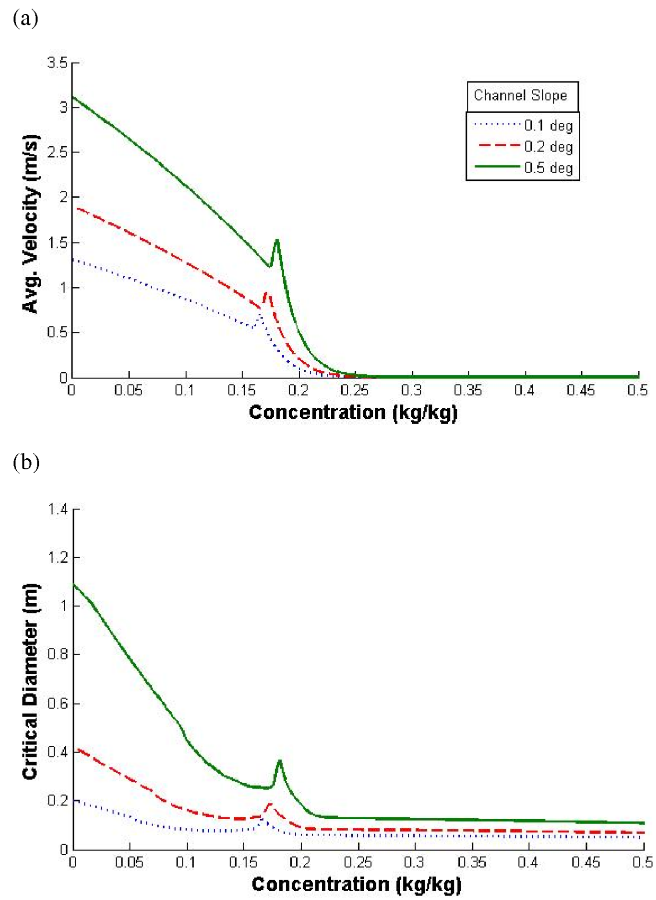

Figure 3: Blue, red, and green lines represent channel slopes of 0.1, 0.2 , and 0.3 deg respectively in a trapezoidal channel of width 5 m and depth 1 m. (a) Average velocity vs. concentration of sediments (b) Critical diameter vs. concentration

Acknowledgements:

This work is funded by NASA Outer Planet Research grant project # NNX10AE10G and NSF award #1157002.

References:

[1] S. Singh et al. (2014) (In prep). [2] Chevrier et al (2009) Geophys. v.114. [3] Wasiak et al. (2013) Adv. Space Res. 51, 1213-1220. [4] McKay et al. (2001) PSS. V. 49. 79-99. [5] Singh et al. (2013) 44th LPSC. #2913. [6] http://www.icare.univ-lille1.fr/progra2/database/indexeng.html [7] http://www.nanosciencekits.org/opal-building-blocks/