CRYOGENIC VISCOUS LIQUIDS ON ICY MoONS. D. G. Neighbour, S. S. Singh and V. F. Chevrier,
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Introduction: The study of cryogenically viscous liquids such as methane, nitrogen, and ethane offers critical insight into the behavior of fluids on icy moons such as Saturn’s moon Titan or even Pluto. Shrouded by a hazy hydrocarbon shield, Titan’s significant nitrogen atmosphere of 1.5 bar, methane-driven hydrological cycle, and lakes and rivers appear similar to Earth. Upon landing, Huygens photographed its landing site, as seen in Figure 1 [1]. The photo depicts rocklike objects, thought to be comprised of water ice sitting in a dry river / lake bed with diameters 15 cm (left object) and 4 cm (right object). Their rounded shape and the darkened depressions at their bases indicate erosion due to fluvial travel. However, the exact properties of the fluid that eroded these objects are still unclear. These properties can be partially determined from the viscosity, which is dependent on both the nature of the fluid and the sediment load of fine particles. On Titan, the atmospheric chemistry generates large amounts of aerosols (tholins) that slowly accumulated on the surface and probably affected the rivers and lakes.

Therefore, through analysis of the viscosity of liquid hydrocarbons mixed with tholins, conclusions regarding the effect of sediments on fluid dynamics on planetary bodies can be obtained.

Table 1. Relevant liquid properties compared to methane and ethane.

<table>
<thead>
<tr>
<th>Name</th>
<th>Formula</th>
<th>Density (g/cm³)</th>
<th>Viscosity (mPa*s)</th>
<th>Melt (K)</th>
<th>Boil (K)</th>
<th>Psat (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>0.4515</td>
<td>0.1934</td>
<td>90.69</td>
<td>111.51</td>
<td>11.7</td>
</tr>
<tr>
<td>Ethane</td>
<td>C₂H₆</td>
<td>0.6515</td>
<td>1.281</td>
<td>90.37</td>
<td>184.33</td>
<td>0.9011</td>
</tr>
<tr>
<td>Acetonitrile</td>
<td>C₂H₆N</td>
<td>0.786</td>
<td>0.343</td>
<td>227</td>
<td>354</td>
<td>9.6697</td>
</tr>
<tr>
<td>Acetone</td>
<td>(CH₃)₂CO</td>
<td>0.791</td>
<td>0.3311</td>
<td>179</td>
<td>330</td>
<td>24.61</td>
</tr>
<tr>
<td>Hexane</td>
<td>C₆H₆</td>
<td>0.6548</td>
<td>0.294</td>
<td>178</td>
<td>342</td>
<td>17.6</td>
</tr>
</tbody>
</table>

Methods: Because methane and ethane are gaseous at room temperature, liquid hydrocarbons with similar properties were used for experimentation. In this study, acetone, hexane, and acetonitrile were examined (see Table 1 for a comparison with methane and ethane). Hexane was selected because it is a non-polar solvent (like methane and ethane) while acetone and acetonitrile were selected for their polar properties.

Moreover, tholins are notoriously difficult to synthesize, and the amounts required for our study prevented any experimental method. Therefore, silicon dioxide nanoparticles were used as analogues to Titan tholins, based on their similar size and morphology (Fig. 2) as well as chemical inertness (to prevent any reaction between the solvent and the particles). By employing liquid hydrocarbons and nanoparticle silicates to simulate Titan conditions, the viscosity of liquids as a function of sediment concentration was obtained using a NDJ-1 rotary viscometer [2]. The viscosity of acetone, hexane, and acetonitrile solutions was determined for nanoparticle concentrations ranging from 0 to 20 weight percent at 5 percent increments.

Each solution was tested continually for a 10 minute time period, with data (solution mass and dynamic viscosity) collected every 30 seconds during the first five minutes and once per minute for the latter half of the testing period. Solution temperature before and after testing was also recorded.

Results: The plot of viscosity and nanoparticle concentration for each solution is displayed in Figure 3 below. As evidenced in the figure, the viscosity of acetone and acetonitrile solutions has no dependency on sediment concentration. For example, acetone’s viscosity at 20% concentration varies by a percent change of 19.6% as compared to the pure compound. For acetonitrile, there is a 14.0% percent difference between the viscosity of the pure compound and a solution with a
20% silica concentration. Alternatively, the viscosity of hexane is strongly dependent on the concentration of nanophase silica, with a percent change of 92.75% between zero and 20 percent silica concentrations.

**Discussion:** Previous analyses about terrestrial mudflows have shown that fluid viscosity follows an exponential function of the sediment concentration [3]. The following equation was used to equate dynamic viscosity ($\eta$, mPa*s) and percent concentration of nanophase silicates ($C$, % mL/mL) [4]:

$$\ln(\eta) = \ln(\eta_0) + \beta(C)$$  \hspace{1cm} Eq. 1

By using the known viscosity at fixed temperatures ($\eta_0$, mPa*s) [5], a dimensionless coefficient $\beta$ was calculated for the hexane compound.

![Graph showing the viscosity of acetone, acetonitrile, and hexane vs. nanophase silica concentration.](image)

**Figure 3:** Dynamic Viscosity of Acetone, Acetonitrile, and Hexane (mPa*s) vs. Nanophase Silicate Concentration (wt %), with $\beta$ value calculated using Equation 1.

Figure 3 indicates similar behavior of the acetonitrile and acetone solutions, while hexane performs differently. Acetonitrile and acetone’s dynamic viscosities do not display any trend with increasing nanophase silica concentration. However, hexane’s dynamic viscosity notably increases with silica concentration (Fig. 3). Hexane’s data also generated the smallest standard deviation, while experiments with acetone yielded the greatest standard deviation due to its lack of dependency of viscosity on sediment concentration.

The difference in viscosity between acetone and acetonitrile versus hexane is likely due to particulate settlement in the testing beaker. Upon agglomeration, nanophase silica becomes a ‘fluffy aggregate’ and settles much faster (an apparent increase of particle size is the only explanation for an increase of Stokes’ velocity). We suggest that this difference of behavior is most probably due to the polarity of the molecules and their interactions with the surface of the nanophase silica, an effect we will investigate in more detail in future experiments.

However, with respect to Titan, as evidenced by the results on hexane-silica solutions, the viscosity of methane and ethane lakes on Titan’s surface should be strongly affected by the presence of tholins due to the compounds’ non-polarity. Therefore, this could provide a simple explanation for the lack of waves on the surface of the lakes. Moreover, since settling does not occur, it would not require large concentrations of tholins to significantly affect the viscosity of the liquids. Future work will investigate the effect of such changes of viscosity of the fluid dynamics on the surface of Titan.

**Future Research:** Testing other non-polar solutions, especially those with varying structures (such as benzene’s ring structure), would assist in noting any cohesive trends among non-polar compounds.