NUMERICAL MODELING OF TITAN FLUVIAL FEATURES. S. Singh[1], V. F. Chevrier[1], R. Ulrich[2], [1]*Arkansas Center for Space and Planetary Science, University of Arkansas,* [2]*Department of Chemical Engineering, University of Arkansas (Fayetteville, AR, 72701, USA; sxs099@uark.edu).*

Introduction

A geologically active extraterrestrial world with similar fluvial landforms as Earth has been observed by Cassini-Huygens mission [1]. The surface of Titan has been observed by infrared and radar wavelength ranges suggesting dendritic patterns, lakes, rivers valleys and erosional remnants [2,3,4]. Other than Earth and Mars, Titan is the only body in our solar system with active atmosphere and surface liquid. Greenhouse and Anti-greenhouse effects in the Titan atmosphere keeps surface temperature of ~94K to constrain methane and ethane to be the only fluids in liquid form and to participate in a methanological cycle [5].

Imaging Science Subsystem (ISS) in Cassini have confirmed low albedo valley network and outflow channels [2]. At Huygens landing site, there was no evidence of any liquid as shown by the Descent Imager Spectral Radiometer (DISR) [1]. However, some moisture was detected by GCMS in the subsurface [6]. Images taken during the Huygens probe's descent were at higher resolution than that of the Radar instrument on the Cassini orbiter providing information on flow features. Stereo images were taken that allowed estimation of incision angle of the channels. Geometry of the channels can be constrained by using width and incision angles of the channels. When paired with the fluid characteristics of flowing liquid methane, constraints can then be placed on the grain size that the fluid in the channel can transport.

The objective of this study is to place minimum constrains on the fluid properties within Titan's large fluvial features to identify the maximum boulder sizes transport that liquid methane flow could support [7]. Equations governing erosion processes remains the same as used in Martian gully code [8], but those of fluid characteristics are altered, as are planetary properties.

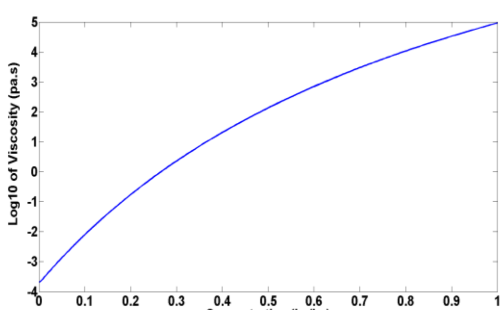


Figure 1: Viscosity vs. Concentration of water ice sediment in the liquid methane flow.

Method

The viscosity determines the internal forces of the fluids and how they behave [8] viscosity can be determined by its dependency on both temperature and concentration. Experimental data obtained from Hanley et al. (1977) [9] was used to generate a new temperature dependent viscosity equation on temperature (T). It has been accepted that viscosity η increase exponentially with the volumetric concentration of fine sediments C [10]. Using the temperature equation and combining with viscosity equation, the concentration dependent viscosity equation is:

$$\eta = 0.0018 e^{-0.025T} e^{\beta C(\frac{\rho_b}{\rho_f})} \quad (1)$$

Where β is he empirical coefficient [10], ρ_b & ρ_f are bolder and fluid densities (kg m^{-3}) respectively. Eq. 1 calculates the viscosity (Pa s) at given temperature and concentration (Fig. 1). The average velocity of a fluid flowing in a channel is defined by classical hydraulics Darcy-Weisbach equation [8]:

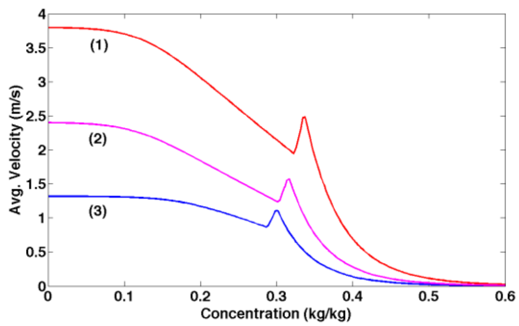
$$g(\Delta z) = f \frac{L}{d_{hyd}} \frac{V_{avg}^2}{2} \quad (2)$$

Where g is the gravity on Titan (1.35 m s^{-2}), Δz is the elevation drop over flow distance, f is the Darcy friction factor, L is the flow distance down the slope, d_{hyd} is the hydraulic radius of the channel (in this case trapezoidal), and V_{avg} is the resulting average flow velocity. Once the average velocity is known the forces created by drag force and boulder's weight are calculated. Setting both the forces equal to each other boulder diameter d is calculated:

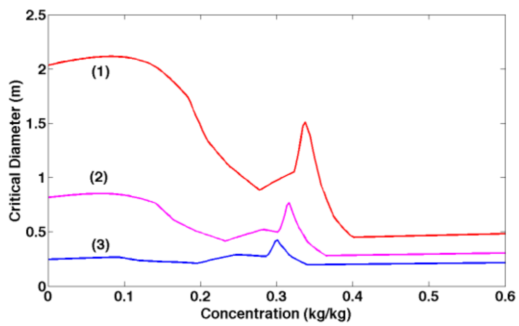
$$d = \frac{3\rho_f C_D V_{avg}^2}{4g(\rho_b - \rho_f)} \quad (3)$$

Where C_D is the drag coefficient; Eq. (3) calculates the boulder's diameter which is less than the liquid depth. If the boulder size comes out to be larger than liquid depth then a different a solution is approached.

(a)



(b)



(c)

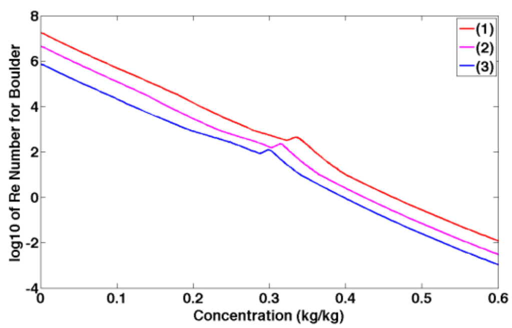


Figure 2: 1, 2, 3 represent the channel slope of 0.5, 0.2, 0.1 degrees respectively with fluid depth of 2m and width of 100m. (a) Average velocity of the flow vs. concentration of the sediments. (b) Critical diameter vs. concentration (c) Reynolds number vs. concentration

Results

This study estimates the amount of fluid flow in the channel needed to transport 15cm diameter water ice boulder as seen at Huygens landing site. The fluid depth used is 2m and the width of 100m for the flow channel. Results yielded that to move a boulder size of 15 cm in diameter it requires 1.5m/s of fluid velocity at the channel slope angle of 0.1 degrees (Fig. 2 a, b). The channel slope angle is directly related to the fluid velocity and the average size of boulder movement. We have considered the trapezoidal channel in this case so the channel angle has not much effect of the flow.

The temperature effect on viscosity was minor, several orders of magnitude lower than the concentration in sediments. Fig. 2(b) shows that there are three types of flow depending on the concentration of sediments. With high sediment concentration a laminar flow was observed with low flow velocity resulting in lesser diameter size boulder transport. We have also observed a transitional flow with very high velocities at around ~ 25% to 35% of sediment load in the fluid. As we see during the transitional flow, there is a strong increase of velocity which is due to the drop in friction factor because of the *Re* ~ 2000 (Fig. 2c). As mentioned by [8] in section 4.2 any turbulent eddies caused by flow energy will disappear and all that energy is available for the flow resulting in velocity increase. Reynolds number is a dimensionless number used as one of the quantities to calculate the friction factor. Fig. 2(c) Cleary shows the laminar, transition and turbulent flow regimes as Reynolds number increase. The turbulent flow is noticed at ~ 25% to 0% of sediment load with greater velocities and greater boulder movement.

Discussion

We have successfully calculated the dependency of liquid methane viscosity on the concentration and temperature. Flow features on Titan are generally considered as channels and river valleys [11]. Both triangular and trapezoidal channels have been observed. In this section, we have considered only trapezoidal channels for our hydraulic diameter calculations resulting different flow velocities. Future work considering sheer stress to constrain the lower limit of flow is in progress. Sheer stress dependency on the fluid will constrain the laminar flow velocities. It will be really interesting to see how the boulder size is affected by the change in laminar flow.

References

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