

# **Project Title: New Propellants and Cryofuels**

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## **Project Goals**

The proposed research will investigate the stability and cryogenic properties of solid propellants that are critical to NASA's goal of realizing practical propellant designs for future spacecraft. We will determine the stability and thermal properties of a solid hydrogen-liquid helium stabilizer in a laboratory environment in order to design a practical propellant. In particular, we will explore methods of embedding atomic species and metallic nano-particulates in hydrogen matrices suspended in liquid helium. We will also measure the characteristic lifetimes and diffusion of atomic species in these candidate cryofuels.

The most promising large-scale advance in rocket propulsion is the use of atomic propellants; most notably atomic hydrogen stabilized in cryogenic environments, and metallized-gelled liquid hydrogen (MGH) or densified gelled hydrogen (DGH). The new propellants offer very significant improvements over classic liquid oxygen/hydrogen fuels because of two factors: (1) the high energy-release, and (ii) the density increase per unit energy release. These two changes can lead to significant reduced mission costs and increased payload to orbit weight ratios. An achievable 5 to 10 percent improvement in specific impulse for the atomic propellants or MGH fuels can result in a doubling or tripling of system payloads.

The high-energy atomic propellants must be stored in a stabilizing medium such as solid hydrogen to inhibit or delay their recombination into molecules. The goal of the proposed research is to determine the stability and thermal properties of the solid hydrogen-liquid helium stabilizer. Magnetic resonance techniques will be used to measure the thermal lifetimes and the diffusive motions of atomic species stored in solid hydrogen grains. The properties of metallic nano-particulates embedded in hydrogen matrices will also be studied and analyzed. Dynamic polarization techniques will be developed to enhance signal/noise ratios in order to be able to detect low concentrations of the introduced species. The required lifetimes for atomic hydrogen and other species can only be realized at low temperatures to avoid recombination of atoms before use as a fuel.

## **Goals for 2005**

**I. Manufacture and characterization of particulates.**—The goal is to test different techniques for producing the solid hydrogen matrices; slow adiabatic cooling of gas mixtures versus rapid injection of hydrogen gas into a pressurized cold helium gas cell. We propose to determine the particle size, diffusion constants and lifetimes of species introduced into matrices prepared by each method to determine optimum conditions for producing a stable cryogenic environment.

**II. Introduction of metallic species into the hydrogen particles.**—We will test methods of introducing metals into the hydrogen matrices by using two different techniques: (i) radio-frequency (RF) discharge dissociation of molecular hydrogen in the cryogenic injection path, and (ii) evaporation of metallic atoms from hot filaments in the hydrogen/helium gas stream in the condensation stream. Magnetic resonance (MR) techniques are the most effective for studying the atomic species *in-situ* because the MR frequency of each species is unique and can be studied independently. By this means we can determine the stability and obtain information about the surroundings of different atomic species.

## Accomplishments

Samples of finely divided hydrogen and methane suspended in liquid helium have been made. Two different methods were tested: condensation from gas mixtures onto cold surface, and injection of H<sub>2</sub>/He gas mixtures into cold helium gas.

The thermal characteristics, notably the relaxation times and thermal diffusion were determined from NMR measurements of the relaxation times T<sub>2</sub> and T<sub>1</sub> that are directly related to the critical path of thermal stability and the internal diffusion of the host matrix.

Methane samples were explored and found to be significantly more favorable than hydrogen slush. The two cryogenic matrices were compared by measuring T<sub>1</sub> and T<sub>2</sub> on CH<sub>4</sub>/He slush and comparing with H<sub>2</sub>/He slush.

## Important Conclusions

Based on our experimental findings we conclude that solid H<sub>2</sub> is not suitable as a host matrix due to the strong surface interactions of ortho-hydrogen molecules with helium at the surface of the hydrogen granules. Since solid H<sub>2</sub> has a strong surface scattering due to its large electric quadrupole moment and its rotational motion that persists to low temperatures, we explored solid methane which has no quadrupole moment as a new matrix.

The results determined from the analysis for the microscopic correlation times  $\tau$  leads to the following conclusions:

- For hydrogen slush the NMR relaxation rate is consistent with scattering at grain boundaries and/or surface (due to large quadrupole moment Q of hydrogen).
- For methane slush the NMR relaxation rate is consistent with the limiting factor in thermalization being internal diffusion as opposed to surface scattering.
- In terms of a host matrix for atomic propellants methane is therefore a better host than hydrogen because the grains of methane are better isolated from the helium bath.

## New Results on CH<sub>4</sub>/He Slush

From spin-spin relaxation times for freshly prepared methane-helium slush at 4.2 K we found two different exponents which show the existence of two time scales in the system. As methane has a very complex ground state at low temperature we carried out our measurement on CH<sub>4</sub>/He slush as the sample was aging with time. The new results show more than one time scales as the sample was aged.

## Publications and Presentations

1. Marcin Matusiak, Jaha Hamida, Gary G. Ihas, Neil Sullivan, *NMR measurements in hydrogen/helium slush at 4.2 K*, Bull. Am Phys. Soc. **48**, 928 (2003).
2. M. Matusiak, J.A. Hamida, G.G. Ihas, N.S. Sullivan, *Measurements of the nuclear spin relaxation times for small grains of solid hydrogen suspended in liquid helium*, Presented at Quantum fluids and Solids International Symposium, 2003.
3. M. Matusiak, J.A. Hamida, G.G. Ihas and N.S. Sullivan, *Journal of Low Temperature Physics* (to be published).
4. J.A. Hamida and N.S. Sullivan, *Transport properties of bulk hydrogen and hydrogen-helium slush at 4 MHz using NMR measurements*, Bull. Am. Phys. Soc. **49**, 550 (2004).
5. J.A. Hamida and N.S. Sullivan, *Nuclear spin relaxation times in hydrogen-helium and methane-helium slush at 4 MHz using pulse NMR*, was presented at APS March Meeting 2005.
6. J.A. Hamida and N.S. Sullivan, *Nuclear Spin Relaxation Times for Methane-Helium "Slush" at 4 MHz using Pulsed NMR* submitted to the JLTP, Proceedings of the Internat. Low Temp Conference, Orlando, 2005.

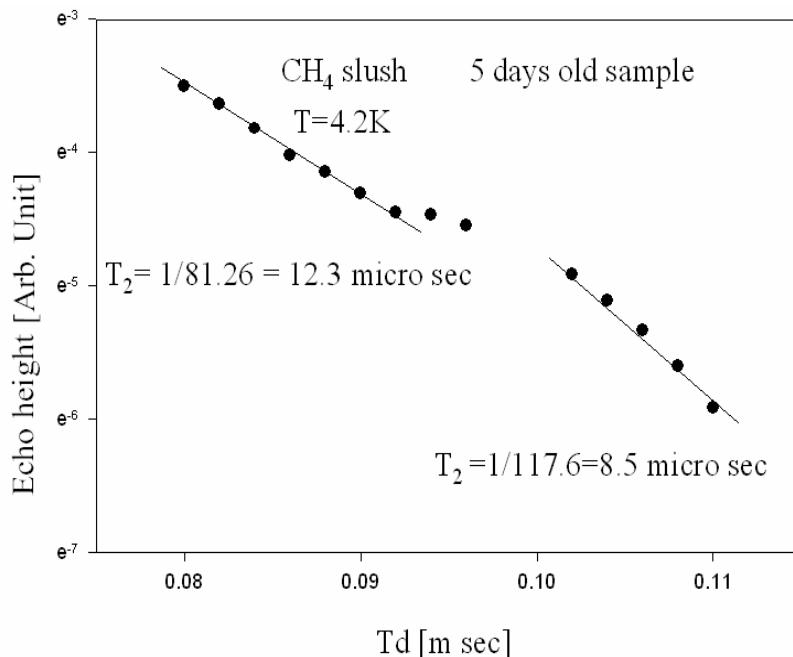


Figure 1.—Spin-spin relaxation times for methane-helium slush at 4.2 K for 5 days old sample. Two different exponents show existence of two time scales in the system.

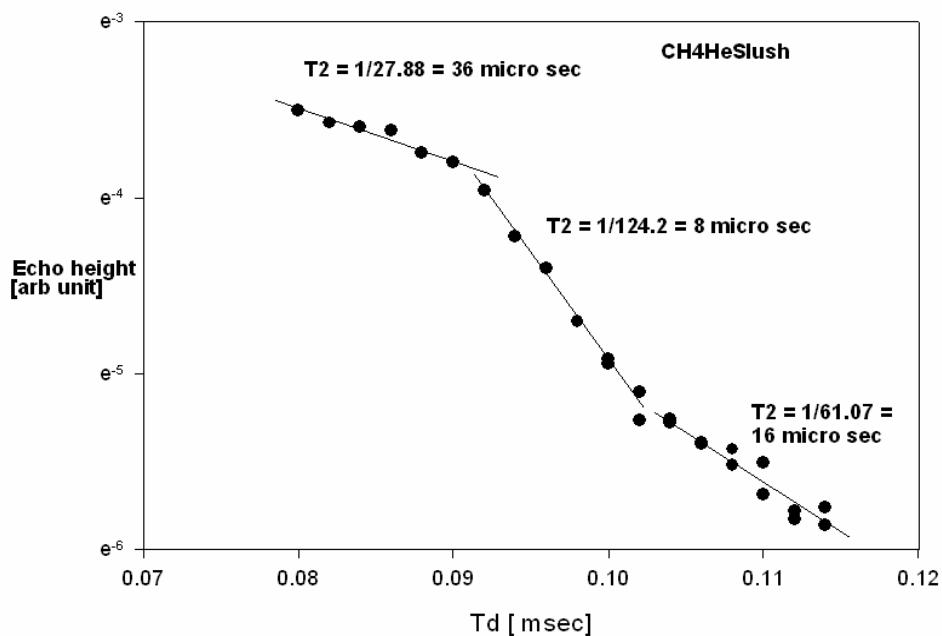


Figure 2.—Spin-spin relaxation times for methane-helium slush at 4.2 K for 21 days old sample. Three exponents show three different time scales in the system.