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Helium Solubility in MMH and NTO

A test program to characterize the solution of helium in nitrogen tetroxide/mixed oxides of nitrogen (NTO)/(MON) and monomethylhydrazine (MMH) at anticipated flight-representative pressures/temperatures was completed. Updated relations for helium solubility in MMH and NTO were generated and documented.

Background

One of the problems encountered in the development of liquid bipropellant rocket engines is the occurrence of low-frequency instabilities, some of which can lead to a phenomenon referred to as chugging. Chugging is caused by a dynamic coupling of the propellant feed system with the combustion dynamics in such a way that it amplifies any disturbance in pressure or propellant flow. Instabilities (e.g., chugging) have been issues for 60 years. Chugging mitigations are often hardware specific and include avoiding the operating regimes that generate instabilities, changing line and manifold volumes, and other design considerations. It has been demonstrated that chugging can be significantly affected by the propellant pressurant, specifically helium, transitioning into and out of solution.

During a literature search for a previous NESC study [ref. 1], it was found that many of the reports containing data on helium transitioning into solution (i.e., MMH, NTO and MON) were reprinted data that were obtained from other sources. Sorting through the reports allowed the original source data to be identified. These various data threads were illustrated to provide improved understanding of the available information and indicated significant scatter in the helium solubility data for both NTO/MON and MMH.

Helium Solubility Testing

A test program was conducted to characterize the solution of helium in NTO/MON and MMH at anticipated flight-representative pressures/temperatures. The testing was conducted at The Aerospace Corporation in El Segundo, California. The testing utilized equipment that had been used for measurements of helium solubility in hydrazine [ref. 2] and was a modified version of the original method used by Chang [refs. 3, 4] (see Figure 1). The major apparatus change from the work of Chang et al. was the use of a steel cylinder instead of a glass bulb, thereby allowing higher pressure test conditions. The current effort used Teflon-lined stainless-steel cylinders that could be safely pressurized to 12.4 MPa (1800 psia). The maximum pressure of the entire system is 6.9 MPa (1000 psia), which is based on the valves as they have the lowest pressure rating. The experiments used two capacitance manometers (i.e., baratrons), the first ranging from 0.35 to 3.5 kPa (50 to 500 psia) and the second ranging from 0.69 to 6.9 MPa (100 to 1000 psia). Since the stainless-steel cylinders prevented the use of magnetic stirring as utilized by Chang et al., the setup was stirred externally by gently shaking. Tests in deionized water were used to calibrate the apparatus by measuring argon and helium solubility (see Figure 2). The same initial calibration sequence was utilized in the hydrazine solubility work [ref. 2].

Testing Results

The findings from the NESC study include:

- Past MMH datasets underpredicted the helium solubility at lower temperatures (i.e., less than ~20°C).
- The assumption of a linear dependence of mole fraction to pressure is valid for MMH and NTO over the temperature range of -18 to 80 °C and pressure range of 0.1 to 6.8 MPa.
- The updated relations for helium solubility in MMH and NTO from the current assessment are considered an improved prediction of the fully saturated condition compared to prior empirical fits.

References

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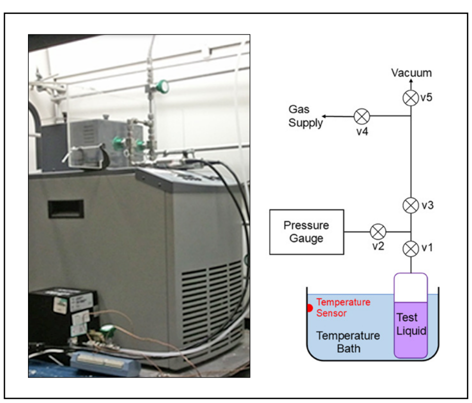

Figure 1: The Aerospace Corporation Test Setup

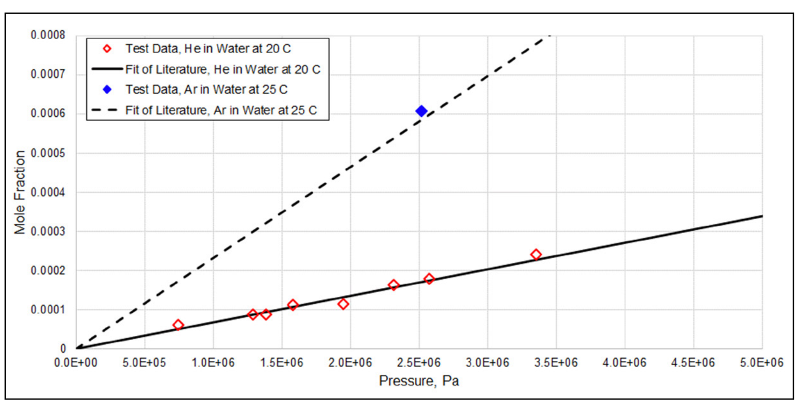

Figure 2: Solubility Tests of Helium and Argon in Water