Modelling the Effects of Dissolved Helium Pressurant on a Liquid Hydrogen Rocket Propellant Tank

HYPER: HYdrogen Properties for Energy Research

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Abstract

For decades NASA has used helium to pressurize liquid hydrogen propellant tanks to maintain tank pressure and reduce boil-off. This process causes helium gas to dissolve into liquid hydrogen creating a cryogenic mixture with thermodynamic properties that vary from pure liquid hydrogen. Traditional NASA models have been unable to account for this dissolved helium due to a lack of fundamental property information. Recent measurements have resulted in the development of the first multi-phase equation of state (EOS) for parahydrogen-helium mixtures. This new EOS has been implemented into NASA's Generalized Fluid System Simulation Program (GFSSP) to determine the significance of mixture non-idealities. A GFSSP model was developed for the self-pressurization of a liquid hydrogen propellant tank due to boil-off. The model was run simulating two conditions: 1) that the liquid propellant was pure liquid hydrogen and 2) that helium was dissolved into the liquid utilizing the new helium-hydrogen EOS. The analysis shows that dissolved helium in the propellant does not have a significant effect on the tank pressurization rate but does affect the rate at which the propellant temperature rises.

Background

Figure 1. Multi-Purpose Hydrogen Test Bed at Marshall Space Flight Center.

The self-pressurization model presented in this work is based on Example 29 in the GFSSP Supplemental Materials for version 701 which investigates the boil off rate of a liquid hydrogen propellant tank under the Multi-Purpose Hydrogen Test Bed (MHTB) program at NASA's Marshall Space Flight Center[1]. The 10 foot diameter aluminum tank is shown in Figure 1. Example 29 verifies the MHTB tank performance using a GFSSP model.

References

1. Majumdar, A., Leclair, A., Moore, R., Dorney, S., "Generalized Fluid System Simulation Program (GFSSP) Supplementary Documentation for Version 701". October 2015.
2. Zimmerli, G. A., Asipauskas, M., and Van Dresar, N. T., Cryogenics 50, 556-560 (2010).

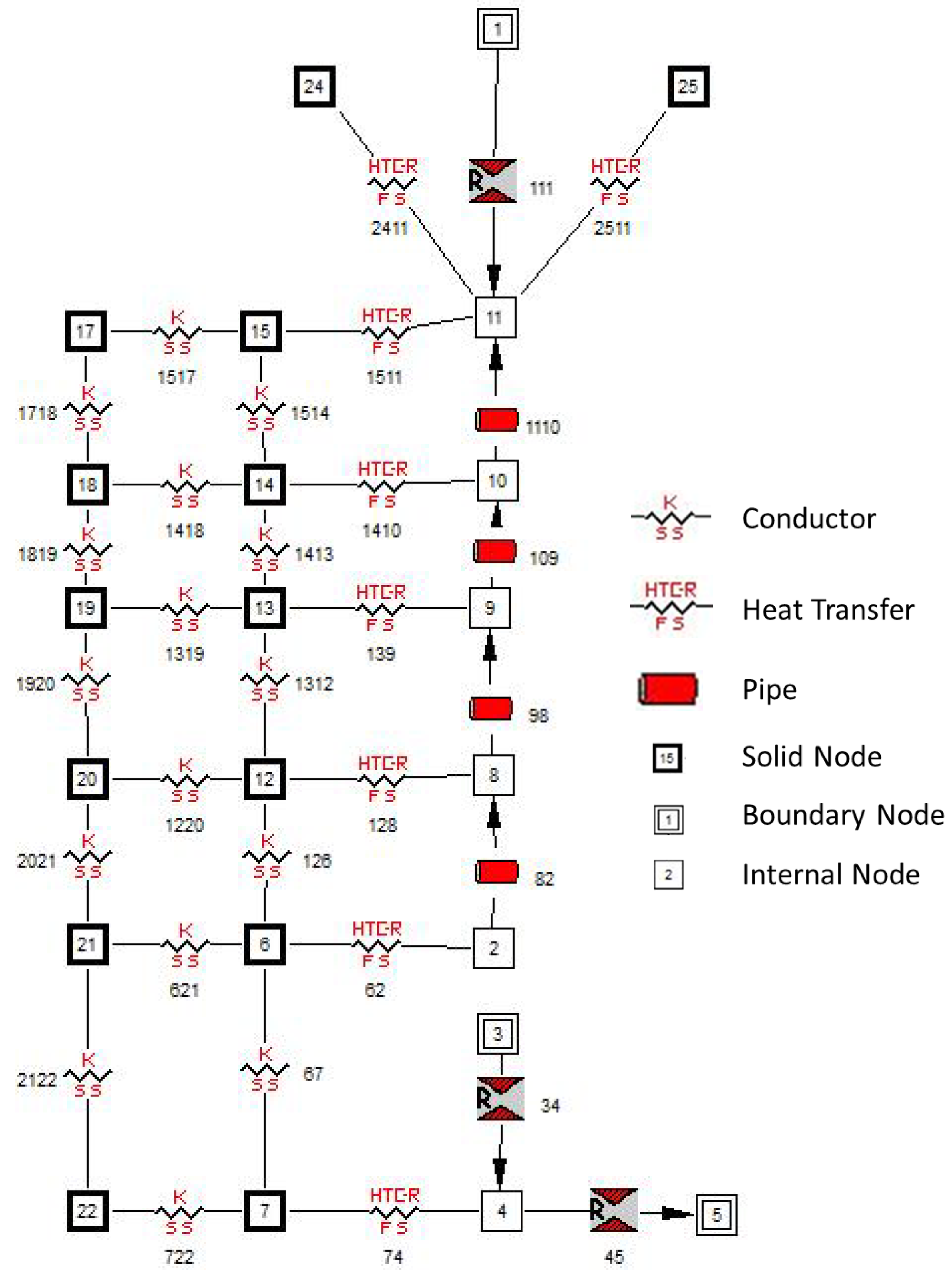

Figure 2. GFSSP self-pressurization of the liquid hydrogen propellant tank.

GFSSP Model

The model was kept identical to Example 29 with the exception of the MLI to compare results to the original model and ensure accuracy. The key takeaways of the model shown in Figure 2 are that Node 4 represents the liquid while nodes 2, 8, 9, 10, and 11 represent the ullage at fill levels of 54 %, 65 %, 80 %, 92 %, and 98 % respectively. The nodes on the left-hand side like nodes 7 and 22 are solid nodes representing the tank wall. Node 3 acts as a pseudo node to separate the liquid from the ullage. The model was solved assuming the liquid propellant was pure liquid hydrogen and then accounting for 0.17 mol % dissolved helium pressurant in the liquid propellant that occurs at -423˚F and 30 psia[2].

Results

The model revealed that dissolved helium pressurant does not have a significant effect on the tank pressurization rate but can slow the rise of the liquid propellant temperature by 0.2 ˚F over 10 hours for traditional propellant tank conditions. Figures 3 and 4 show the resulting tank pressurization and propellant temperature curves.

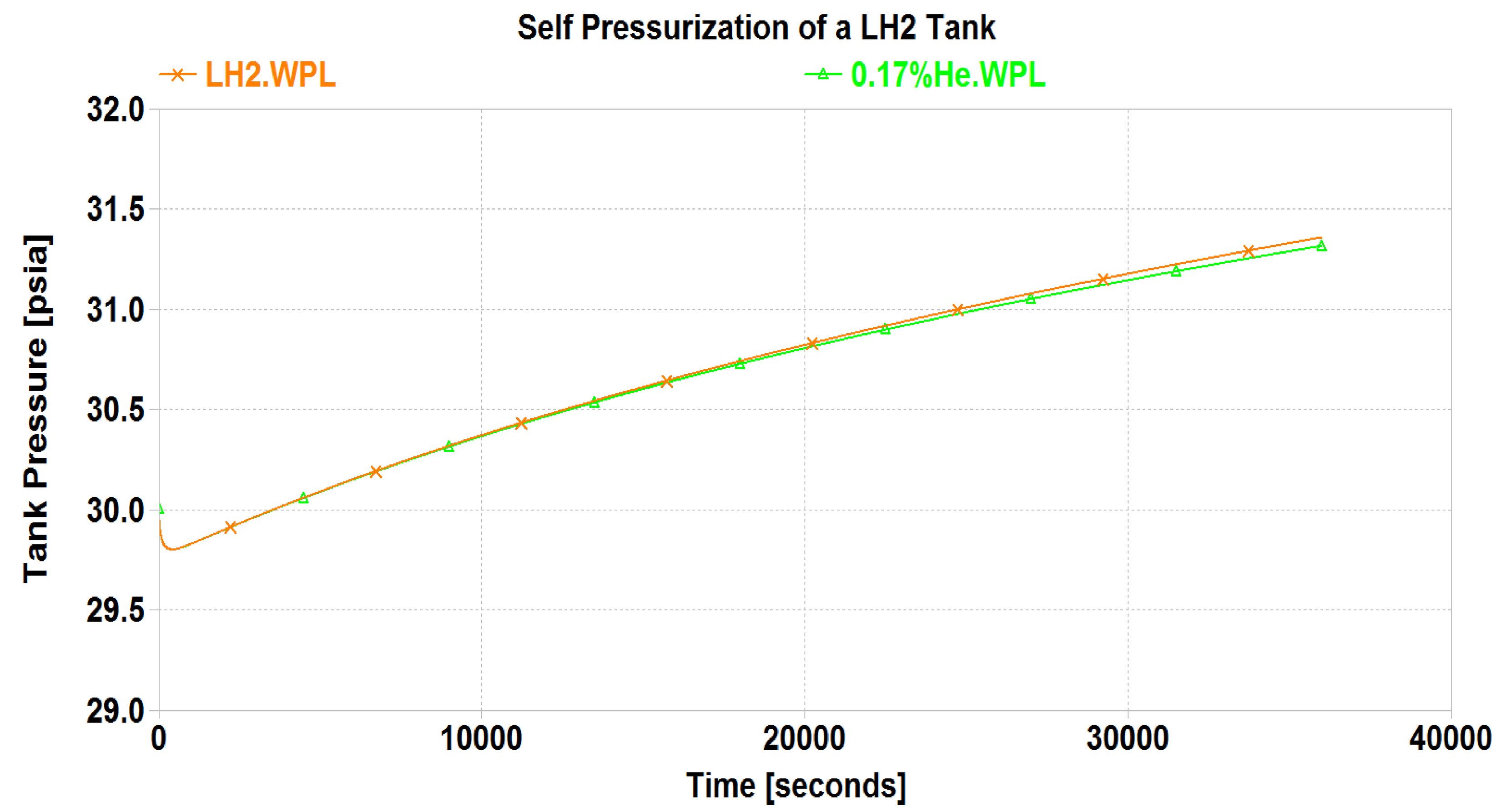

Figure 3. Comparison of the self-pressurization rate of a liquid hydrogen propellant tank assuming pure liquid hydrogen propellant (orange x's) and 0.17% dissolved helium in the liquid (green triangles).

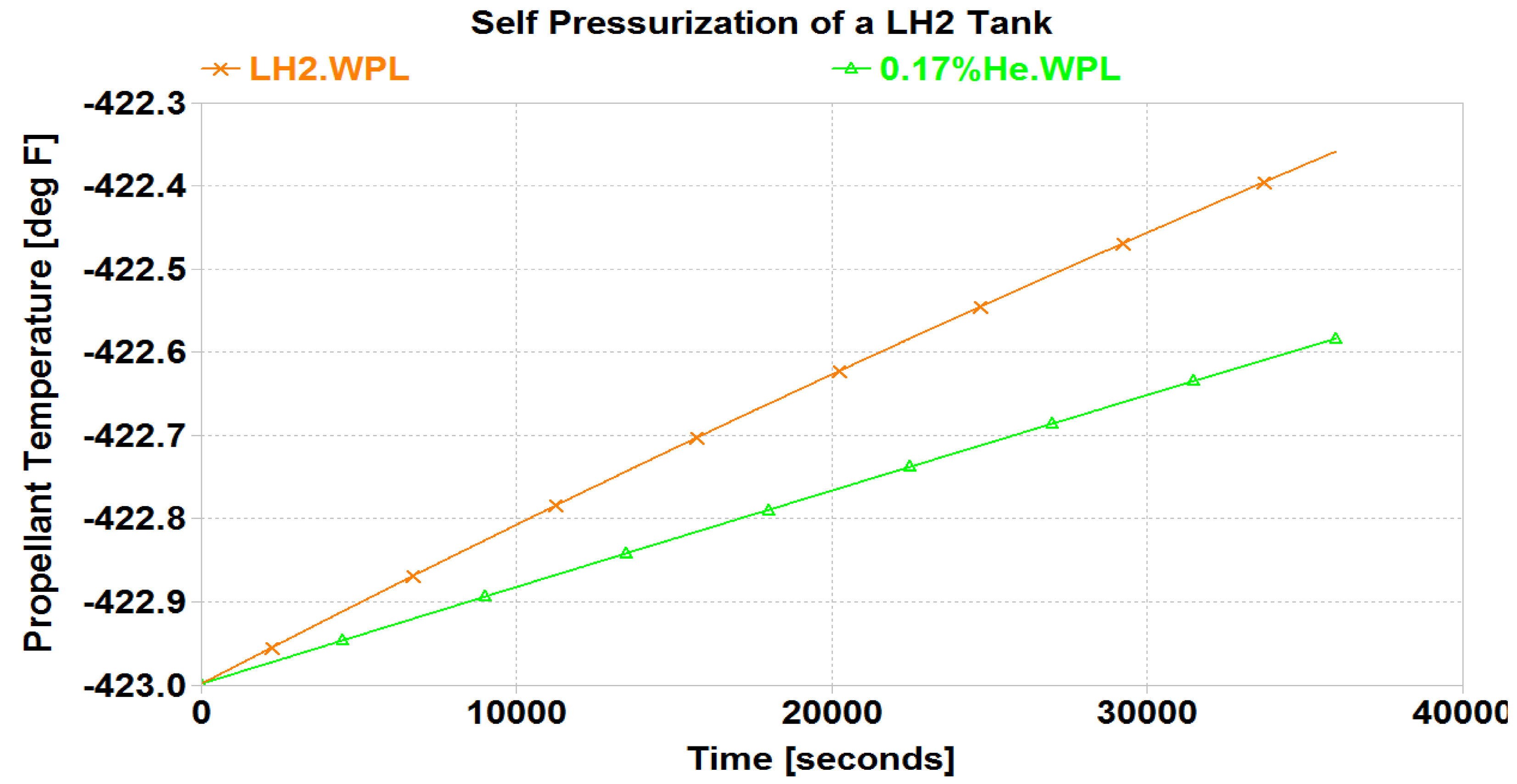

Figure 4. Comparison of the propellant temperature assuming pure liquid hydrogen propellant (orange x's) and 0.17 mole % dissolved helium (green triangles).

Recommendations

Under traditional liquid hydrogen propellant tank conditions (-423 ˚F and 30 psia) dissolved helium pressurant does not have a significant effect on the tank performance. However, as tank pressure increases, the amount of dissolved helium increases which will increase the effects on the tank performance. Little is known about the effects of dissolved helium and helium effervescence in liquid hydrogen as it pertains to rocket engines. Additional research is needed to determine when dissolved helium will come out of solution in liquid hydrogen and what effects it will have on subsequent systems.

Acknowledgements

The authors would like to thank Alok Majumdar and Andre Leclair from the Marshall Space Flight Center for their assistance setting up the GFSSP model. This work was supported by NASA Space Technology Research Fellowship grant NNX14AL59H.