National Aeronautics and Space Administration

NASA

TECHNOLOGY SOLUTION

Mechanical and Fluid Systems

3D-Printed Injector for Cryogenic Fluid Management

Minimize Boil-off When Filling Cryogenic Tanks

Innovators at the Marshall Space Flight Center have developed a system to minimize boil-off during cryogen transfer and storage using an additive manufactured injector with an augmented thermodynamic venting system (TVS). Cryogenic fluid transfer is important for both ground and space-based systems and typically requires venting of a receiver vessel during the chill and fill process to maintain a pressure favorable to fluid flow. NASA's TVS Augmented Injector offers an alternative system that gradually cools the inside of receiving tanks, improving cryogenic fluid transfer and storage efficiency and minimizing or eliminating the time the receiver tank vent needs to be open. The injector is a small piece of 3D-printed hardware that can be easily used with or integrated into tanks or filling equipment in any space or industrial application where a cryogenic fluid is being transferred. The injector may also be employed for long-term cryogenic fluid storage as a means of controlling tank pressure if integrated with a recirculation pump.

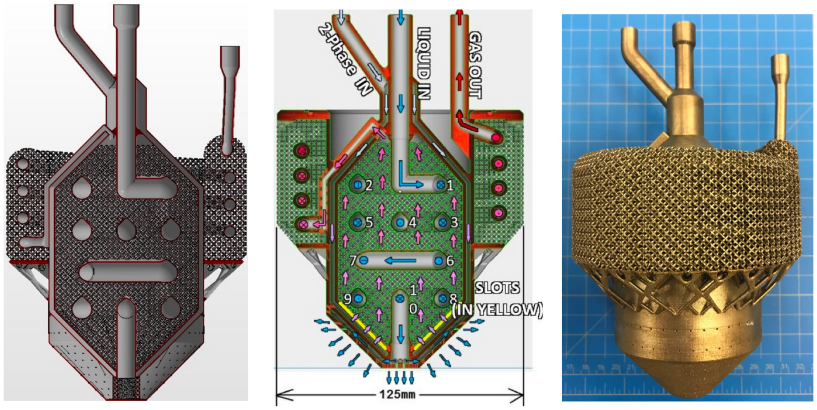
BENEFITS

- Less filling loss & lower cost: The injector prevents stored fluid from escaping during the filling process, increasing efficiency and requiring about 5-15% less liquid to fill the receiving tank
- Liquid reclamation: The unavoidable boil off that happens is drawn back into the injector, liquified, and largely reclaimed
- Higher filling levels: The injector allows filling levels approaching 100%
- Simple operation: The injector can be easily integrated into receiving tanks or filling equipment via mounting to small tank flanges
- Facilitates manufacturing and customization: An optimal injector can be easily designed for a given application (e.g., cryogen selection, injector material selection, dimensions, etc.) and manufactured using additive manufacturing (e.g., powder bed fusion)

THE TECHNOLOGY

NASA's TVS Augmented Injector includes an internal heat exchanger, a fluid injector spray head, and an external surface condensation heat exchanger - all combined with multiple intertwined flow paths containing liquid, two-phase, and gaseous working fluid. The TVS provides a source of coolant to the injector, which chills the incoming fluid flow. This cooled flow promotes condensation of the tank ullage dropping pressure and maintains incoming fluid flow. The system eliminates the potential for a stalled fill condition and reduces tank pressure during cryogenic fluid transfer. During fill operations, the tank vent can be closed early in the process before fluid is introduced, and, in some cases, the tank vent may not even need to be opened. Furthermore, the TVS Augmented Injector can remove sufficient thermal energy to reach a 100% liquid level in the receiver tank. A cryo-cooler can be used in place the TVS flow circuit for a zero-loss system. The TVS Augmented Injector couples internal fluid flow cooling and external surface ullage gas condensation into a single, compact package that can be mounted to small tank flanges for minimal impact insertion into any vessel. The injector is printed as one part using additive manufacturing, resulting in part count reduction, improved reproducibility, shorter lead times, and reduced cost compared to conventional approaches.

The injector may be of particular interest in applications where cryogenic fluid is expensive, fluid loss through vents is problematic, and/or achieving high filling levels would be helpful. The injector can benefit typical cryogenic fluid transfer between containers or, alternatively, can serve as a tank pressure control device for long-term storage using a fluid recirculation system that pumps fluid through the injector and sprays cooled liquid back into the tank. Additionally, where ISRU processes are employed, the injector can be used to liquefy incoming propellant streams.



Left: TVS Augmented Injector cross section; Middle: flow paths diagram; Right: injector prototype

APPLICATIONS

The technology has several potential applications:

- Aerospace: propellant resupply, long-term cryogenic fluid storage, etc.
- Cryogenics: transferring and storing liquid oxygen, hydrogen, helium, nitrogen, ISRU-produced propellant liquefaction, and more
- Industrial machinery: cryogenic fluid supply, transport, and equipment/tank manufacturing
- Oil and gas: liquid natural gas transfer
- Propulsion: liquid propellant storage/transfer

PUBLICATIONS

Patent Pending

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More Information

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