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DESIGN, MODELING AND SIMULATIONS OF A HIGH PRESSURE CRYOGENIC SYSTEM FOR A SPACE PROPULSION TEST FACILITY

Abstract

The current era demands innovative test benches to explore the combustion dynamics of cryogenic propellant combinations like Liquid Methane and Liquid Oxygen. These test setups typically feature cryogenic Storage Tanks transferring their contents to Run Tanks, pressurized for various experimental conditions.

Amidst this context, the conception of a jacketed double-vessel, vacuum-insulated cryogenic Run Tank emerges as a groundbreaking yet intricate solution to achieve subcooling under high pressure. The confluence of mechanical and thermal considerations adds complexity to their design, necessitating the careful selection of materials capable of withstanding vacuum, cryogenic temperatures, and high pressures.

Moreover, the deployment of such Tanks mandates a thorough thermo-mechanical assessment encompassing compliance with specifications, structural analysis using Finite Element Method (FEM), and the cooling mechanism facilitated by the liquid Nitrogen-operated jacket. This paper delves into the mechanical intricacies of the Tank, shedding light on its blueprint with a specific focus on the cryogenic components. Notably, the Run Tank comprises three primary elements: a high-thickness inner vessel tasked with pressurization; two thermal shields facilitating the circulation of liquid Nitrogen (LN2) to uniformly cool the inner vessel, mitigating the risk of weld cracking; and an outer vessel enveloping the inner vessel to enable vacuum pumping of the interstitial space, thereby minimizing thermal loads.

Furthermore, the study conducts a transient analysis of the cooldown process utilizing EcosimPro, incorporating thermal and fluidic dynamics to construct a comprehensive simulation. This modeling approach encompasses various phases such as cooldown, filling, pressurization, test bench feeding, and depressurization, specifically considering the fluid behavior of two-phase liquid oxygen or methane.

The outputs of this endeavor are twofold: initially, the determination of mechanical parameters (such as diameter, thickness, and materials) of the Tank contingent upon design requirements. Subsequently, an in-depth exploration of the fluid behavior during aforementioned operational phases, providing insights crucial for optimizing performance and ensuring operational safety.

The obtained results will serve as a crucial foundation for the impending commissioning phase, where operational challenges will be scrutinized to either corroborate or refine the simulation outcomes.