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C2Po1F-05 [35]: Effect of wall ribs on thermal stratification and self-pressurization in a liquid hydrogen tank

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Storage of cryogenic propellants in rocket fuel tanks gives rise to an undesirable phenomenon called thermal stratification. Large temperature difference between the cryogen and ambient results in significant heat leakage into the tank. The liquid near the walls heat up and flow to the interface due to natural convection giving rise to an axial temperature gradient inside the tank. Maintaining the temperature of the stratified liquid below the cavitation limit of the cryopumps is challenging. Extensive studies, both theoretical and numerical, on the growth of thermally stratified layer in cryogenic liquid tanks is well documented. Heat transfer degradation in the vicinity of ribs has been observed for a case of natural convection flow of air over a heated ribbed plate. This phenomenon can be utilized in delaying the stratified layer growth and consequently, the self-pressurization rate. The protrusion of ribs induces turbulence which enhances mixing of the heated liquid in the vicinity of the wall with the cooler bulk liquid. The result is a delayed stratification, and lesser boil-off rate. A numerical model of a 50 % filled liquid hydrogen tank of height 1.0 m and diameter 0.5 m with rectangular ribs of 40 X 40 mm cross-section was developed to analyse the stratification rate. A reduction in self-pressurization rate was observed compared to the smooth walled case. Better performance of semi-circular ribs in delaying stratification over rectangular ribs has been reported. This seems counter intuitive if the problem is looked at through the prism of aerodynamics. Rectangular rib being a less aerodynamic bluff body in comparison to a semi-circular rib should induce more turbulence and consequently, better mixing. The effect of a variety of wall rib (present on the inner wall) cross-sections like rectangular, semi-circular and triangular on self-pressurization rate hence requires a deeper understanding. Numerical model of a 50 % filled smooth walled liquid nitrogen tank has been validated with experiment. The physics can be extended to the numerical models on liquid hydrogen.

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