Simulation studies on cooling of cryogenic propellant by gas bubbling

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Introduction

Injection cooling can be used to store cryogenic liquids. It involves bubbling a suitable gas through the liquid. Liquid evaporates into gas bubbles due to the difference between the saturation pressure of the liquid and partial pressure of the liquid component in the bubble. The overall process involves simultaneous heat and mass transfer between the liquid and gas.

Objectives

- Modeling and simulation of the injection cooling system to determine the cooling performance.
- Study the effect of the bubble dynamics, bubble distribution and operating conditions on the liquid cooling.

Initial and boundary conditions

At 1 = 0, \( T_1 = T_0 \) and \( T_y = T_0 \)

\[ M_{in} = \frac{m_{in}}{S_y}, \quad M_{out} = \frac{m_{out}}{S_y} \]

Model equations

Volume fraction equation (Gas only):

\[ \frac{\partial (\rho \phi)}{\partial t} + \nabla \cdot (\rho \phi \mathbf{u}) = -\nabla \cdot \left( \rho \mathbf{F} + \rho \mathbf{F} \right) + \rho \mathbf{F} + \mathbf{F} \]

Momentum equation (Gas only):

\[ \frac{\partial (\rho \mathbf{u})}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = -\nabla \cdot \left( \rho \mathbf{F} + \rho \mathbf{F} \right) + \rho \mathbf{F} + \mathbf{F} \]

Energy equation:

\[ \frac{\partial (\rho E)}{\partial t} + \nabla \cdot (\rho E \mathbf{u}) = -\nabla \cdot \left( \rho \mathbf{F} + \rho \mathbf{F} \right) + S_e \]

\[ S_e = -k_s \left( T_{eff} - T_{F} \right) \]

Typical experimental setup

Injection cooling of a cryogenic liquid has been studied numerically.

The average rate of cooling is found for the case studied is about 0.00255 K in 5.05 seconds.

Future studies of injection cooling are aimed to carried out by considering the model is being modified to account for the shape and size of the bubbles, and the variable evaporation rate.

Results

- Contour plot of volume fraction for liquid Nitrogen at t= 5.05 s
- Contour plot of temperature at t= 5.05 s

Conclusion

- Injection cooling of a cryogenic liquid has been studied numerically.
- The average rate of cooling is found for the case studied is about 0.00255 K in 5.05 seconds.

Selected references