Simulation studies on cooling of cryogenic propellant by gas bubbling

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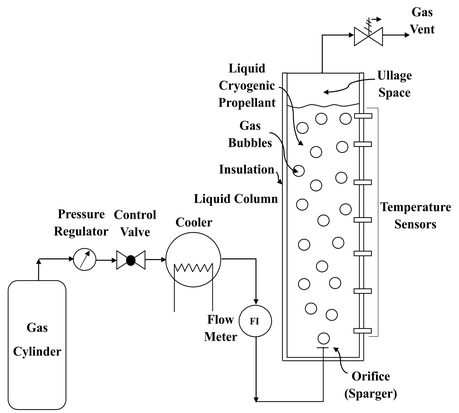
Introduction

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.

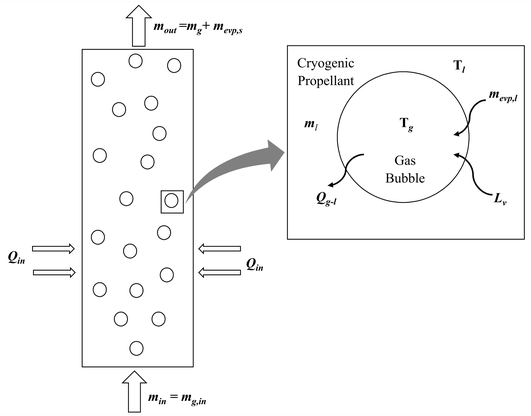
Objectives

- 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.

Typical experimental setup



Cooling mechanism



Assumptions

- Two dimensional mathematical model is considered.
- Injected gas is insoluble in liquid
- Zero heat inleak from the surroundings to the column.
- Constant evaporation rate from the liquid to gas.
- Constant bubble interfacial area.

Initial and boundary conditions

$$At\ t = 0, \quad T_l = T_{l_0}\ and\ T_g = T_{g_0}$$

$$At\ x = 0\ and\ x = R_{cyl}, \quad \frac{\partial T_l}{\partial x} = 0$$

$$At\ y = 0, \quad T_g = T_{g,in}\ and\ \frac{\partial T_l}{\partial y} = 0; \quad At\ y = L_{cyl}, \quad \frac{\partial T_l}{\partial y} = 0$$

Model equations

Volume fraction equation (Gas only):

$$\frac{\partial \alpha_k}{\partial t} + \vec{u}\,.\nabla \alpha_k = \frac{S_m}{\rho_k}\ ; \qquad \sum_{k=1}^{n} \alpha_k = 1\ ; \qquad \dot{M} = \frac{\dot{q}}{h_{fg}}$$

Momentum equation (Gas only):

$$\frac{\partial}{\partial t}(\rho\vec{u}) + \nabla.(\rho\vec{u}\vec{u}) = -\nabla p + \nabla.[\mu\left(\nabla\vec{u} + \overrightarrow{\nabla u^T}\right)] + \rho\vec{g} + \vec{F}$$

Energy equation:

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\left(\vec{u}(\rho E + p)\right) = \nabla.\left(k_{eff}\nabla T\right) + S_h\ ; \quad S_h = k_g(P_{sat} - p)h_{fg}$$

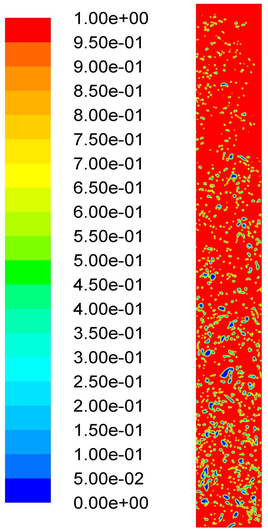
$$\vec{u}(\rho E + p) = 0 \text{ for liquid and } (k_{eff}\nabla T) = 0 \text{ for gas}$$

Results

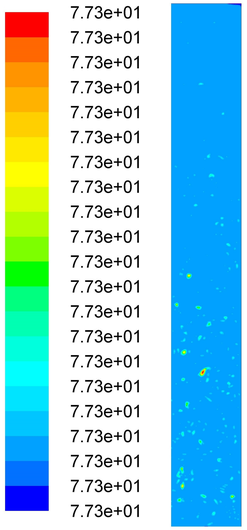
Operating Conditions

$$u_g = 0.25\ ms^{-1}$$
$$P = 1\ atm$$
$$T_{l_0} = T_{g_0} = T_{g,in} = 77.3\ K$$

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.
- 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.

Selected references

1. Larsen P. S., Randolph W. O., Vaniman J. L., and Clark J. A., Cooling of cryogenic liquids by gas injection. *Advances in Cryogenic Engineering*. Vol. 8. K. D. Timmerhaus, ed., Plenum Press, pp 507-520, 1962.
2. Schmidt A. F., Experimental Investigation of liquid-hydrogen cooling by helium gas injection. *Advances in cryogenic Engineering*. Vol. 8. K. D. Timmerhaus, ed., Plenum Press, pp 521-528, 1962.
3. Cho N., Kwon O., Kim Y., Jeong S., Investigation of Helium Injection cooling to liquid oxygen propellant chamber, *Cryogenics*, vol. 46, pp 132-142, 2006.

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