Modeling Cryogenic Fluids for application to LNG as fuel in Small-scale tanks

Nicolò BAIGUINI – Mines Paris – CTP – Center Thermodynamic of Processes

Introduction

Using fuel gases such as Hydrogen (H_2) and Natural Gas (NG) can reduce the Carbon Dioxide (CO_2) emissions in maritime and heavy-road transports sector, and in off-grid electricity production because they are environmentally friendly. For these applications, these gases are stored as liquid to increase the heating value per unit of volume and they are contained at high pressure, limiting the Boil-Off Gas (BOG) , which is the vapor produced by the evaporation. Cause of thermal inputs, phenomena such as natural convection, thermal stratification and evaporation / condensation, cause the pressure build-up, affecting the Hold-Up Time (HUT), the quality of liquid as fuel and the risk of cavitations of cryogenic pumps. Considering the lack of models to predict the behavior of cryogenic fluids, the work aims to develop a multi-models approach and to predict the behavior of LNG and other cryogenic fluids in SS-tanks by describing the thermodynamics and the fluid-dynamics involved.

Homogeneous Model

It is assumed that both liquid and vapor are pure component and they are isothermal and homogeneous. Secondly, the thermal inertia of the tank is negligible and the interface is a flat rigid surface permeable to both energy and mass. The system can be described by these equations of mass and energy conservations:

$$\frac{\partial m^L}{\partial t} = -\dot{m}_N - \dot{m}^L{}_{OUT} + \dot{m}^L{}_{IN}$$

$$\frac{\partial m^V}{\partial t} = \dot{m}_N - \dot{m}_{BOG} + \dot{m}^V{}_{IN}$$

m : mass V : volume ρ : density T : temperature P : pressure t : time $\dot{m}$: convective flow h : specific enthalpy u : specific internal energy q : heat fluxes S : surface A : interface area $\dot{W}$: work

$$\frac{\partial}{\partial t}[m^V \cdot \tilde{u}^V(T^V, P^V)] = \dot{q}_R^V \cdot S_R + \dot{q}_S^V \cdot S_S^V - \dot{q}_V^I \cdot A + \dot{m}_N \cdot \tilde{h}^V(T^I, P^I) - \dot{m}_{BOG} \cdot \tilde{h}^V(T^V, P^V) + \dot{m}^V{}_{IN} \cdot \tilde{h}^V(T_{IN}^V, P_{IN}^V) - \dot{W}^V$$

$$\frac{\partial}{\partial t}[m^L \cdot \tilde{u}^L(T^L, P^L)] = \dot{q}_B^L \cdot S_B + \dot{q}_S^L \cdot S_S^L - \dot{q}_L^I \cdot A - \dot{m}_N \cdot \tilde{h}^L(T^I, P^I) - \dot{m}^L{}_{OUT} \cdot \tilde{h}^L(T^L, P^L) + \dot{m}^L{}_{IN} \cdot \tilde{h}^L(T_{IN}^L, P_{IN}^L) - \dot{W}^L$$

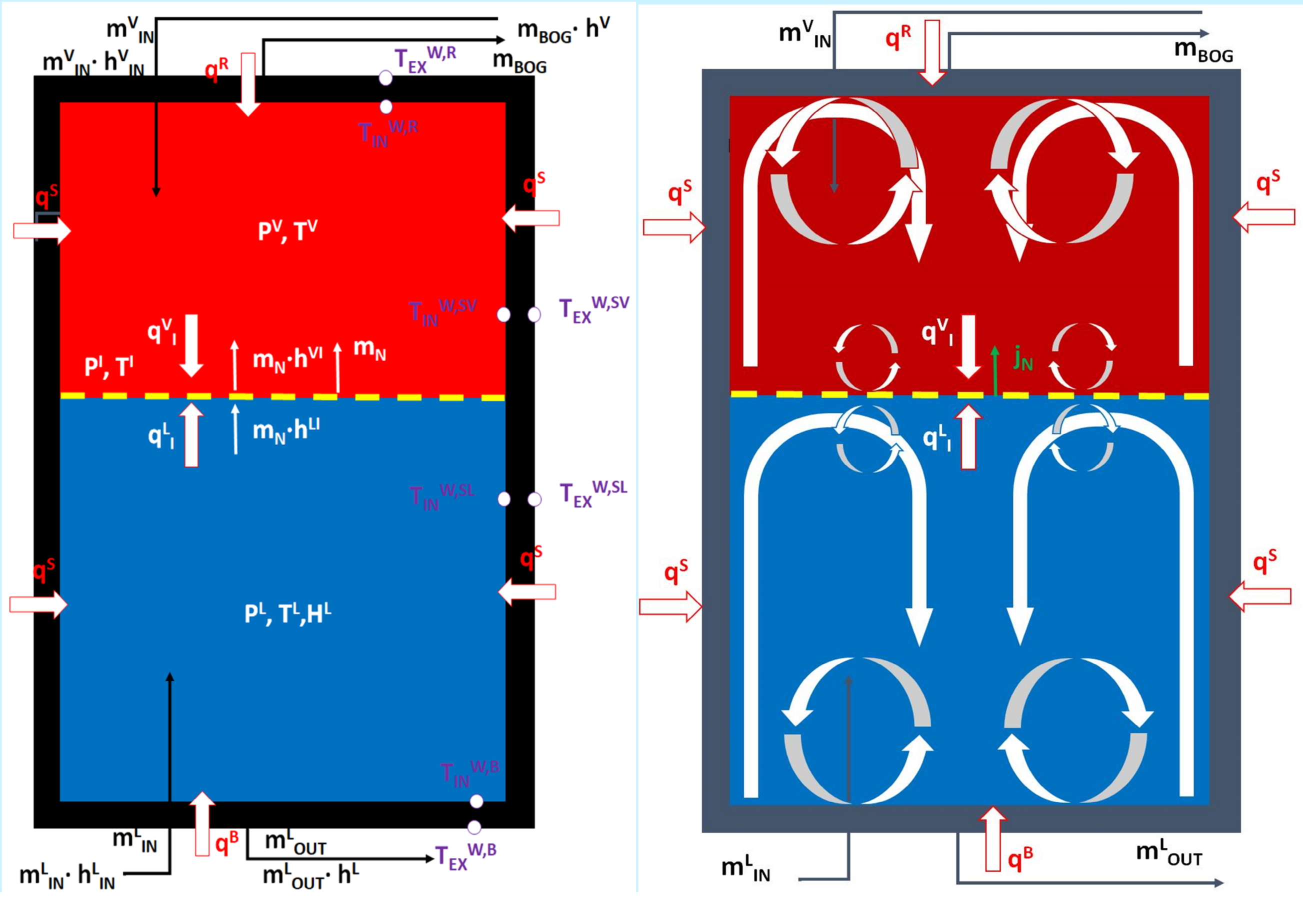

Figure 1. Homogenoeus Model.

The system of differential equations is solved with 5^{th} explicit Runge Kutta method with adaptive step size.

Results

This model is compared to the experimental data of liquid nitrogen given by Kang et al. - 2018 and by Seo et Jeong – 2010, which are obtained using liquid nitrogen at different heat inputs rate and liquid level. The simulations are done in two steps; firstly the behavior of liquid nitrogen in open tank at constant pressure and liquid level is determined. At steady state condition, the tank is virtually close and the behavior of liquid nitrogen in close tank is described.

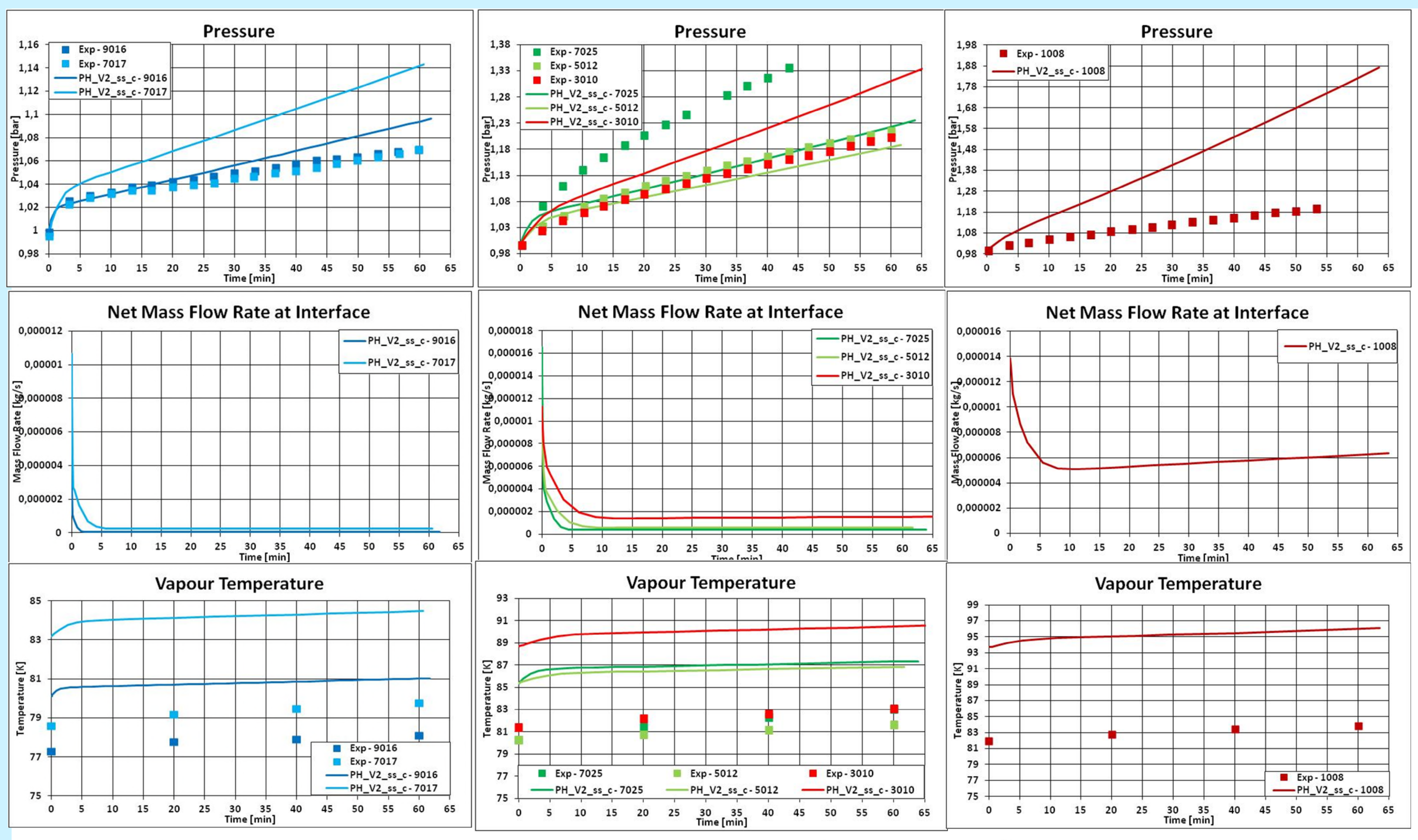

Figure 1. Pressure, vapour temperature and net mass flow rate at interface for the experimental data of Seo et Jeong – 2010.

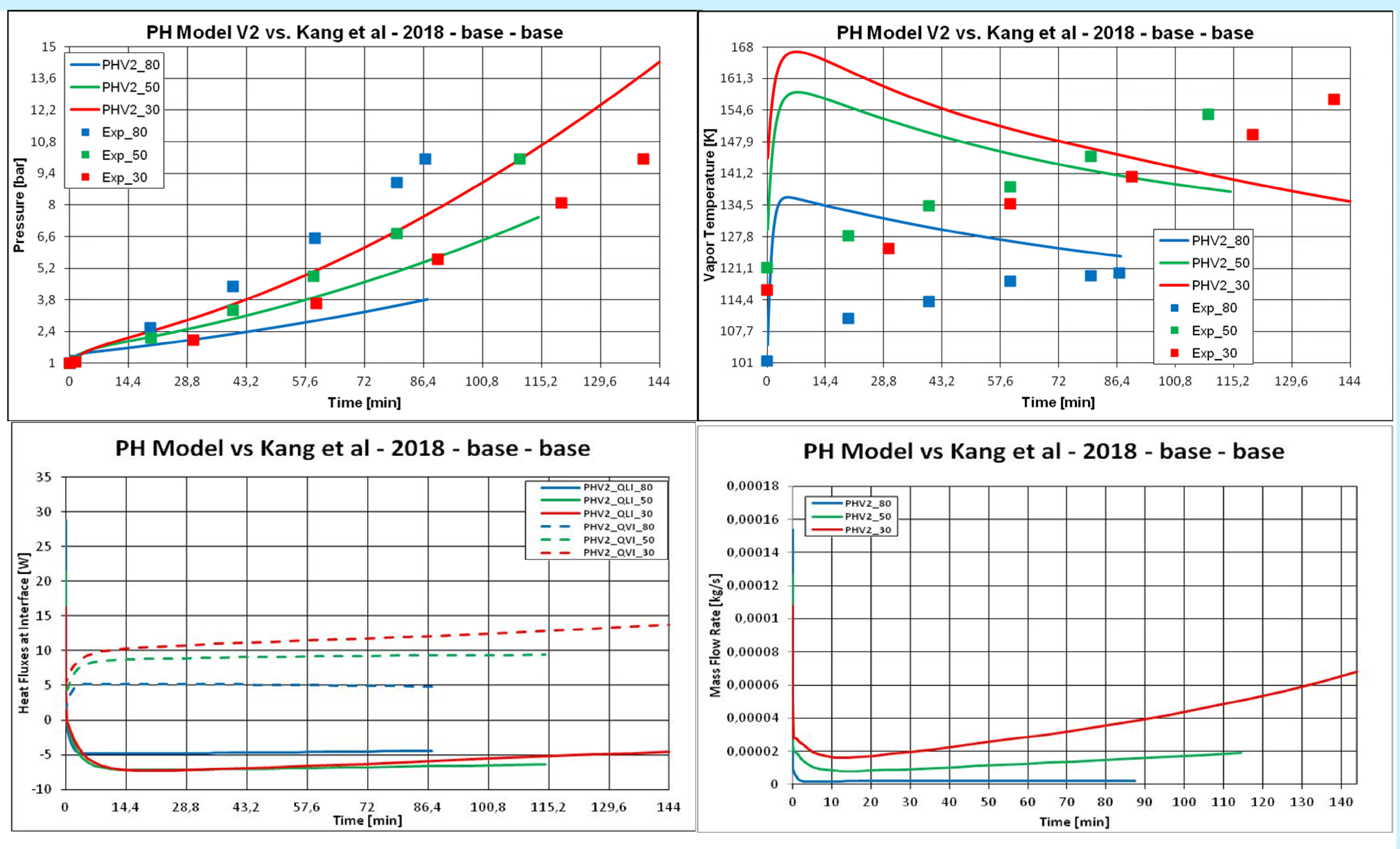

Figure 2. Pressure, vapor temperature, net mass flow rate at interface, and liquid – interface and vapor-interface heat fluxes for the experimental data of Kang et al – 2018 .

Conclusions

The model qualitatively describes the pressurization at low heat inputs and high liquid level because the thermal stratification is neglected. The proposed model shows the methodology to describe the storage of pure cryogenic fluids and the thermal stratification will be added to the model. This model is useful for industrial operators because it predicts the pressure build-up and BOG.