Poster ID: Wed-Po-2.1

Email:saurabhksingh0815@gmail.com

Heat transfer study on cryogen evaporation in stationary and moving tank

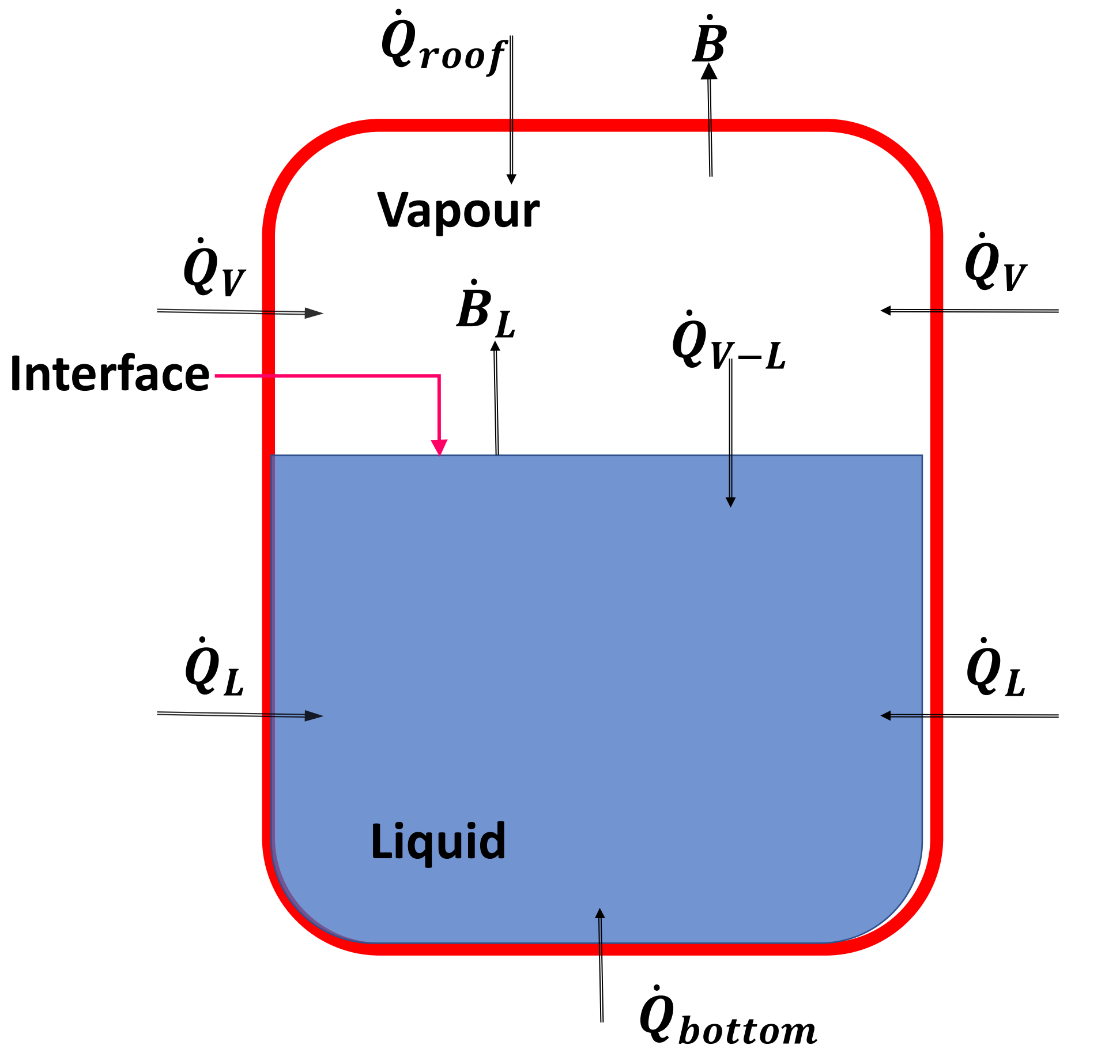
Saurabh Kumar Singh, Atul Sharma and M D Atrey

Department of Mechanical Engineering, Indian Institute of Technology Bombay, Mumbai-400076, India

Abstract

The thermal characterisation of cryogenic fluids is quite important during their storage and transportation due to external heat leaks. Cryogens are prone to large liquid motions w.r.t the container due to external disturbance (sloshing) during transportation. In the present work, thermal stratification in both liquid and vapour phases is studied for the stationary condition of the LN_2 tank along with the boil-off rate measurement. Boil-off rate measurement is also investigated during the sloshing phenomena. Experiments are also performed to measure the pressure evolution inside a 110-liter and 25-liter LN_2 tank in stationary conditions.

Mathematical model



- total volume conservation of the tank:

$$V_T = V_L + V_v \quad \Rightarrow \frac{dV_L}{dt} + \frac{dV_v}{dt} = 0$$

- Mass balance over entire tank volume:

$$-\dot{B} = \frac{dM_T}{dt} = \frac{d(\rho_L V_L + \rho_v V_v)}{dt}$$

- Mass balance over liquid phase volume:

$$-\dot{B}_L = \frac{dM_L}{dt} = \frac{d(\rho_L V_L)}{dt}$$

- Energy balance over entire tank volume:

$$\left(\frac{\dot{Q}_{L,T} - \frac{\rho_L V_L dh_L}{dt}}{h_{V,Sat} - h_{L,Sat}}\right) = \frac{d(\rho_L V_L)}{dt}$$

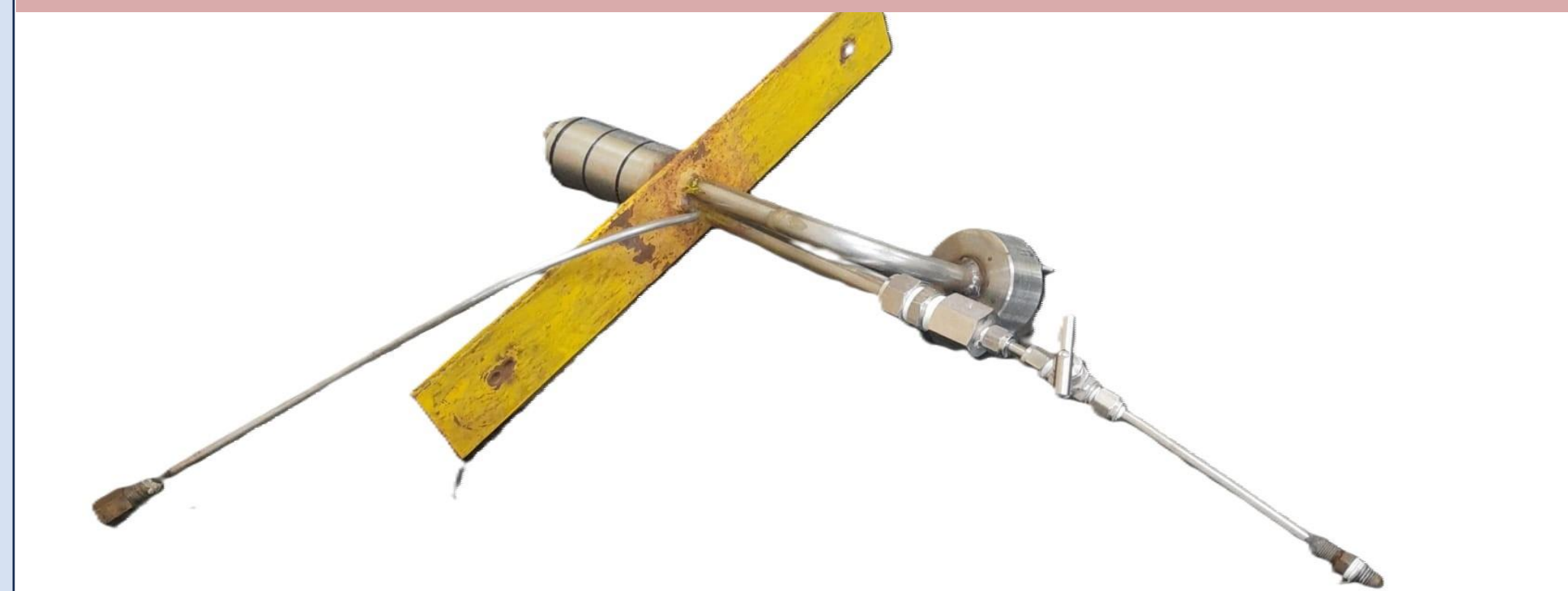
- external heat transfer model:

$$\dot{Q}_L = U_L A_L (T_{air} - T_L)$$

$$\dot{Q}_V = U_V A_V (T_{air} - T_V)$$

Experimental set-up

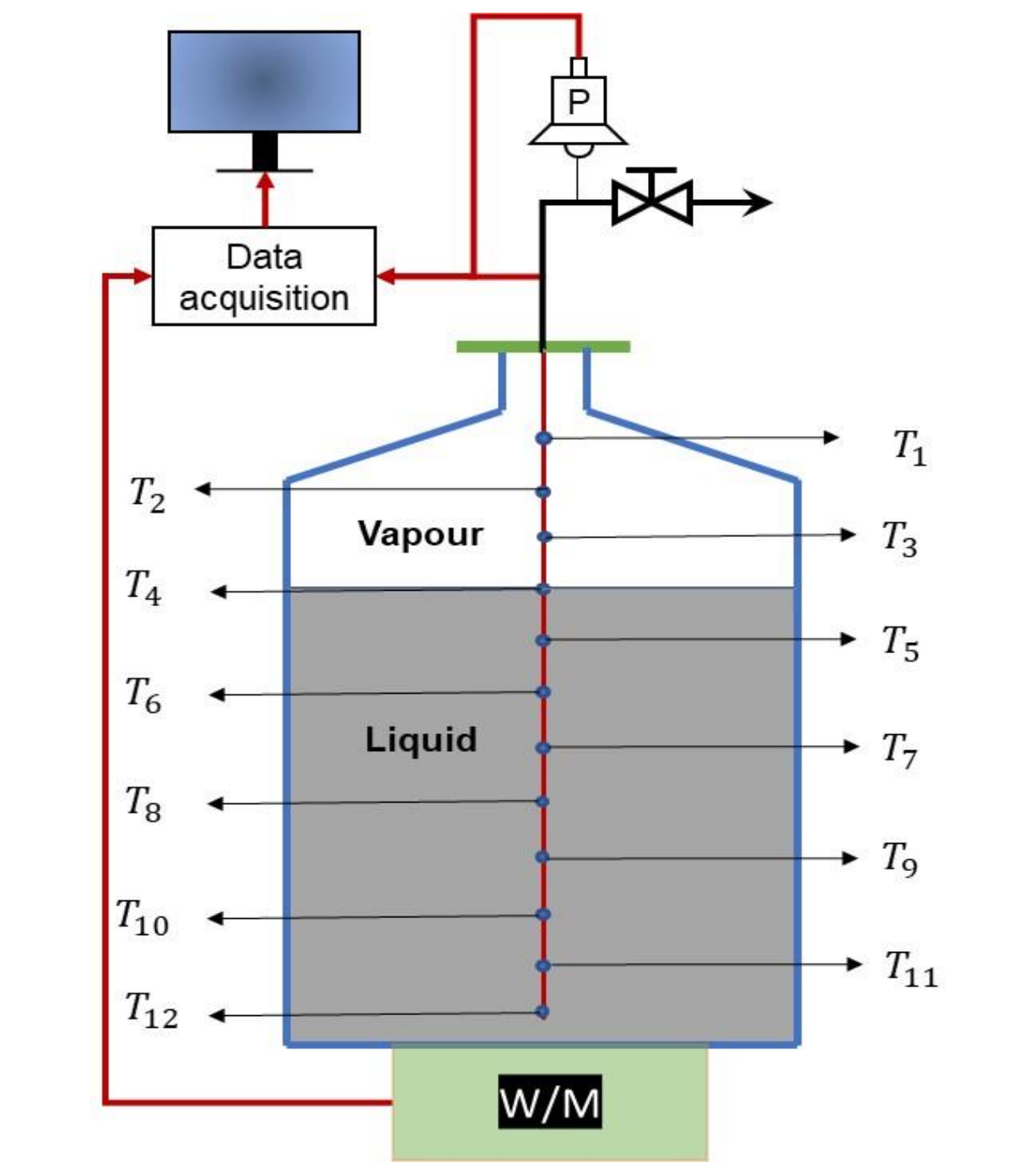
Temperature sensor mounted on axial rod at different height



Flange for LN_2 tank mounting

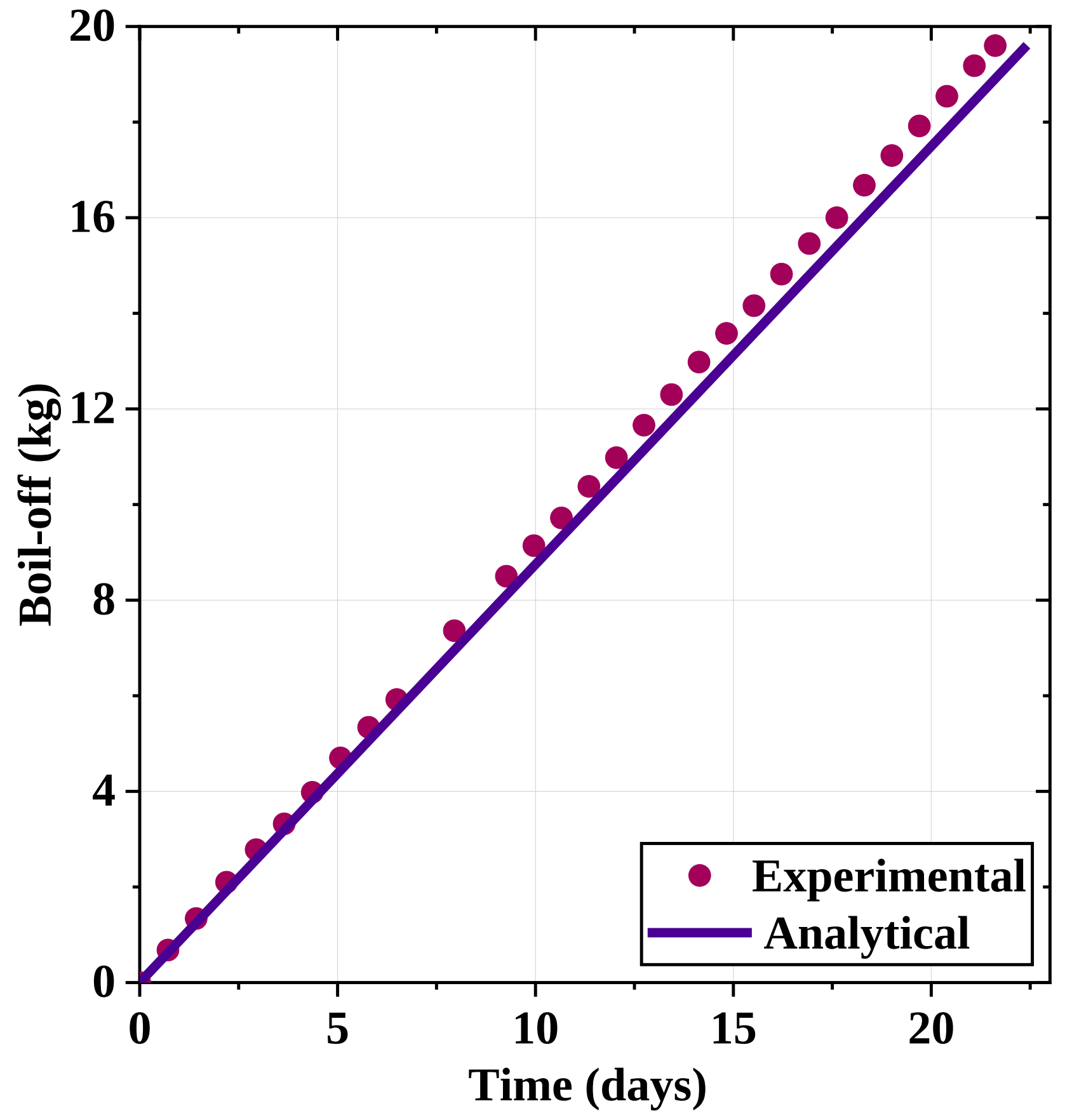
LN_2 tank on sinusoidal vibrator

Stationary tank schematic

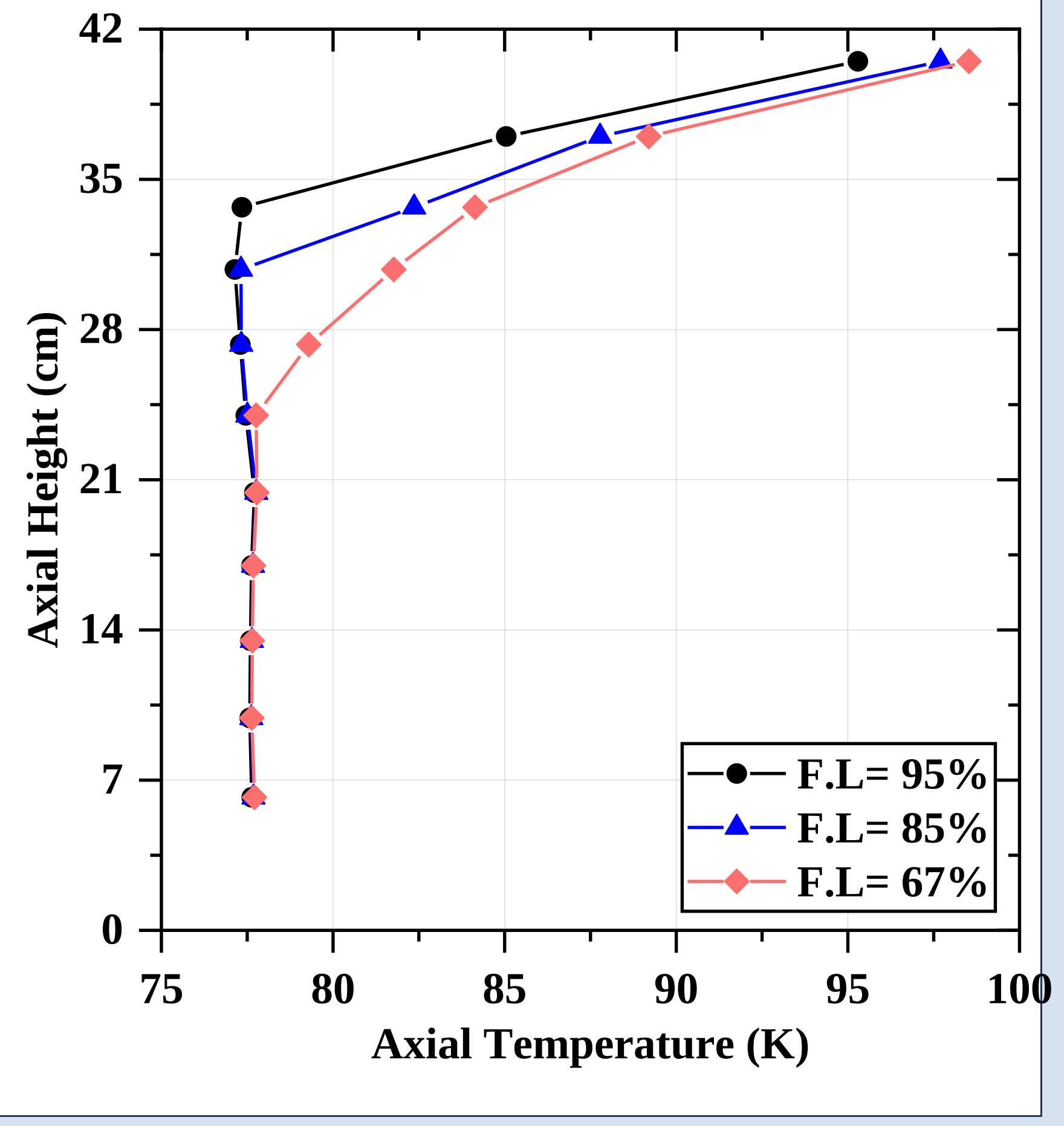


Schematic of 25.0 liter LN_2 tank with all accessories

Boil-off and temperature stratification in stationary cryogenic tank



- A relative comparison of the experimental and theoretical boil-off rate has been done to calculate the value of overall heat transfer coefficient.
- The ullage temperature fluctuates only near the interface
- Heat in-leak to the vapour phase from surroundings mostly transfers to the interface region from the side wall of ullage space

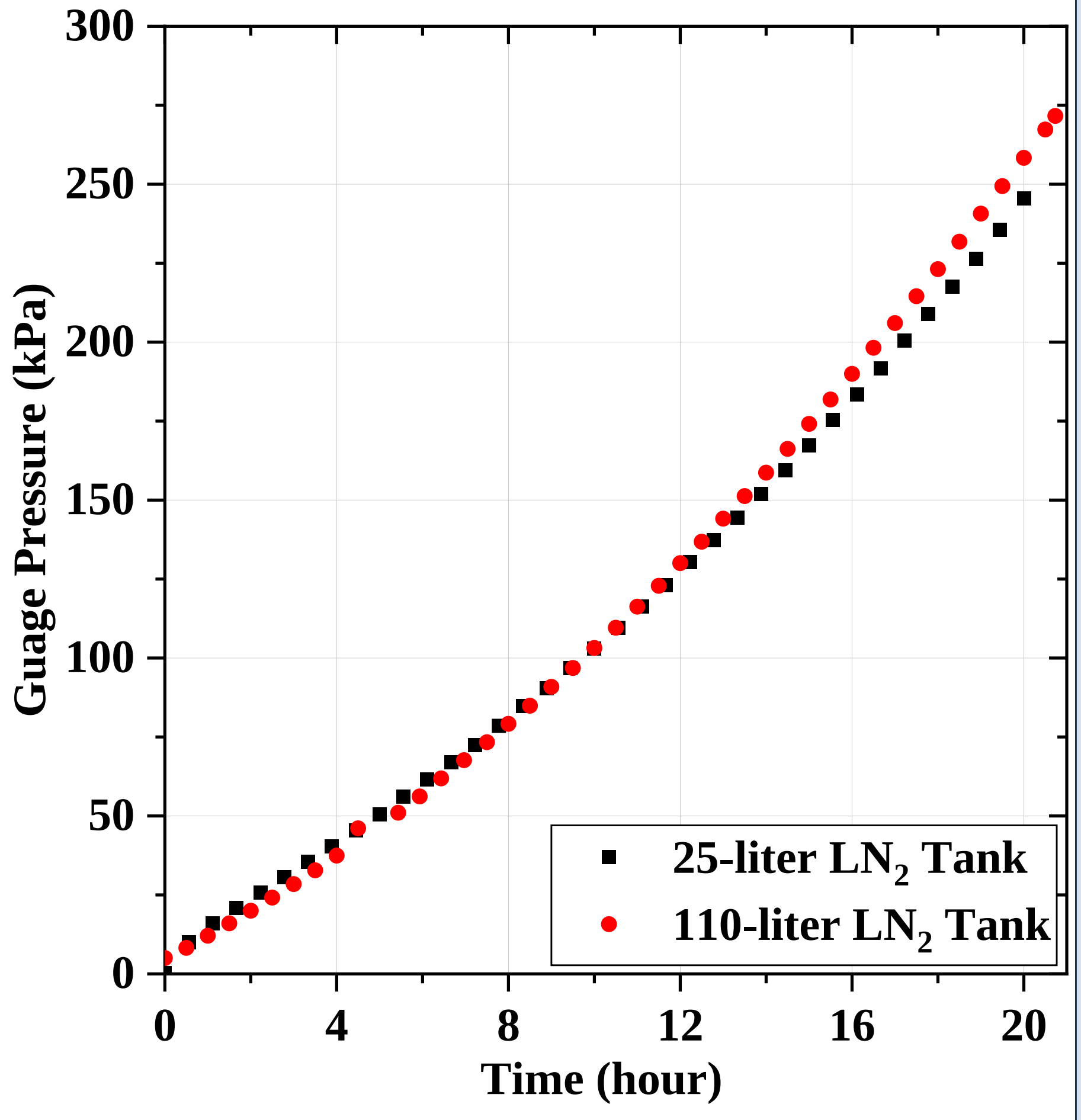


Conclusion

- ❖ The vapour phase is always superheated and heat in-leak to ullage space walls from the surrounding is then almost transferred to the interfacial region.
- ❖ It has been experimentally found and can also be theoretically derived that pressure evolution inside the geometrically similar containers having same surface area-to-volume ratio is similar.
- ❖ In isobaric conditions, sloshing increases heat transfer from the interface to the liquid phase and induces forced convection heat transfer from the tank walls, resulting in higher boil-off.

Self-pressurization in different size stationary cryogenic tank

- pressure rise in two different size cryogenic tank is investigated
- the pressure rise in both vessels follows an overlapping trend
- containers are geometrically similar i.e., upright cylindrical container and having same surface area-to-volume ratio



Sloshing and stationary boil-off comparison

- Boil-off during sloshing having larger slope in comparison to the stationary tank
- There is relative bulk fluid movement w.r.t container due to which forced convection heat transfer takes place from side walls.