ASEC 2024 Conference

The 5th International Electronic Conference on Applied Sciences

04–06 December 2024 | Online

Analysis of natural vaporization in LPG tanks

Filip Pokorny, Paolo Blecich, Igor Bonefačić

Faculty of Engineering, University of Rijeka, Croatia

INTRODUCTION

At standard atmospheric pressure and temperature, the main components of liquefied petroleum gas (LPG) – propane and butane exist in the gaseous form. Moderate pressurization converts LPG into the liquid form, which is suitable for storage into cylinders and tanks. When gas is required for consumption, the valve at the top of the tank opens, pressure drops, and the liquid LPG vaporizes. This natural vaporization process relies on ambient heat from the surroundings, which is transferred through the walls of the LPG tank. The natural vaporization rate depends on several factors such as the ambient temperature, the surface area of the tank in contact with the liquid (i.e. the filling percentage), the exact composition of LPG, the design and positioning of the LPG tank. LPG properties are calculated using the fluid properties databases REFPROP10 and COOLPROP 6.

METHODS

LPG installations are usually equipped with LPG vaporizers when natural vaporization rates cannot meet the gas demand, as in the case of cold climates, large commercial applications, and butane-heavy LPG mixtures. The natural vaporization rate of an LPG tank is calculated from

$$\dot{m}_{vap} = (w \cdot A) \cdot U \cdot \frac{T_e - T_i}{\Delta h_{vap}} \quad (1)$$

where m_{vap} is the vaporization rate in kg/s, A is the tank surface area in m^2, w is the fraction of the wetted tank surface area and U is the overall heat transfer coefficient between the ambient and the LPG tank in W/m^{2}K. The exterior temperature is T_e while the internal vaporization temperature T_i is evaluated at the working pressure. Figure 1 shows the main dimensions of the LPG tank. The LPG tank is fitted with side torispherical heads. The torospherical head geometry is determined by the German standard DIN 28011 and comprises a toroidal section (the knuckle), which connect to the cylindrical section of the tank, and a dish section. The knuckle radius is $R_k = 0.1 \cdot D_o$ while the dish radius is equal to the outer diameter of the cylinder ($R_c = D_o = 2R_o$).

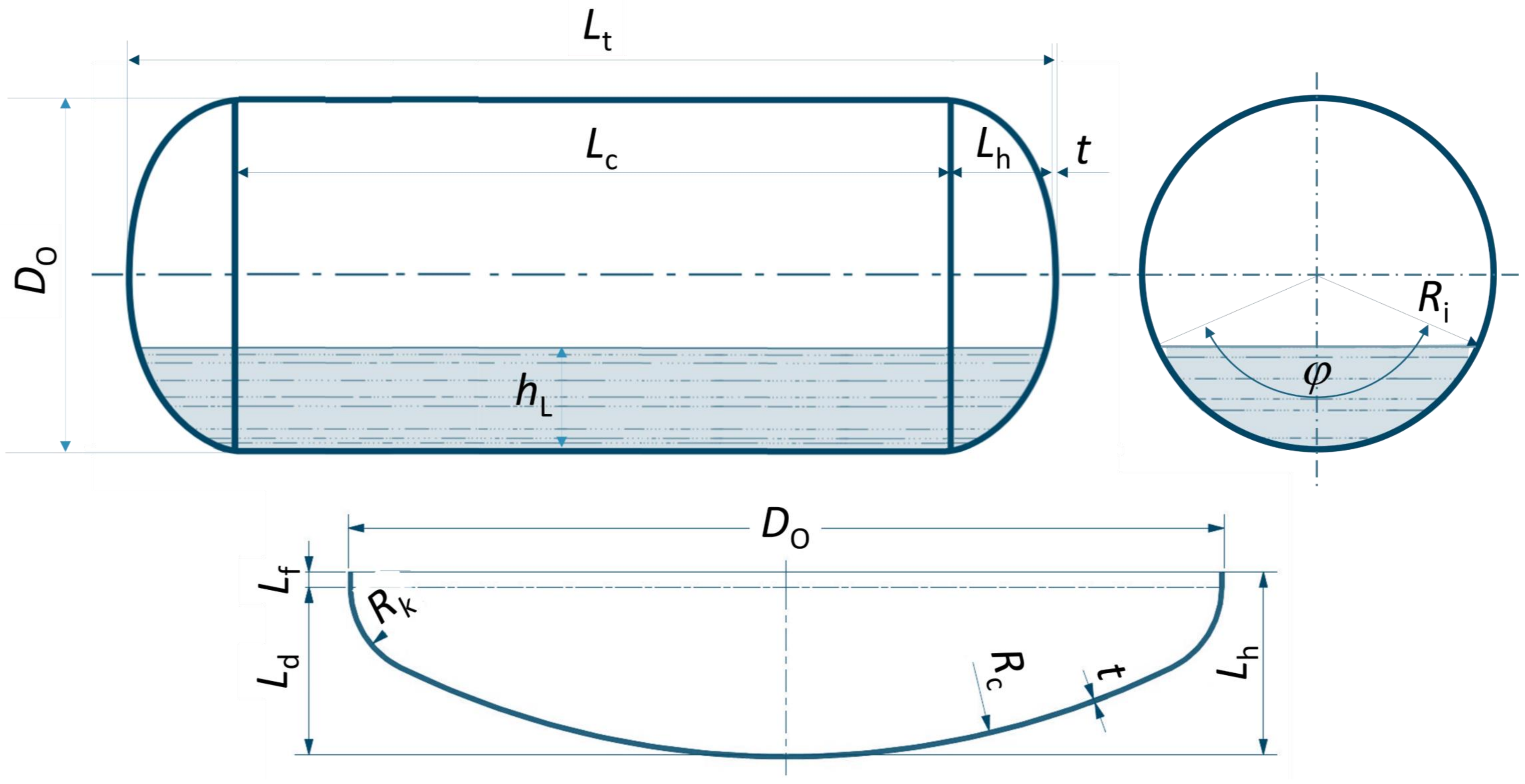

Figure 1. Main dimensions of the LPG tank (above) and of the torispherical side head (below)

The overall tank length L_t is related to the length of the cylindrical section L_c, the internal head length L_h and the wall thickness t:

$$L_t = L_c + 2(L_h + t) \quad (1)$$

The head length L_h is the sum of the dish length L_d and the flange length L_f:

$$L_h = L_d + L_f, \text{ where } L_d = 0.1935 \cdot D_o - 0.455 \cdot t \text{ and } L_f = 3.5 \cdot t \quad (2)$$

The surface area of the LPG tank is calculated from:

$$A_t = A_{cyl} + 2A_{head} = 2R_o\pi \cdot (L_c + 2L_f) + 2 \cdot R_o^2\pi \left[1 + \frac{L_d^2}{R_o^2}\left(2 - \frac{L_d}{R_o}\right)\right] \quad (3)$$

The volume of the LPG tank is

$$V_t = V_{cyl} + 2V_{head} = R_i^2\pi \cdot (L_c + 2L_f) + \frac{4}{3} \cdot R_i^3\pi \cdot \sqrt{\left(\frac{R_c}{R_i} - 1\right)\left(\frac{R_c}{R_i} + 1 - 2\frac{R_k}{R_i}\right)} \quad (4)$$

The surface area of the wetted cross-section in the tank is approximately equal to the surface area of the circular segment with radius R_i and central angle φ

$$F_{wet} = \frac{V_{fill}}{L_t - 2t} = \frac{f \cdot V_t}{L_t - 2t} \approx \frac{R_i^2}{2}\left[\hat{\varphi} - \sin\varphi\right], \text{ where } \hat{\varphi}(\text{rad}) \text{ and } \varphi(°) \quad (5)$$

After determining the central angle from (5), the wet surface area of the tank is calculated by substituting 2π with the central angle φ in equation (3).

RESULTS AND DISCUSSION

The natural vaporization rate of aboveground horizontal LPG tanks is shown in figures 2 and 3 as a function of the tank volume and assuming the following conditions: the tank filling percentage is f = 20% (wetted fraction w = 0.393), the external temperature is T_e = -8 °C bar, the tank outer diameter and the wall thickness are fixed at D_o = 1200 mm and t = 15 mm. The tank length L_t varies to accomodate the tank volume. The internal temperature of the LPG mixture is evaluated at a mains pressure of 0.75 bar (figure 2) and 0.1 bar (figure 3). Generally, it is seen that the natural vaporization rate increases with the tank size (the wetted surface) and the propane fraction in the LPG mixture. Moreover, lower external temperatures, higher butane fractions and higher mains pressures also reduce the natural vaporization rate by diminishing the temperature difference between the ambient and the tank ($T_e - T_i$).

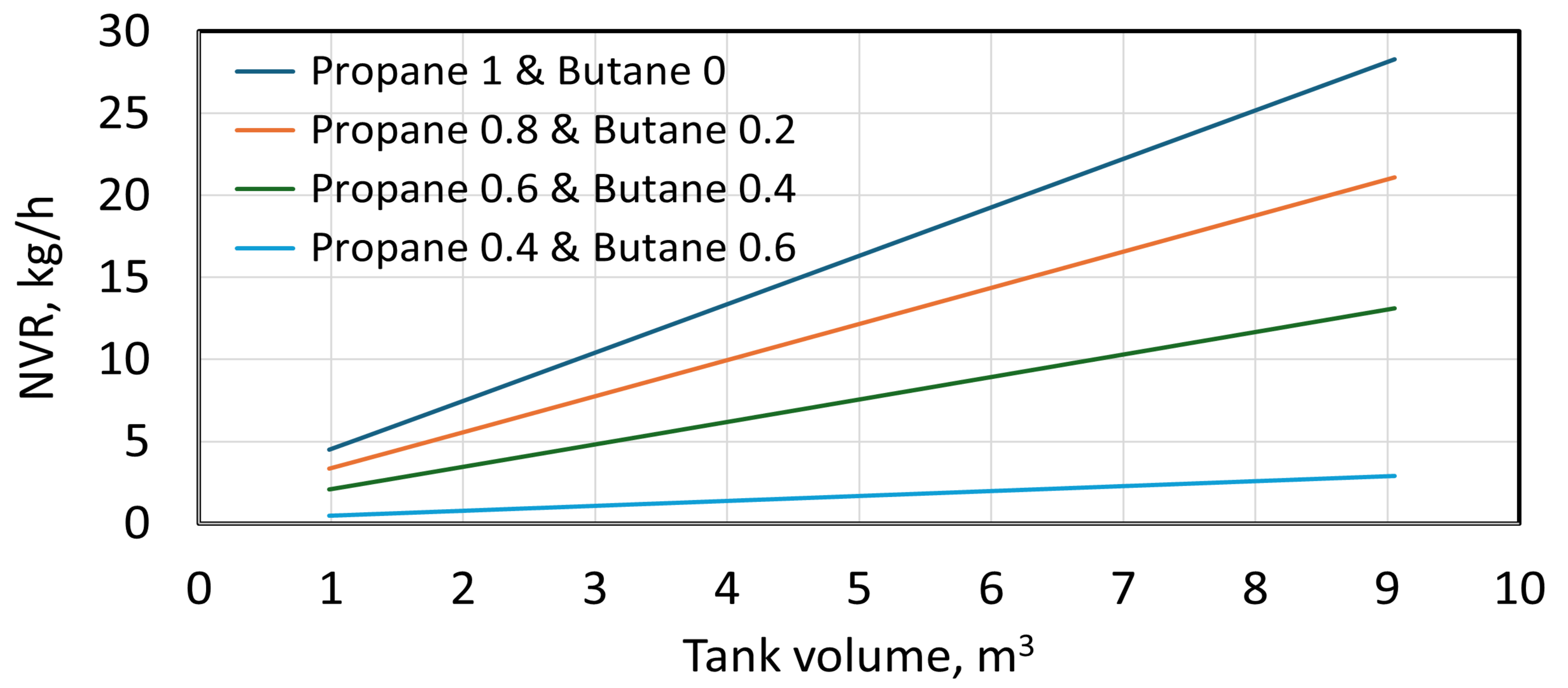

Figure 2. Natural vaporization rate (NVR) in aboveground horizontal LPG tanks for mains pressure of 0.75 bar (p_{abs} = 1.75 bar)

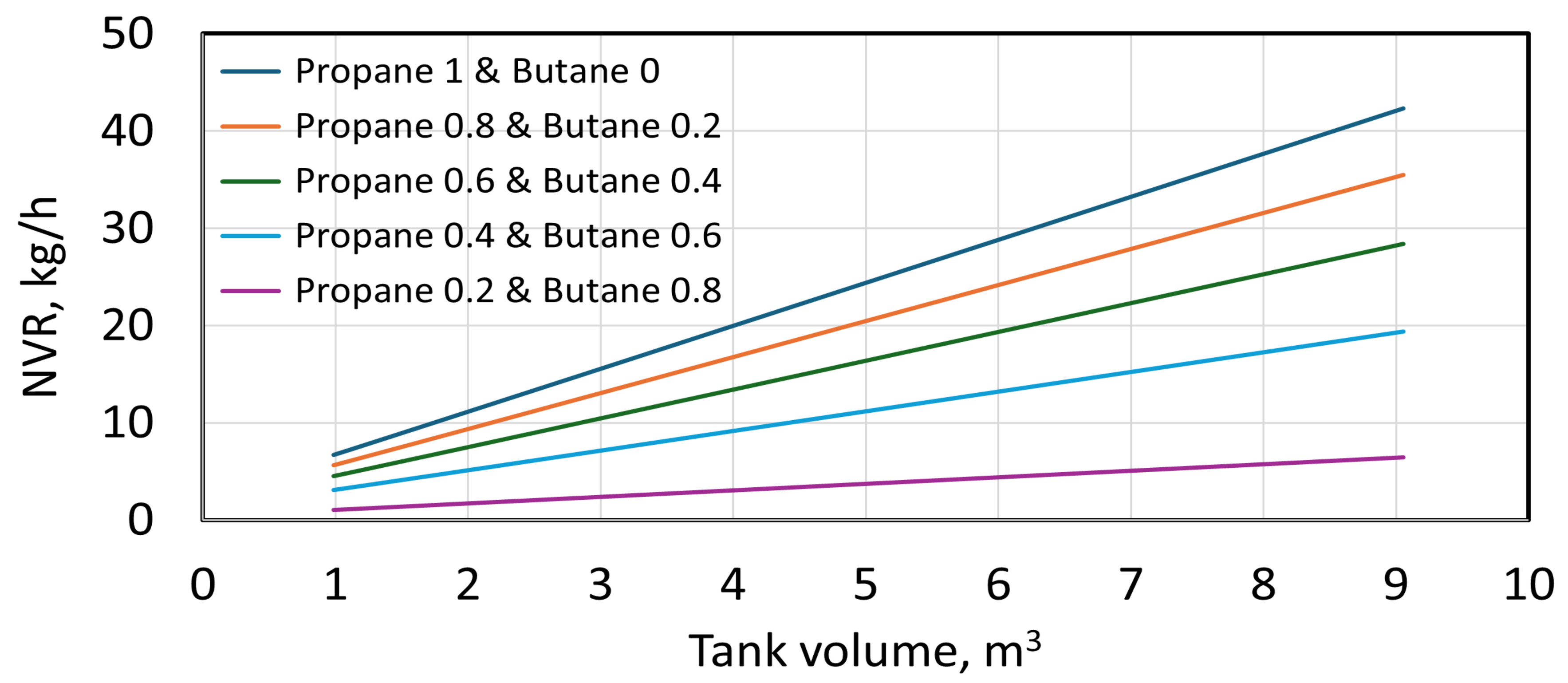

Figure 3. Natural vaporization rate (NVR) in aboveground horizontal LPG tanks for mains pressure of 0.1 bar (p_{abs} = 0.1 bar)

CONCLUSION AND FUTURE WORK

This study developed an exact calculation procedure for calculating the natural vaporization in LPG tanks. Generally, the natural vaporization rate is insufficient in situations of high gas demand, low-temperature environment, limited tank size, and for butane-heavy LPG mixtures. Future work should address the effects of different side head geometries, and tank placements.