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Heat Transfer Analysis of the Liquefied Petroleum Gas Storage Containers

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Abstract

Liquefied petroleum gases (LPG) are composed of a mixture of saturated and unsaturated hydrocarbons mainly with 3 or 4 carbon atoms in the molecule which at the ambient temperature and pressure are in the liquid state.

LPG under pressure at the ambient temperature, once released within the workspace very quickly reaches the vapor-liquid equilibrium state, corresponding to atmospheric pressure. This phenomenon is produced by cooling due to the heat taken out by passing a portion of the liquid in vapor state. It suddenly generates a large amount of vapor.

The paper contains data and computing relations for setting the wall thickness of cylindrical tanks, namely of the heat transfer coefficients by conduction at their wall, as well as case studies both in cylindrical tanks of propane and butane in terms of their insulation and non-insulation.

Key words: *Heat transfer coefficient, cylindrical tanks, insulation*

Introduction

The basic requirement that must meet the design, execution, installation, operation, reparation and inspection of the tanks from liquefied petroleum gas deposits, is to ensure their safe use throughout the duration of utilization.

Dangers posed by LPG require that the design, execution, operation, maintenance and reparation works of the installations to be in compliance with the rules, standards and laws in force in Romania, as well as with the rules and international standards.

The storage and packaging of petroleum products is a specific problem of these products, depending on their state of aggregation, of the high volume of production and consumption as well as they are flammable products, with varying degrees of risk [3].

Packaging for storage or transport are mostly specific to these products, such as tanks, reservoirs trucks and railway wagons, tanks, containers, cylinders under pressure and barrels.

Containers, cylinders and barrels are intended for storage of petroleum products supplied in small quantities to consumers.

Thermodynamic and Heat Transfer Processes Involved in the Storage of Liquefied Petroleum Gas in Cylindrical Tanks

Storage conditions of liquefied hydrocarbon gases

The storage of liquefied petroleum gas is achieved by various methods.

The method of storage at a equal pressure or close to atmospheric pressure, characterized by the fact that the storage temperature is equal to the temperature of vaporization of the liquefied gas. The storage at a pressure close to atmospheric pressure is characterized by a systematic loss of the stored product, proportional to the heat input from the outside. The method of storage under isothermal regime, characterized by the fact that, during the storage, the temperature of liquefied gas remains practically constant, this being achieved through the reliquefaction of a certain amount of vapor in a closed cooling circuit [1, 2, 4].

The storage of liquefied petroleum gas under pressure is achieved in spherical or cylindrical horizontal tanks.

The deposits of liquefied hydrocarbon gases are designed to work either at ambient temperatures under pressure or at low temperatures, but at slightly higher pressure than atmospheric pressure, as follows:

- at the environmental temperature and vapor pressure corresponding are stored: stove, butane, propane, propylene;
- from 0^0C ÷ - 50^0C and pressure 1 bar abs. are stored butane, LPG, propane, propylene;
- from - 50^0C ÷ - 150^0C and pressure 1 bar abs. are stored ethylene, ethane, acetylene;
- below - 150^0C and pressure 1 bar abs. are stored liquefied methane, liquefied natural gas (LNG).

The storage tanks for liquefied hydrocarbon will be located on land specially designed, at a lower elevation than the surrounding land on which are buildings or installations and in the opposite direction of the prevailing winds, because if gas leaks they are not transported in installations areas with open fire.

The storage capacity and the number of reservoirs depend in particular on:

- quantity and quality of petroleum products deposited, on varieties and types;
- the number and complexity of the products handling operations;
- the number and the capacity of the pipes to supply and to exhaust products;
- seasonal variation in production or consumption of goods;
- distance towards the producers and consumers.

Table 1 presents a classification of deposits as storage capacity and flash point products.

Table 1 Categories of deposits [7]

Categories of deposit	Product storage capacity (m^3)	
	Flammability < 55^0C	Flammability > 55^0C
I	over 100000	over 500000
II	30000 ÷ 100000	150000 ÷ 500000
III	2500 ÷ 30000	12500 ÷ 150000
IV	500 ÷ 2500	2500 ÷ 12500
V	50 ÷ 500	250 ÷ 2500
VI	10 ÷ 50	50 ÷ 250
VII	to 10	to 50

LPG storage can be done in [8]:

- small deposits - total storage capacity of 100 to 500 bottles - (LPG stored from 2600 l to 13 000 l);
- medium deposits - from 500 to 1000 bottles - (LPG stored from 13 000 l to 26 000 l);
- large deposits - from 1000 to 2000 bottles - (LPG stored from 26 000 l to 52 000 l) .

Vaporization / Reliquefaction

Liquid - gas steady state of the liquefied petroleum gas changes during gas use. The output of quantities in the gaseous state also leads to the evaporation of a liquid quantity. The evaporation absorbs the heat and causes the cooling of the remaining liquid mass. The use of gas continuously, leads to a pronounced cooling of the liquid mass which receives increasingly less heat from the environment. In this case, the value of the vapor pressure decreases and terminates the emission of gas, the use may be resumed only after the re-establishment of equilibrium.

If there is no consumption of gas and also, possibly the heat input from the outside is important, it is necessary to discharge a controlled quantity of gas. Outside the cylindrical tank, within a reliquefaction plant, gas vapor are cooled, are reliquefied and are reintroduced into storage [2, 5]. The transferred heat flux is calculated as:

$$\dot{Q} = \sum k\, A \Delta T \qquad (1)$$

or:

$$\dot{Q} = k_e A_e \left(T_{fe} - T_{fi}\right) \qquad (2)$$

$$A_e = A_{side} + 2\, A_{caps} \qquad (3)$$

The quantity of LPG to evaporate, due to the heat input from the outside, can be calculated with the formula:

$$\dot{m} = \frac{\dot{Q}}{L} \qquad (4)$$

Overall transfer of heat between two fluids having different temperatures, separated by cylindrical walls, consisting of several concentric and homogeneous layers

Let's consider more concentric cylindrical walls, separating two fluids at $T_{f,i} \neq T_{f,e}$. A homogeneous layer of rays $r_j < r_{j+1}$, has a coefficient of thermal conductivity $\lambda_j = const.$ There takes place in succession, the following heat exchange: by convection and radiation from the fluid inside the cylinder at the inner wall, by conduction through the walls of the cylinder, and then, by convection and radiation from the outer wall to the fluid outside of the cylindrical tank [4, 6]. It is considered that the heat transfer through the wall takes place through conduction, one-way, along the radius of the cylinder. There were noted with α_i, α_e the heat transfer coefficients by convection and radiation on both sides of the solid (fig. 1) [5].

The thermal resistance of the wall will be of the form:

$$R = \sum R_j \qquad (5)$$

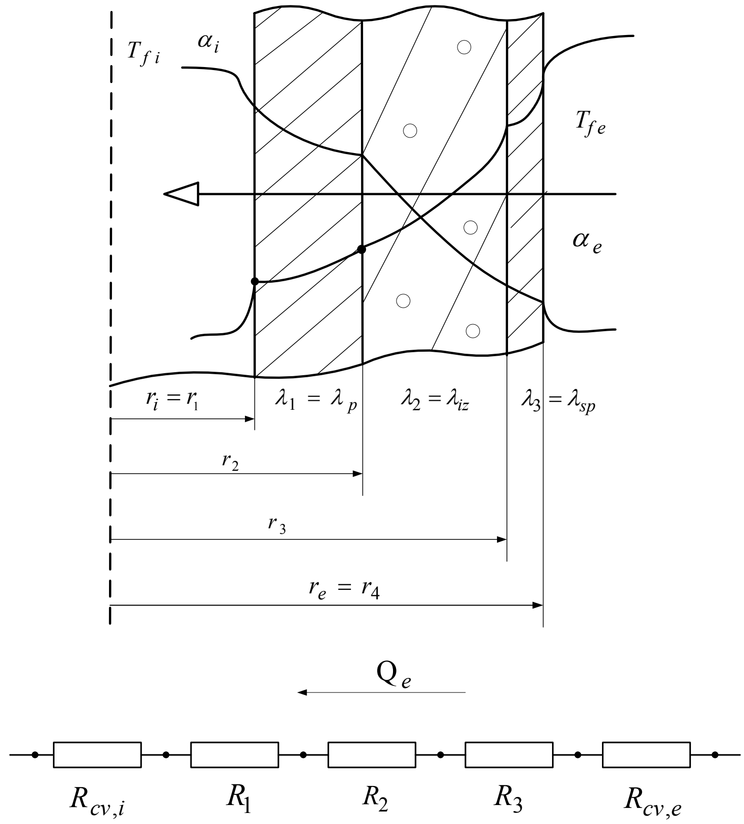

Fig. 1. Overall heat transfer between two fluids at different temperatures, separated by a cylindrical wall formed of several concentric layers

Namely:

$$R_1 = R_{cv,i} = \frac{1}{\alpha_i}\frac{r_e}{r_i} \tag{6}$$

$$R_2 = R_{cd,p} = \frac{r_e}{\lambda_1}\ln\frac{r_2}{r_1} \tag{7}$$

$$R_3 = R_{cd,iz} = \frac{r_e}{\lambda_2}\ln\frac{r_3}{r_{21}} \tag{8}$$

$$R_4 = R_{cd,sp} = \frac{r_e}{\lambda_3}\ln\frac{r_4}{r_3} \tag{9}$$

$$R_5 = R_{cv,e} = \frac{1}{\alpha_e} \tag{10}$$

Areas of the heat transfer inside and outside of the cylinder is calculated from the relationship of the following form:

$$A_i = 2\pi r_1 L + 2 \cdot 2\pi r_{n+1}{}^2 \tag{11}$$

The overall coefficient of heat transfer, if more uniform cylindrical walls, where in the expression is:

$$k_e = \frac{1}{\frac{1}{\alpha_i}\frac{r_e}{r_i} + r_e\left(\frac{1}{\lambda_1}\ln\frac{r_2}{r_1} + \frac{1}{\lambda_2}\ln\frac{r_3}{r_2} + \frac{1}{\lambda_3}\ln\frac{r_4}{r_3}\right) + \frac{1}{\alpha_e}} \quad (12)$$

Case Studies

Case study on mass loss by vaporization

For the weight loss study at propane it was considered a vessel for which the area is 22.09 m^2, temperatures are $T_{f,i}$ = 283.15 K and $T_{f,e}$ = 313.15 K and the latent heat of vaporization *L*= 358.2 kJ / kg. For the calculations were used the equations (1) and (4).

Table 2. Initial data and results of calculations regarding the vaporized mass flow during the propane storage in cylinder tanks

Inputs and outputs	Overall heat transfer coefficient, *k* , W / (m^2 K)	Vaporized mass flow $\dot{m}$, kg/h
Variant 1	11.69	98.11
Variant 2	17.54	147.17
Variant 3	23.38	196.24

Case study for the heat transfer from the external environment, towards propane respectively butane, in case of their storage in insulated or not insulated cylinder tanks.

If LPG is stored inside spheres, the heat flow direction is from outside environment fluid towards the inside fluid. For the calculus were used the equations (1), (3), (11) and (12).

In case studies were considered:

- Inside radius, r_1 is 0.6 m;
- Inside area, A_i , 20.89 m^2;
- The steel wall thickness of the cylinder, δ_{OL} , is 0.034 m for propan and 0.012 m for butan;
- The thermal conductivity of steel, λ_1 , is 45 W/(mK);
- Thickness of insulation (mineral wool), δ_{iz} , 0.05 m;
- Thermal conductivity of insulation (mineral wool), λ_2 , 0.07 W / (mK)'
- The thickness of the protective layer (steel sheet) δ_{sp} , 0.0004 m;
- The thermal conductivity of the protective layer (steel sheet), 45 W / (mK);
- Temperature of the fluid in the tank, $T_{f,i}$, 283.15 K;
- Outside air temperature, 313.15 K.

Were analyzed two fluids, propane and butane, considering two scenarios: not insulated tanks and insulated tanks.

RESULTS obtained by calculations on heat transfer to the storage tanks of propane and butane in the cylinder insulated and non-insulated are shown in Table 3.

Table 3. Transferred heat flow

Tanks type	**Transferred heat flow** $\dot{Q}$, **(W)**	
	Propane	Butane
Insulated	812.29	745.73
Not insulated	19923.73	19735.45

From Table 3 is found that, by isolating cylindrical tanks, heat flux transferred decreases as follows:

- to propane 24.53 times;
- to butane 26.46 times.

Some specifications are needed to be made:

- to the location of of LPG storage tanks is mandatory observance of safety distances imposed by law, the reason for such locations is the safe operation (maintenance) in the event of fire occurrence;
- when the tank is insulated, any detectable fault is quick and easy, which is impossible if the thermal insulation of the storage tank

Conclusions

The design, the execution, the installation, the operation, the reparation and the inspection of the tanks from the liquefied petroleum gas deposits requires ensuring the safe operation during the service life.

In the operation of liquefied petroleum gas deposits may occur vaporization processes, dependent, among other, on weather conditions, which result in a discharge of a mass flow of the substance.

In terms of the energy issue, due to the heat dissipation, is suitable the decision of isolating the liquefied petroleum gas deposit. Technological, this option is not eligible because cannot detect possible deteriorations on the metal walls of the tanks.

Non-isolation of the cylinder tanks requires the existence of the reliquefaction plants, so additional expenses.

Nomenclature

A	Heat transfer area, m^2	r	Radius of the cylinder, m
k	Overall coefficient of heat transfer, W/(m^2 K)	T	Temperature, K
L	Phase transition specific latent heat, J/kg	α	Convection and thermal radiation coefficient, W/(m^{2}K)
$\dot{m}$	Mass flow, kg/h	δ	Thickness, m
$\dot{Q}$	Thermal flow, W	λ	Thermal conductivity, W/(mK)

Subscript

i	Interior	*j*	Current index
e	Exterior	*n*	Index
f	Fluid	*sp*	Protector layer

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Analiza transferului de căldură în cazul containerelor pentru depozitarea gazelor petroliere lichefiate

Rezumat

Gazele petroliere lichefiate (GPL) sunt formate dintr-un amestec de hidrocarburi saturate şi nesaturate în principal cu 3 şi 4 atomi de carbon în moleculă care la temperatura ambiantă şi sub presiune sunt în stare lichidă.

GPL aflate sub presiune la temperatura ambiantă, odată eliberate în spațiul de lucru ajung foarte rapid în starea de echilibru lichid – vapori, corespunzătoare presiunii atmosferice. Acest fenomen se produce prin răcire pe seama căldurii preluate de trecerea unei părți din lichid în stare de vapori. Se generează brusc o mare cantitate de vapori.

Lucrarea conține date şi relații de calcul pentru stabilirea grosimilor de perete a rezervoarelor cilindrice, respectiv a coeficienților de transfer de căldură prin conducție la peretele acestora, precum şi studii de caz atât la rezervoarele cilindrice de propan, cât şi de butan în condițiile izolării şi neizolării lor.