POSSIBLE THERMAL PROCESSES INVOLVED IN THE STORAGE OF LIQUEFIED PETROLEUM GAS

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Abstract. Liquefaction has become widespread as a result of its favorable economic effects that are achieved by significantly reducing the required storage and transport volumes. LPG are substances which at ambient temperature and atmospheric pressure are normally gaseous, consisting mainly of any of the following hydrocarbons or a mixture of these: propane, propylene, butane and butylene. They can be liquefied by increasing the pressure or by lowering the temperature or by a combination of thereof. The heat absorbed by liquefied hydrocarbon gas produces vaporisation of a quantity of liquid that is discharged in order to keep the pressure to the level required for a safe operation of the container. By vaporisation, heat is absorbed resulting the cooling of the remaining mass of liquid. If the use of the gas takes place continuously, then, also the cooling of the liquid mass is increased and the liquid in the reservoir receives just a little heat from the environment. In this case, the value of steam pressure decreases and leads to cessation of gas emission. Resumption of gas consumption can start only after restoration of the equilibrium state.
Keywords: heat transfer coefficients, spherical tanks, insulation.

1. INTRODUCTION

Talking about energy policy of a country we may admit that, taking into account the corresponding natural resources and the specific energy policy, the energy sources are: basic and complementary. Complementary sources of energy could be defined as: energy sources that are added to the basic ones in order to cover consumption under circumstances conditions (high energy consume for a limited duration, purchase opportunities, imposing a reduced zone of pollutant emission, technical failures, natural disasters). A fuel must meet a number of conditions, namely, to be able to get it easily from the nature, not to be toxic, to be cheap and sufficient so that the heat produced to have a competitive cost, at that time, on the energy market.

The interest in "fossil" energy forms is justified if we take into account that they might be stored, as opposed to "noble" energy for which storage is limited and expensive. Liquefied gaseous hydrocarbon are complementary sources of energy and can be stored. Gas liquefaction has become widespread due to the favorable economic effects that are achieved by significantly reducing the required storage and transport volumes. LPG is obtained from natural gas or from refinery gas and contains mainly butane, propane or mixtures of thereof. Liquefied petroleum gas was introduced as fuel gas for domestic use in 1932, as "blau gas" and was manufactured by one of the refineries near Ploiesti. At present, liquefied petroleum gas (LPG) is widely used both in petrochemical plants as well as by home users to obtain thermal energy or for other purposes.

2. THERMODYNAMIC PROCESSES AND HEAT TRANSFER INVOLVED IN THE LIQUEFIED PETROLEUM GAS STORAGE IN SPHERICAL TANKS

This chapter deals with storage conditions of gaseous liquefied hydrocarbons. Liquefied gaseous hydrocarbon deposits are designed to work either at a temperature equal to the ambient temperature and at high pressure or at low temperature, but at a pressure close to the atmospheric one (slightly higher). When storing at a pressure equal to or close to atmospheric pressure, the storage temperature is equal to the temperature of vaporization of the liquefied gas and takes place a systematic loss of the stored product, in proportion to the heat supply, from the outside towards the storage place. If storage method is under isothermal regime, low temperature of the liquefied gas remains practically constant, which requires a second liquefaction of a certain amount of steam in a closed cooling circuit. Table 1 presents specific data on the thermodynamic state of some liquefied gaseous hydrocarbons under their storage conditions.

Table 1. **Thermodynamic states of liquefied gaseous hydrocarbon, proper to storage methods**

Storage temperature and pressure	Liquefied gaseous hydrocarbons
Ambient environment temperature and the corresponding vapor pressure	Blau gas, butane, propane, propylene
$0\,^{o}$C ÷ -50 ^{o}C and pressure 1 bar abs.	Butane, LPG, propane, propylene
-50^{0}C ÷ -150^{0}C and pressure 1 bar abs.	Ethylene, ethane, acetylene
Below -150^{o}C and pressure 1 bar abs.	Liquefied methane, liquefied natural gas (LNG)

Blau gas, butane, propane and propylene are stored in spherical, spheroid or horizontal cylindrical pressure tanks designed for the corresponding vapor pressure of the hydrocarbon stored at the maximum temperature of the ambient environment. Because of the relatively high cost price and because of the construction and execution difficulties, these tanks are made for limited capacities and pressures. Spherical tank is used for storage of oil liquefied products, obtained in refineries in large quantities, assigned as combustion products and also as petrochemical raw material in petrochemistry. For LPG spherical storage tanks are more economical than storage in cylindrical tanks due to the uniform distribution of the internal pressure on the walls of the sphere.

Vaporization / Second liquefaction. The heat absorbed by liquefied gaseous hydrocarbon produces vaporisation of a quantity of liquid that is discharged in order to keep the pressure to the level required for safe operation of the container. By vaporisation, heat is absorbed resulting the cooling of the remaining mass of liquid. If the use of the gas takes place continuously, then also the cooling of the liquid mass is increased and the liquid in the reservoir receives just a little heat from the environment. In this case, the value of steam pressure decreases and leads to cessation of gas emission. Resumption of gas consumption can start only after restoration of the equilibrium state.

If there is no consumption of gas and eventually also the heat input from the outside environment is important, it is necessary to discharge a controlled quantity of gas. Outside the spherical tank, in a second liquefaction facility, gas vapor are cooled, then they suffer second liquefaction and are re-introduced into the storage. Transferred heat flow is calculated as:

$$\dot{Q} = kA\left(T_{f,e} - T_{f,i}\right) \quad (1)$$

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

$$\dot{m} = \frac{kA(T_{f,e} - T_{f,i})}{L} \quad (2)$$

Second liquefaction is the vaporization reverse process. The two processes happen upon an isobar-isothermal mode, if we neglect pressure losses. During liquefaction, the system sends heat to the outside environment.

Overall transfer of heat between two fluids having different temperatures, separated by spherical walls, consisting of several concentric and homogeneous layers. Let's consider more concentric spherical 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 $\lambda_j = \text{const.}$ There takes place in succession, the following heat exchange:by convection and radiation from the fluid inside the sphere, at the inner wall, by conduction through the walls of the spheres, and then, by convection and radiation from the outer wall to the fluid outside of the sphere. It is considered that the heat transfer through the wall takes place through conduction, one-way, along the radius of the sphere in the direction Or. There were noted with α_i, α_e the heat transfer coefficients by convection and radiation on both sides of the solid (Fig. 1).

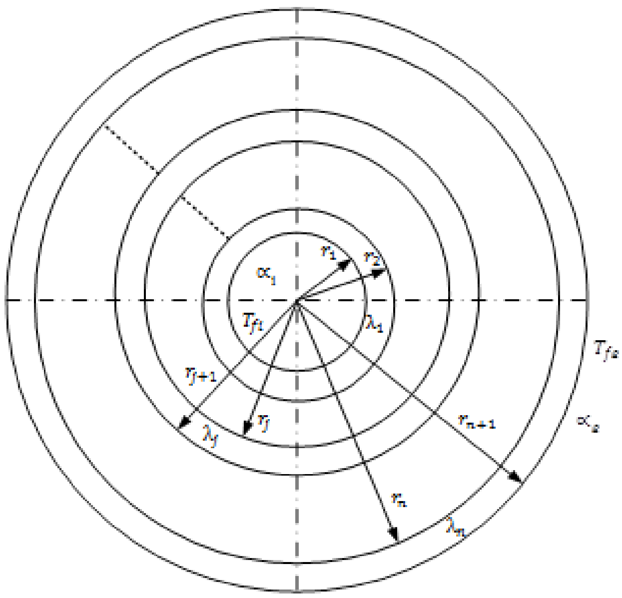

Fig. 1. Concentric spherical homogeneous walls.

Areas of the heat transfer inside A_i and outside of the sphere A_e, is calculated using the equation having the following form:

$$A_i = 4\pi r_1^2 \tag{3}$$

$$A_e = 4\pi r_{n+1}^2 \tag{4}$$

The overall coefficient of heat transfer, in case of more spherical concentric homogenous walls, has the expression:

$$k_e = \frac{1}{\frac{A_e}{\alpha_i A_i} + A_e \sum_{j=1}^{n} \frac{1}{4\pi\lambda_j}\left(\frac{1}{r_j} - \frac{1}{r_{j+1}}\right) + \frac{1}{\alpha_e}} \tag{5}$$

3. CASE STUDIES

a) Case study on mass loss by vaporization. For the weight loss study at propane it was considered a vessel for which the area is 17.87 m^2, temperatures are $T_{f,i}$ = 313.5 K and $T_{f,e}$ = 288.15 K and the latent heat of vaporization L = 358.2 kJ / kg. For the calculations were used the equations (1) and (2).

b) Case study for the heat transfer from the external environment, towards propane respectively butane, in case of their storage in insulated or not insulated spheres. 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), (4) and (5). Table 3 contains the initial data and results of calculations of heat transfer during the propane and butane storage in spherical insulated tanks or not insulated. From Table 3 it appears that by the isolation of the spheres, the flow of heat transfer decreases more than 20 times.

Some specifications are needed to be made:

– the spherical storage tank of propane or butane is to be insulated only when the location where the spherical tank will be situated will not allow us to keep safe distances, according to the security and firefighting norms, so in case of fire in a sphere, the next one has to be protected against the thermal radiation emitted by the fire;

– the possible deterioration of the spherical wall is difficult to detect if they have thermal insulation, and therefore, practically, it is preferable the storage in not insulated areas, because only this way their corrosion is monitored;

– not insulating the spherical tanks requires these stores fitting-out with cooling system in order to ensure the hydrocarbon second liquefaction.

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

Inputs and outputs	Variant 1	Variant 2	Variant 3
Overall heat transfer coefficient, k [W / (m^2 K)]	11,63	17,445	23,26
Vaporized mass flow $\dot{m}$, kg/h	52,2	78,3	104,4

Table 3. **Incipient data and results of calculations of heat transfer when depositing propane and butane in isolated and not insulated spherical tanks**

Inputs and outputs	Insulated tanks	Not insulated tanks	Insulated tanks	Not insulated tanks
Stored fluid	propane	propane	butane	butane
Inside radius, r_1 [m]	6,2	6,2	6,2	6,2
Inside area, A_i , (m^2]	482,8	482,8	482,8	482,8
The steel wall thickness of the sphere, δ_{OL} [m]	0,034	0,034	0,012	0,012
The thermal conductivity of steel, λ_1 [W/(mK)]	45	45	45	45
Thickness of insulation (mineral wool], δ_{iz} [m]	0,05	-	0,05	-
Thermal conductivity of insulation (mineral wool), λ_2 [W / (mK]]	0,07	-	0,07	-
The thickness of the protective layer (steel sheet) δ_{sp} [m]	0,0004	-	0,0004	-
The thermal conductivity of the protective layer (steel sheet], λ_3 [W / (mK)]	45	-	45	-
Temperature of the fluid in the tank, $T_{f,i}$ [K]	288,15	288,15	288,15	288,15
Outside air temperature, $T_{f,e}$ [K]	313,15	313,15	313,15	313,15
Transferred heat flow $\dot{Q}$ [W]	16170	378589	16770	385400

4. CONCLUSIONS

1. Interest for liquefied gaseous hydrocarbons is justified because they are additional sources of energy, they can be stored and thus they play an important role within the energy strategy of a country or of an economic operator.

2. The technological flow of the liquefied petroleum gas implies possible thermodynamic and heat transfer transformations.

3. When choosing a storage solution for liquefied petroleum gas, during the design and operation of these deposits it is required the knowledge and assessment of the possible thermal processes involved (thermodynamic transformations and heat transfer).

3. During exploitation of the liquefied petroleum gas deposits may occur vaporization processes, depending, inter alia of the weather, resulting the discharge of a mass flow of the substance.

4. Although, from the energy point of view, due to heat dissipation, it would be suitable the decision of insulation the deposit of liquefied petroleum gas; technologically speaking this variant is not eligible because, this way can not be found the possible damages of the metal walls of the tanks.

5. Moreover, not insulating the spherical tanks implies the existence of installations for second liquefaction, resulting additional expenses.

Nomenclature

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

Subscript

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

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