Scientific Paper / Artículo Científico

UNIVERSIDAD POLITÉCNICA SALESIANA ECUADOR
INGENIUS
Revista de Ciencia y Tecnología
https://doi.org/10.17163/ings.n31.2024.07
pISSN: 1390-650X / eISSN: 1390-860X

Liquefied Petroleum Gas Systems: A Review On Desing And Sizing Guidelines

Sistemas de gas licuado de petróleo: una revisión sobre lineamientos de diseño y dimensionamiento

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Received: 15-05-2023, Received after review: 26-06-2023, Accepted: 17-07-2023, Published: 01-01-2024

Abstract

Liquefied Petroleum Gas (LPG) is a fossil fuel widely used in residential, commercial, and industrial applications. LPG systems must be designed and sized considering minimum safety standards established in national and international regulations. An LPG system comprises fuel storage containers, pipelines, valves, meters, consumption equipment, and safety and protection elements. These must be sized and selected to withstand the action of the fuel gas and the working conditions to which they will be subjected. This article presents a review of the most important points to consider in the design and sizing of an LPG system based on the most representative international regulations.

Keywords: Liquefied Petroleum Gas, sizing, installations, safety, normative, criteria

Resumen

El gas licuado de petróleo (GLP) es un combustible de origen fósil ampliamente utilizado en aplicaciones residenciales, comerciales e industriales. Los sistemas de GLP deben diseñarse y dimensionarse bajo estándares mínimos de seguridad, los cuales son establecidos en normativas nacionales e internacionales. Un sistema de GLP está conformado por recipientes de almacenamiento del combustible, tuberías, válvulas, medidores, equipos de consumo y elementos de protección y seguridad. Estos deben ser dimensionados y seleccionados para soportar la acción del gas combustible y las condiciones de trabajo a las que serán sometidos. En este documento se presenta una revisión de los puntos más importantes a tener en cuenta en el diseño y dimensionamientos de un sistema de GLP a partir de las normativas más representativas a nivel internacional..

Palabras clave: gas licuado de petróleo, dimensionamiento, instalaciones, seguridad, normativas, criterios

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Suggested citation: Venegas-Vásconez, D.; Ayabaca-Sarria, C.; Reina-Guzmán, S.; Tipanluisa-Sarchi, L. and Farías-Fuentes, O. "Liquefied Petroleum Gas Systems: A Review On Desing And Sizing Guidelines," *Ingenius, Revista de Ciencia y Tecnología*, N.° 30, pp. 81-94, 2024, DOI: https://doi.org/10.17163/ings.n31.2024.07.

1. Introduction

Energy demand worldwide is experiencing an annual increase due to rapid population growth, lifestyle changes, and industrialization [1]. In 2019, global energy consumption reached 418 EJ, and a 23% increase is expected by 2040, reaching 516 EJ. Currently, over 80% of the energy comes from fossil fuels, with oil, coal, and natural gas accounting for 30.9%, 26.8%, and 23.2%, respectively [2]. Regarding petroleum derivatives, liquefied petroleum gas (LPG) is one of the most widely used fuels globally due to its versatility as an energy source in domestic, commercial, and industrial services [3]. Despite its fossil origin, it is considered a clean fuel in terms of emissions to the environment since it does not contain sulfur. Therefore, during combustion, it does not emit SO_X [4], making it an attractive energy source.

To use LPG systems, storage, distribution, regulation, and control elements are required, which must be installed considering safety standards established in international technical norms such as NFPA 58 [5]. In Ecuador, compliance with the Ecuadorian Technical Standard INEN 2260:2010 [6] is followed to minimise risks associated with fuel handling. These technical norms outline the minimum safety requirements to be considered by those responsible for LPG installations, fuel distributors, and authorities tasked with overseeing compliance. The NFPA 58 standard has been in effect since 1930, serving as the foundation for LPG systems regulations in most countries worldwide [7–9]. In Ecuador, the first version of the INEN 2260 technical standard was developed in 2001 and has undergone two revisions to the current version, in force since 2010.

The technical standards in force in each country establish the minimum conditions for implementing LPG system projects. These regulations cover aspects such as the acceptance of types, materials and manufacturing standards for pipelines, safety distances between containers and third parties, and physical and human safety and protection. Compliance with these standards is usually mandatory within the corresponding territorial jurisdiction. However, these documents do not provide specific design parameters or technical criteria to ensure the feasibility of projects involving liquefied petroleum gas systems. They also do not include information about brands and manufacturers of different components or mention elements with higher safety standards. This information is typically found in manufacturer catalogs and specialized journals.

This article reviews the minimum safety guidelines established in international technical standards for handling liquefied petroleum gas (LPG) systems and their surroundings. Additionally, it examines details related to the design, selection, location, and maintenance of elements and parts of LPG systems. It also addresses important aspects that must be considered by the technical authorities responsible for the systems during the approval process by the competent authority. The article presents advantages and recommendations provided by manufacturers of equipment and materials used in LPG systems. Finally, it highlights some poor practices observed in LPG systems to alert users unfamiliar with handling combustible gas like LPG.

1.1. LPG properties

- LPG is typically pressurized, stored, and transported above its boiling point. Upon release, it evaporates rapidly and, being denser than air (with a relative specific gravity of 1.53 with respect to air [5]), tends to accumulate in low-lying areas near the ground. In the presence of an ignition source, this can lead to an explosion and fire.
- LPG vapor forms an explosive compound at concentrations between 2% and 10 % [10].
- LPG is mainly composed of butane (C_4H_{10}) and propane (C_3H_8), with a small amount of lighter and heavier compounds, such as ethane and pentane. It is produced as a byproduct of natural gas and crude oil refining and production processes [11].
- LPG has a higher calorific value than other energy sources (the maximum calorific value of LPG is approximately 50.3 MJ/m^3 or 12 000 $kcal/m^3$ [8].
- LPG is gaseous under ambient conditions (1 atm and 25 °C).
- The specific gravity of LPG in liquid state is 0.55 kg/m^3 [5].

1.2. Advantages of using LPG

In comparison with other energy sources such as diesel, gasoline, coal, and wood, LPG offers several advantages, such as:

- LPG is clean regarding polluting gas emissions to the environment, as its combustion does not generate SO_X since it does not contain sulfur [4].
- LPG is neither toxic nor poisonous to humans, although it could cause death by displacing oxygen and causing anoxia [12].
- LPG is a highly versatile fuel. It can be used for cooking, heating water, drying agricultural products, and raising poultry. It is also used in forklifts, industrial ovens, boilers, and as a vehicle fuel [13].

- LPG is a fuel used in residential, commercial, and industrial applications [14].
- When LPG acts as a fuel, it burns completely, leaving no carbon residues and producing no soot [15].
- Its low cost, high accessibility, and environmental advantages have led several governments, such as India [16], Indonesia [17, 18], Burkina Faso [19], Ghana [20], South Africa [21], México [22], Brazil [23], Ecuador [24], Peru [25] among others, to implement compensatory measures such as subsidies to encourage the widespread use of LPG among their citizens.

1.3. Errors identified when using LPG

Despite the advantages mentioned above, several problems have been detected regarding the management of installations, such as:

- Lack of awareness of the technical standards in force when designing, installing, and maintaining LPG systems, resulting in poor applications [26].
- Lack of foresight in the original design of new installations considering the space allocated for storage, causing tanks to be installed in unsafe locations [27].
- Lack of protection for the containers storing the fuel and the systems in general, causing severe accidents worldwide [28].
- Neglect by users to provide preventive maintenance to equipment and components, resulting in them being used beyond the recommended service life by manufacturers [29].
- Failure to comply with national requirements and regulations, especially in countries with targeted subsidies for residential installations, causing the fuel to be used in commercial and industrial applications [30].
- Being classified as a safe fuel creates an excess of confidence in users of the systems regarding its handling. This has led to accidents with severe physical and human consequences [30].

1.4. Elements of an LPG System

Figure 1 shows the elements of an LPG system, which include:

- **Storage:** It refers to the containers used to package LPG fuel. These containers can be cylinders, which, due to their weight, are easily transportable by a human and are used through the exchange system. Also included are installed fixed tanks that must be supplied from tanker tanks through hoses for proper operation.
- **Transportation:** It refers to distribution pipelines or pipes and control elements such as valves, regulation devices like pressure regulators, and measurement devices like meters.
- **Consumer appliances:** It refers to devices that use LPG to meet human needs. Due to their ability to generate energy or their specific application, these devices can be used in residential, commercial, and industrial settings.
- **Protection or prevention systems:** It refers to systems designed to protect containers, pipelines, and consumer equipment installed to prevent accidents and reduce the risks associated with fuel handling.

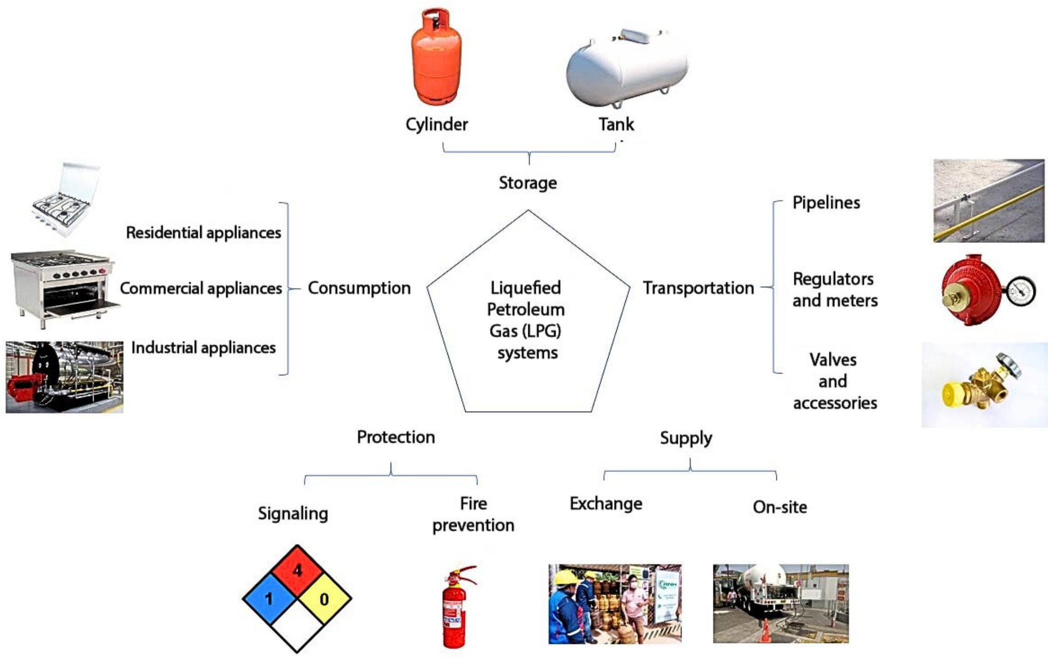

Figure 1. General diagram of an LPG system. Adapted from [31]

2. LPG storage

As mentioned in the previous section, containers store the fuel in a liquid state. LPG is typically used in a gaseous state, so a natural vaporization phenomenon occurs inside the containers before consumption.

2.1. Types of containers

Containers can be classified considering size into portable containers (cylinders) or stationary containers (tanks). Each container has various characteristics that differentiate them in terms of use and application, as shown in Figure 2.

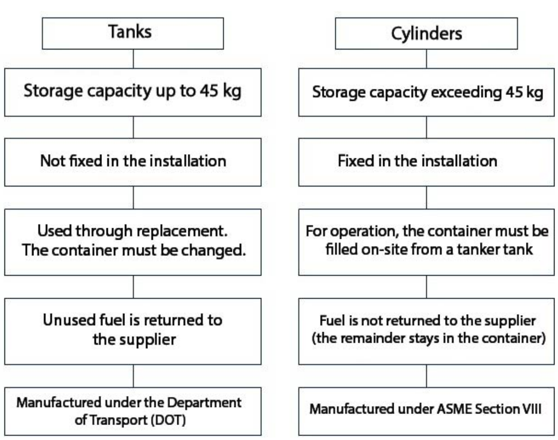

Figure 2. Differences between cylinders and tanks Adapted from [32, 33]

2.2. Container sizing

To determine the necessary storage capacity in an LPG system, it is crucial to consider the required demand for fuel in consumer appliances and the peak demand hours [34].

2.2.1. Cylinder sizing

There are cylinders with standard storage capacities of 15 kg and 45 kg for residential and commercial use, respectively. There are also cylinders of 5 and 11 kg. One way to determine the number of cylinders is through the vaporization ratio, as illustrated in equation (1), [35]:

$$N = \frac{P_{it}}{R_v} \tag{1}$$

Where: N represents the number of cylinders (in case it is a fractional number, it is approximated to the nearest whole number), P_{it} is the total installed power [kW/h], and R_v is the vaporization ratio, as shown in Table 1.

Table 1. Vaporization ratio for 15 kg and 45 kg cylinders [35]

T [°C]	Cylinder 45 [kW/h]		Cylinder 15 [kW/h]	
	Intermittent consumption	Continuous consumption	Intermittent consumption	Continuous consumption
10	41	35	19	16
5	37	31	17	14
0	34	28	16	13
-5	30	24	15	12
-10	28	21	14	10

The T[°C] values presented in Table 1 correspond to the minimum temperature of the area where the cylinders will be located. Intermittent consumption refers to less than 4 consecutive hours of operation of consumer equipment daily, while continuous consumption implies more than 4 consecutive hours per day.

2.2.2. Sizing of stationary tanks

Equation (2), [36] indicates the natural vaporization capacity of LPG from a stationary storage container.

$$Q = p.S.K.\frac{(T - T_g)}{CLV} \tag{2}$$

Where: Q is the natural vaporization capacity in kW, p is the percentage of liquid fuel in the container in %, S is the surface area of the container in m^2, K is the heat transmission coefficient through the walls of the container in kW/m^2 ºC, T is the minimum external ambient temperature of the area where the container will be installed in ºC, T_g is the liquid-gas equilibrium temperature in ºC, and CLV is the latent heat of vaporization of LPG in kWh/kg.

The so-called simultaneity factor is applied in residential applications with multiple users, such as in buildings, as presented in Table 2. This factor allows for a reduction in the maximum demand during the peak consumption hour, assuming that not all users are using the fuel service at that moment.

Table 2. Simultaneity factor in buildings [36]

Number of houses	S_1	Number of houses	S_2
1	1	1	1
2	0.50	2	0.70
3 a 5	0.40	3 a 5	0.60
6 a 8	0.30	6 a 8	0.55
9 a 14	0.25	9 a 14	0.45
15 a 39	0.20	15 a 39	0.40
40 a 50	0.15	40 a 50	0.35

Where: S_1 is the simultaneity factor without heating boilers in the installation, and S_2 is the simultaneity factor with heating boilers.

2.2.3. Vaporizers

When the gaseous phase flow supplied by the natural vaporization of the containers is insufficient to meet the demand of the installation, it is necessary to resort to forced vaporization through a vaporizer. This equipment has an inlet for liquid LPG from the container and an outlet in the gaseous phase towards the service [37].

Equation (3) is used to select the appropriate vaporizer:

$$Q = \frac{E_T \cdot F_d}{PC} \tag{3}$$

Where: Q is the required vaporization capacity in gal/h, E_t is the total energy needed for the system in BTU/h, F_d is the load variation factor (usually considered as 1.10 for gradual loads), and PC is the calorific value of LPG, considered as 94 450 BTU/gal.

2.3. Container location

LPG storage containers must be placed outside buildings, whether installed on the surface or buried. When installed on the surface, they should be in open, well-ventilated areas and equipped with protective elements and signaling [38].

2.3.1. Location of containers on terraces

A particular case regarding the location of containers on the surface is the installation on terraces. To do this, the following requirements must be met [39]:

- Verify beforehand that the rooftop structure is resistant to the load of the container filled with water. Additionally, periodic preventive maintenance tests, including conducting a hydrostatic test, must be carried out on the container.
- Consider installing a lightning rod covering the LPG storage area.
- Consider that the grounding connection for the container should be independent of the building's grounding.
- Consider installing an equipped fire hydrant (EFH) at an accessible point on the terrace.
- Keep a water supply operational to conduct the hydrostatic test of the container.

2.3.2. Location of buried containers

The location of buried containers involves considering various aspects, such as:

- Consider the characteristics of the terrain where the container will be located to implement electrical protections through sacrificial anodes or cathodes.
- Consider that the containers must be anchored on firm and level bases to prevent them from coming out or floating to the surface in case of floods.
- Consider that the containers must come prepared from the factory for burial, including protective paint, space for control and filling elements, and access from the exterior.

2.3.3. Incorrect container locations

LPG storage containers should not be placed under the following conditions [27]:

- Confined spaces without ventilation.
- Basements or subfloors of buildings.
- Under buildings.
- Parking areas and locations with elements that may increase the likelihood of disasters, such as BLEVE, which stands for Boiling Liquid Expanding Vapor Explosion, meaning a sudden explosion of the fuel as it transitions from liquid to gas state [40].
- Areas where garbage accumulates or where there are materials around the containers that could increase the likelihood of fire, as well as areas with storage facilities for fats and oils.

2.4. Safety distances from containers

The technical regulations for LPG installations establish minimum distances from containers to third parties that must be considered. These distances are determined based on the stored volume and the container's location (above or below the surface). Although there may be variations in safety distances, the criteria used to calculate these distances follow the guidelines outlined in Figure 3. This figure refers to the distances considered for stationary containers that can be placed either above or below the surface and filled on-site or through displaced intakes; these containers must have safety devices for pressure relief and venting in case of overpressure.

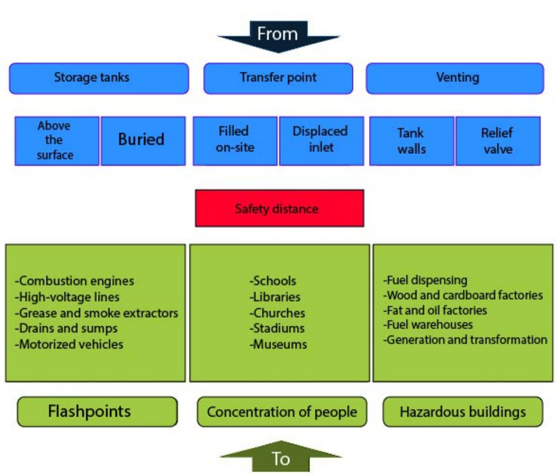

Figure 3. Criteria for locating stationary containers based on safety distance [27]

3. LPG transportation

This section refers to the fuel distribution pipes connecting the storage containers to the consumption points.

3.1. Minimum conditions for selecting pipes

La NTE INEN 2260:2010 [6] establishes minimum criteria for pipe installation, such as:

- Pipes can be metallic or plastic and must withstand the action of the fuel gas and the external environment. They must be protected by an effective system depending on the type of pipe.
- The thickness of the pipe walls must meet at least the pressure test conditions established for these installations. Additionally, they must have a mechanical strength that complies with the manufacturing standards' requirements for each type of pipe.
- Visible pipes must be marked and identified with colors following the ASME A13.1 [41] standard (ochre yellow for gas phase conduction pipes and white for liquid phase conduction pipes); concealed pipes (embedded, buried or in ducts) must also be marked [42].
- Pipes must convey the necessary flow for the operation of consumer appliances.

3.2. Location of pipes

To facilitate inspection, maintenance, and repair in case of leaks, installing the pipes that transport LPG visibly is recommended. However, for aesthetic reasons, users prefer the pipes to be concealed. Figure 4 shows the accepted ways to install pipes for LPG:

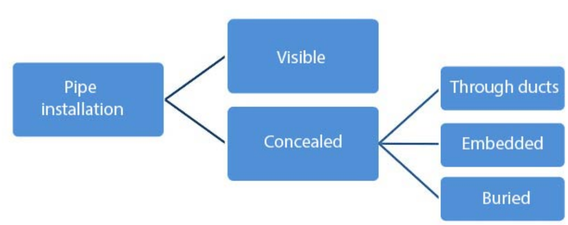

Figure 4. LPG pipe location [26]

It is important to note that embedded pipes, that is, those that are part of the building's structure, are not accepted for LPG transportation [6].

3.3. Pipe sizing

Dependiendo de la ubicación de las tuberías con respecto a los reguladores de presión, estas se clasifican en de media presión de baja presión.

3.3.1. Medium-pressure pipes

These pipes are located at the outlet of the storage containers, between the regulator of the first stage and that of the second stage.

Various publications that present criteria for LPG pipe sizing [43], can be found in the literature. Equation (4), [44] illustrates one of the most used methods, according to Renouard:

$$p_1{}^2 - p_2{}^2 = 4810.L.d.Q_s{}^{1.82}.D^{-4.82} \tag{4}$$

Where: Q_s represents the volumetric flow at standard conditions in m^3/s, D is the internal diameter of the pipe in m, p_1 is the absolute pressure at the pipe's inlet in Pa, p_2 is the absolute pressure at the pipe's outlet in Pa, d is the relative density of the gas d = 1.5 [5], and L is the equivalent length of the pipe in m.

The length in equation (3) corresponds to the equivalent pipe length, representing the losses experienced by the fuel passing through the pipes. This equivalent length is expressed in equation (5), [37]:

$$L_{eq} = 1,2.L \tag{5}$$

Where: L is the pipe length in meters, and L_{eq} is the equivalent length in m.

In equation (3), p_1 is the absolute pressure at the outlet of the first stage regulator, which depends on the atmospheric pressure. It is known that atmospheric pressure varies with the altitude above sea level of the location where the system is installed. Equation (6) shows the atmospheric pressure correction considering a city's height above sea level [37].

$$p = 1,013.(1 - 0,0000225577.H) \tag{6}$$

Where: p is the pressure as a function of altitude in bar, and H is the city's height above sea level in m.

3.3.2. Low-pressure pipes

These pipes are located after the second stage regulator [45]. Among the established criteria for sizing low-pressure pipes, one of the most widely used is the equation proposed by Pole, presented in equation (7), [44]:

$$Q_s = C.\left(\frac{D^5(p_1 - p_2)}{L.d}\right)^{0.5} \tag{7}$$

Where: Q_s is the volumetric flow at standard conditions in m^3/s, C = 4.635 [44], D is the internal pipe diameter in m, p_1 is the absolute pressure at the pipe's inlet in Pa, p_2 is the absolute pressure at the pipe's outlet in Pa, d is the relative density of the gas d = 1.5 [5], and L is the equivalent pipe length in m.

Considering what is expressed in equation (7), the pressure difference between the initial and final points of the pipe section (the section between the second stage regulator and the inlet of the consumer equipment) is used. Therefore, the pressure expressed in these criteria is gauge, not absolute, as in the medium-pressure criteria. Consequently, the altitude above sea level of the city location is irrelevant [43]. An accepted value for pressure difference in low-pressure sections is 150 Pa [35].

3.3.3. Gas velocity in pipes

The gas velocity is the value obtained by dividing the flow rate by the duct section [36], and it can be a determining factor in optimizing pipe diameters due to the excessive noise generated by the fluid flow through them.

Equation (8) is used to calculate the velocity [46]:

$$v = 360.\frac{Q}{D^2} \tag{8}$$

Where: v is the gas velocity in m/s, Q is the flow rate in m^3/h, and D is the diameter in mm.

Table 3 shows the established maximum values of permissible gas velocities, considering the area through which the conduits pass, to prevent any potential noise generated from becoming bothersome.

Table 3. Gas velocity in pipelines [36]

Velocity	Pipe location
30	General distribution network and service connections, buried conduits.
20	General distribution network and service connections, overhead conduits.
10	Standard building installation and individual installation

3.4. Pipe materials

Various pipe materials are accepted for LPG piping. Table 4 displays the materials allowed by NFPA 58 [47] for LPG pipes, along with commonly employed joining methods. Additionally, some regulations support using polyethylene-aluminum-polyethylene (P-Al-P) pipes in gas system installations [6].

Table 4. Materials accepted by NFPA 58 for LPG transportation [26]

Material	Manufacturing standard	Joining procedure
Steel	ASTM A 53 ASTM A106	SMAW
Stainless steel	ANSI/CSA 6.26	Pressing fit
Copper	ASTM B 88 ASTM B 280	Oxy-acetylene
Polyethylene	ASTM D 2513-09	Thermofusion Electrofusion

The pipes that are not accepted for LPG conveyance are:

- Cast iron pipe [33].
- Lead pipe [35].

3.5. Pipe selection criteria

It is essential to consider various aspects when choosing a pipeline for LPG service, as these can significantly impact the system's total cost or even make the installation unfeasible. Figure 5 illustrates two of the criteria used for selecting LPG pipes.

The weight per unit length of the pipe is crucial, especially in tall installations (buildings) or when covering extensive distances. Tensile strength must be considered essential when the pipeline is installed in areas with a high impact probability.

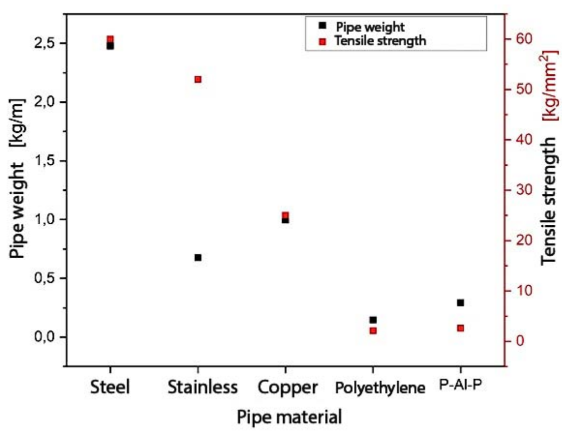

Figure 5. Factors for selecting LPG pipes. Adapted from [48]

Other additional factors are also crucial when selecting pipes, such as:

- Having a sufficient stock of materials to meet the needs of a project.
- Having skilled personnel to join pipes using fittings.
- Having the required energy for the pipe joining equipment with fittings.

4. Pressure regulation

It is a device that automatically reduces the gas inlet pressure, resulting in a lower (outlet or "regulated") but constant pressure downstream from where it is installed, keeping it within established limits for a specified flow range [36]. Pressure regulators can be fixed or adjustable (referring to the outlet pressure). In regulation systems, there are single-stage systems (a single pressure regulator) and dual-stage regulation systems (medium-pressure regulator and low-pressure regulator) [49]. The pressure regulator is the heart of an LPG installation as it compensates for upstream pressure variations and delivers the required pressure and flow downstream.

4.1. Location of pressure regulators

Medium-pressure regulators should preferably be placed in outdoor areas of buildings. They must be accessible from the common areas of the building or the exterior in the case of single-family homes [50].

They can be installed inside spaces designated for the placement of meters as long as these spaces are located in ventilated areas. If the meters are placed in cabinets inside the building, these cabinets must be sealed, and the interior must be ventilated directly to the outside [51].

A single-stage pressure regulator must be installed outside buildings, and exceptionally, it may be located inside buildings as long as it has an integrated relief valve, with the outlet directed towards the exterior [50].

4.2. Selection of pressure regulators

Figure 6 shows the curves for selecting the first-stage pressure regulator based on energy demand. To use the graph, a specified consumption and service pressure must be considered as a starting point. With these data, a minimum pressure in the container should be considered, and according to the manufacturer's catalog, the model that meets these conditions is selected.

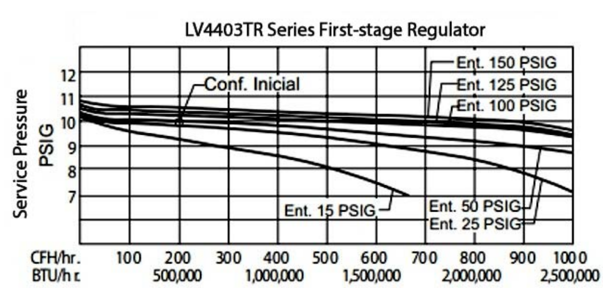

Figure 6. Selection of the first-stage regulator [52]

Figure 7 shows the curves for selecting the second-stage regulator. Reading and selecting these regulators is similar to what has been indicated for selecting first-stage regulators.

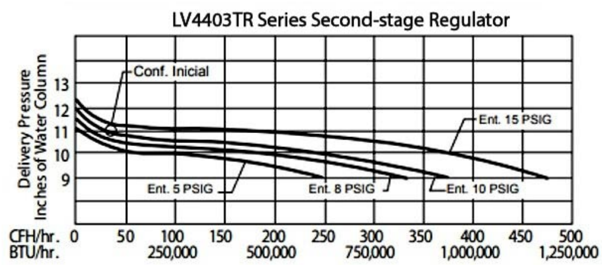

Figure 7. Selection of the second-stage regulator [52]

5. Consumer equipment

These are the elements that require fuel to meet the needs of a user. These devices must have specific characteristics, including [31]:

- Withstand the action of the fuel gas (GLP).
- Be designed to operate with the fuel gas.
- Withstand the action of the external environment in which they must be located.

5.1. Accessibility of consumer equipment

Accessibility to GLP consumption equipment is an essential requirement. This implies that they must be within reach of users for manipulation and control. Three levels of accessibility are established, as shown in Table 5.

Table 5. Accessibility to gas appliances [53]

Level of accessibility	Characteristic
1	They can be manipulated without opening locks, and no stairs or mechanical means are required to access them.
2	They are protected by a cabinet, accessible register, or door with a standard lock, and no stairs or mechanical means are required to access them.
3	Stairs or special mechanical means are needed for manipulation. Access to them is through private areas, which, even if they are common areas, are for personal use.

5.2. Consumer equipment power

The basis for the sizing of an LPG system is linked to the power required by consumer equipment, which must be satisfied through the natural vaporization of the containers. Appliances can be categorized as domestic or industrial. Table 6 shows typical power ratings for LPG consumer equipment.

Table 6. Potencias típicas de equipos de GLP [53]

Appliance	Power [kcal/h]	Appliance	Power [kcal/h]
Water heater		Heater	
80 l	6000	5 l/min	10000
150 l	8000	10 l/min	20000
200 l	8200	13 l/min	26400
260 l	8200	16 l/min	31400
Domestic stove	8000	Cooktop	8000
Semi-industrial stove	24000	Fryer	9300
Clothes dryer	12700	Heater	3000

The power consumption of each system device must be added to determine the total power. In the case of multifamily residential networks (buildings), this power must be adjusted by the simultaneity factor.

Equation (9) shows the power consumption ratio affected by the simultaneity factor for multifamily residential systems (buildings) [50].

$$Q_{sc} = \sum Q_{si}.S_{1-2} \tag{9}$$

Where: Q_{SC} is the maximum probable flow rate, Q_{Si} is the maximum flow rate of each consumer equipment, and S_{1-2} is the simultaneity factor according to the number of users, as established in Table 2.

6. Start-up of systems

To ensure the optimal operation of the LPG system, it is necessary to conduct various tests and verifications before supplying the fuel and igniting the consumption equipment.

6.1. Tightness test

It is necessary to carry out the tightness test on all piping systems before putting them into operation [54]. This test must be conducted at a pressure higher than the system's maximum operating pressure (MOP), as established in Table 7.

Table 7. Pressure and test times according to MOP [6]

Operating pressure [kPa]	Test pressure [kPa]	Test time [min]
200<MOP<500	>1.50. MOP	60
10<MOP<200	>1.75. MOP	30
MOP<10	>2.50. MOP	15

This tightness test must be performed on all pipeline sections and can be conducted in segments. The test result must be satisfactory, meaning there should be no pressure drop in the pipeline network during the minimum established time. Additionally, a record must be completed with all the data collected during the test and must bear the signature of the professional in charge of the work and a representative of the building's user [54]. If the test result is not satisfactory, the location of the possible leak must be verified, and the corresponding repair must be carried out.

6.2. Purge

It is necessary to carry out a network sweep or purge before start-up to eliminate debris and residues that may enter the pipeline during the assembly phase, including welding slag. This helps eliminate such residues and prevents the risk of obstruction or blockage in the regulators or burners of consumer equipment [49].

6.3. Signaling

To alert individuals unfamiliar with the LPG system (storage, pipelines, equipment), safety signs must be installed warning of the danger associated with handling fuel gas. These signs should be placed in visible locations and have appropriate dimensions to be easily identified by users.

6.4. Protections

LPG systems must be protected from third-party interference. The worst-case scenario in storing an LPG system is the formation of a BLEVE (Boiling Liquid Expanding Vapor Explosion) [40]. This phenomenon represents a particular case of a catastrophic explosion of a pressure container, in which there is a sudden release of a large mass of pressurized and superheated liquid or liquefied gas into the atmosphere.

It is necessary to install water-based cooling systems in storage. In the event of a fire around the containers, these systems can delay the formation of this phenomenon until the competent authority can control the fire.

6.5. Required technical documentation

LPG system installation projects must have the necessary documentation. This documentation must be submitted to the competent authority [7] to verify compliance with the technical and legal regulations in force in each territory. The technical documentation must include [30]:

- Technical report of the project, including all aspects considered during the design, construction, assembly, and suitability verification phases of the LPG system.
- Installation drawings, including all the construction details used during the assembly phase.
- Signed records of tightness tests and other verifications on the system to ensure compliance with regulatory and safety standards.
- Certifications of the elements used in the system to verify compliance with the required quality standards.

7. Conclusions and recommendations

LPG is one of the most widely used fossil fuels in residential, commercial, and industrial settings. Its utilization, however, poses risks to both individuals and buildings. This review outlines the minimum safety criteria that should be incorporated into an LPG installation.

It is crucial to emphasize that these systems must be designed by professional engineers with expertise in regulatory compliance to provide users with safe and efficient systems.

Each system has characteristics and peculiarities that set it apart from others. For this reason, the technical designer in charge of the design must be familiar with all the material and accessory options approved by regulations to provide users with high-quality systems.

Acknowledgments

To the Escuela Politécnica Nacional EPN-Ecuador, with its research lines: Sustainable Manufacturing in Manufacturing Processes and Mitigation of Vibrations, and Energy Efficiency in Automotive and Aeronautical Transportation Systems, for the support provided in the development of this work.

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