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Analysis of storage in Liquefied Petroleum Gas systems: Stationary Tanks vs. Cylinders

Análisis del almacenamiento en sistemas de gas licuado de petróleo: tanques estacionarios *vs.* cilindros

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Abstract

In Ecuador, liquefied petroleum gas (LPG) is used as an energy source for residential, commercial and industrial equipment. In its natural state this fuel is in gas phase, but for easiness of transportation and storage it is liquefied and stored in containers called cylinders (by spare) or tanks (stationary), where it is re-gasified for consumption. The present work measures the remaining LPG that is returned in cylinders to the marketers, by 20 commercial and industrial users in Ecuador during a month, 8 with 15 kg cylinders and 12 with 45 kg cylinders. The average return was 3.82 kg/cyl. (25.49%) and 9.69 kg/cyl. (21.54%) respectively. Then, 8 safety parameters considered in the current Technical Standard in Ecuador were verified for these 20 facilities, and the results of those users who do not comply with these parameters are presented. Finally, some arguments are given about why there are economic and security advantages in the storage of LPG in stationary tanks over the storage in cylinders.

Keywords: Liquefied petroleum gas, tanks, cylinders, vaporization, remainder, safety.

Resumen

En el Ecuador se utiliza el gas licuado de petróleo (GLP) como fuente de energía para equipos residenciales, comerciales e industriales. En estado natural este combustible se encuentra en fase gaseosa, pero por facilidad de transporte y almacenamiento es licuado y depositado en recipientes denominados cilindros (por recambio) o tanques (estacionarios), donde se vuelve a gasificar para su consumo. El presente trabajo mide el GLP remanente que es devuelto en cilindros a las comercializadoras por veinte usuarios comerciales e industriales en el Ecuador durante un mes, 8 con cilindros de 15 kg y 12 con cilindros de 45 kg. El promedio de devolución fue de 3,82 kg/cil. (25,49 %) y 9,69 kg/cil. (21,54 %) respectivamente. Luego se verificaron ocho parámetros de seguridad contemplados en la norma técnica vigente en el Ecuador para estas veinte instalaciones, y se presentan los resultados de aquellos usuarios que no cumplen con estos parámetros. Finalmente, se entregan algunos argumentos sobre por qué existen ventajas económicas y de seguridad en el almacenamiento de GLP en tanques estacionarios sobre cilindros.

Palabras clave: gas licuado de petróleo, tanques, cilindros, vaporización, remanente, seguridad.

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1. Introduction

The liquefied petroleum gas (LPG) is a fuel which is utilized as energy source in residential [1], commercial [2] and industrial [3] applications. Its use has various advantages, such as

- High calorific power compared to other energy sources [4].
- It satisfies various energy needs as a unique source [5].
- It is easy to transport and store, reducing its temperature and increasing its pressure [6].
- It is not toxic for humans [7].

Despite all these benefits reported about the handling of the GLP, there are various disadvantages regarding its use, such as:

- It generates complacency in the user regarding its manipulation. This has caused accidents with severe physical and human consequences [8].
- Lack of foresight in the design of new buildings on the part of builders, which makes that the recipients (cylinders) should be stored in stacked places, without ventilation and piled one on top of the other (Figure 1), which causes insecurity for the user.

Figura 1. Storage of LPG in cylinders.

1.1. Transportation and storage of LPG

At environmental conditions the LPG is found in gaseous phase [9] obtained from a petroleum refining process, and then is transformed to liquid phase increasing its pressure and reducing its temperature before being stored in big containers, from which it is transported to filling plants or delivered to the final users.

The delivery is made in containers [10] known as cylinders, which are easily manipulable and replaced when the fuel is over, or tanks which are permanently stored and a cistern truck is required for recharging them [11]. Figure 2 shows the main characteristics of the storage, both in cylinders and tanks.

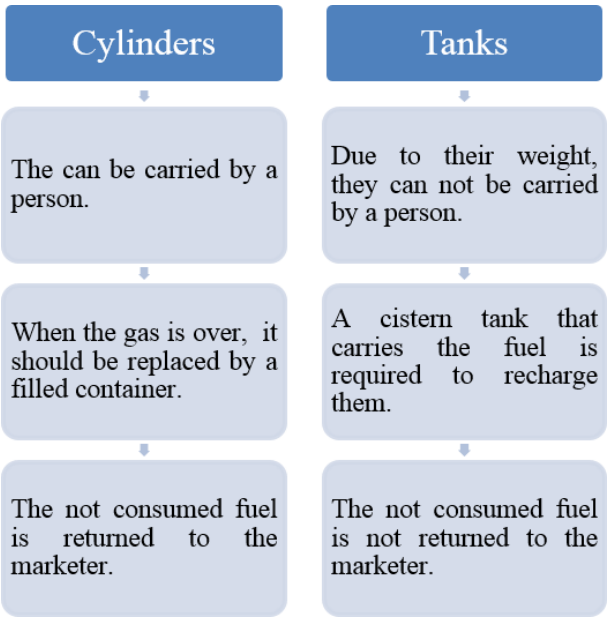

Figura 2. Differences between the storage of LPG in cylinders and tanks [12].

1.2. Consumption of LPG

With the exception of particular cases, the LPG is required in gaseous phase by the consuming equipment. This phase is obtained inside the containers, through a heat transfer process from the fuel to the surrounding environment. The «vaporization capacity» of the containers depends on [13]:

- ***Exterior environmental temperature:*** a greater exterior environmental temperature, will cause a greater variation of the temperature with the fuel, and thus the vaporization capacity of the container will also be greater.
- ***Size of the container:*** For a greater size of the container, there is a greater area of contact with the fuel.
- ***Material of the container:*** It should favor the heat transfer between the fuel and the surrounding environment

When the fuel required by the consuming equipment is greater than the vaporization capacity of a container, the vaporization of the LPG is very fast and the walls of the container cool down, starting the

condensation of water drops which are suspended in the air surrounding the container (humid air). Then, a water film appears in the exterior area, corresponding to the internal zone in which there is fuel. If the request for fuel by the consuming equipment continues, the water in the exterior will start forming ice layers in the same area, as shown in Figure 3a. As a consequence of this excessive cooling, the fuel delivery to the equipment decreases, and they will start to operate inadequately.

In order to counteract this phenomenon, empirical mechanisms have been utilized to enable consuming the fuel remaining in a container whose walls have frozen. One of these practices is to put the containers in hot water (Figure 3b), to increase the temperature difference between the exterior and the fuel in the interior, and vaporize more LPG.

a) b)

Figura 3. a) Ice layers on a cylinder due to the loss of natural vaporization capacity. b) LPG cylinder in a container with hot water to improve the natural vaporization capacity.

1.3. LPG consumption in Ecuador

In Ecuador, the LPG is commercialized with two fares:

- A subsidized fare for residential consumption and nonprofit activities [14, 15].
- An industrial fare for food sale, profit-seeking industrial activities and sumptuous residential uses, such as heating water for pools, jacuzzis and sauna baths. This fare is set by the National Government through the Executive Decree N° 799 [16], is revised monthly, is in accordance with international oil prices, and is published in the web site of the governmental agency [17].

Each local Fire Department and the Hydrocarbon Regulation and Control Agency (HRCA), are the competent authorities with regards to the supervision and inspection of the LPG facilities in Ecuador.

1.4. Problems detected in LPG handling in Ecuador and problem justification

The following problems have been identified related the handling of LPG in Ecuador:

- Due to the difference between the residential and industrial fares, 15 kg cylinders with subsidized LPG (0,10666 USD/kg) are utilized in commercial and industrial facilities, instead of using the fuel without subsidy (0,767229 USD/kg), and because of the high fuel consumption in this type of systems, the saving due to the difference in fare is significant.
- Lack of planning in the design of new buildings for commercial and industrial use, which do not consider safe rooms to locate the gas supply.
- Due to the high flammability of LPG [18], there is high probability for the occurrence of disasters with the presence of fire and explosion, known as «Boiling Liquid Expanding Vapour Explosion» (BLEVE) [19] in the surroundings of the gas storage in commercial and industrial buildings, due to the lack of foresight and security measures. BLEVE is an explosion of vapors that expand as the liquid boils [20], with devastating consequences [21, 22], especially because of the energy release with separation of fragments of the involved containers [23] (Figure 4).
- Manipulation of the LPG systems by nonqualified personnel who ignores the current legal framework [24], and does not apply engineering criteria in the calculation and dimensioning

of such systems, thus making them insecure [25] (Figure 4).

The present work shows the losses of users of LPG systems with cylinders, caused by the return of non-consumed fuel, i.e. remaining, to the marketer. In addition, an analysis is carried out of the following security aspects of these facilities regarding the use of cylinders, which are considered in the current regulation for gas systems in Ecuador [26]:

Figura 4. LPG cylinder that has suffered BLEVE [27].

- Security distances to third parties.
- Ventilation of the storage area.
- Number of cylinders in storage.
- Availability of extinguishers in the storage area.
- Validity of extinguishers.
- Availability of leak detectors.
- General condition of accessories (valves, regulators and hoses).
- Availability of emergency plans in the facility.

At last, some advantageous aspects of the facilities that have stationary tanks are presented, compared to those that have returnable cylinders.

2. Materials and methods

In order to determine the gas remaining in the cylinders returned by the users of LPG systems, such cylinders have been weighted before connecting them for use, and after they have been emptied. For this purpose, a GTC scale with a capacity of 150 kg and a measuring sensitivity of 50 g was utilized. The remaining weight in kg is calculated as

$$kg = W_{comb} - (W_{lleno} - W_{serf}) \quad (1)$$

where kg are the returned (remaining) kilograms, W_{fuel} is the weight of the fuel, W_{full} is the weight of the full cylinder and W_{empty} is the weight of the empty cylinder.

A GTC 100 detector with a range 0-30000 ppm of propane, was used to measure if the presence of gas in the storage environment is greater than the lower limit of flammability of the fuel.

3. Presentation and analysis of results

3.1. Remaining gas

Tables 1 and 2 show the remaining gas returned in 15 kg and 45 kg cylinders, respectively, which were utilized for four weeks, by commercial and industrial users.

Tabla 1. Remaining gas returned in used 15 kg cylinders

User	Week 1		Week 2		Week 3		Week 4		Total				
N.	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	$ US ret real*	Kg ret cil	% filling
1	4	8,5	3	7,1	4	8,7	4	8,4	15	32,7	$25,09	2,18	15
2	4	13,4	5	17,8	5	18,2	4	13	18	62,4	$47,88	3,47	23
3	5	15,1	5	15,7	6	21	6	20,8	22	72,6	$55,70	3,30	22
4	6	27,8	7	31,1	8	35,6	7	30,9	28	125,4	$96,21	4,48	30
5	10	41	9	35,9	8	33,2	8	32,7	35	142,8	$109,56	4,08	27
6	11	35,4	11	36,1	12	39,8	12	40,2	46	151,5	$116,24	3,29	22
7	12	55,6	11	50,1	10	47,1	11	52,1	44	204,9	$157,21	4,66	31
8	12	61,1	12	60,9	11	57	13	67	48	246	$188,74	5,13	34
								Average:	**32,00**	**129,79**	**99,58**	**3,82**	**25,48**

Tabla 2. Remaining gas returned in used 45 kg cylinders

User	Week 1		Week 2		Week 3		Week 4		Total				
N.	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	Cil	Kg. ret	$ US ret real*	Kg ret cil	% filling
9	4	35	4	34,2	4	32,9	4	33,5	16	135,6	$104,04	8,48	19
10	5	36,7	5	35,8	4	28,4	4	27,9	18	128,8	$98,82	7,16	16
11	5	53,1	4	47,6	6	62,9	6	61,4	21	225	$172,63	10,71	24
12	5	61,4	5	63	5	62,1	4	55,2	19	241,7	$185,44	12,72	28
13	6	58,8	5	49,2	6	61,5	6	62,4	23	231,9	$177,92	10,08	22
14	6	70	6	74,2	8	91,1	6	72,1	26	307,4	$235,85	11,82	26
15	7	43,7	6	37	8	51,7	8	54,6	29	187	$143,47	6,45	14
16	9	77,9	9	82,1	8	78,4	8	73,7	34	312,1	$239,45	9,18	20
17	9	88,4	8	78,9	10	101,1	8	82,4	35	350,8	$269,14	10,02	22
18	10	75,7	10	78	11	87,6	10	79,8	41	321,1	$246,36	7,83	17
19	10	114,6	10	117,5	9	105,4	9	106,3	38	443,8	$340,50	11,68	26
20	11	110,2	10	100,2	11	114,3	12	123,7	44	448,4	$344,03	10,19	23
								Average:	**28,67**	**277,80**	**213,14**	**9,69**	**21,54**

Simbology:

User: Número de usuario
Cap: Cylinder capacity of the facility
Cyl: Number of returned cylinders
kg ret: kg returned weekly
$ US ret:

- For 15 kg cylinders = kg ret x 0,10666 USD/kg (residential fare)

- For 45 kg cylinders = kg ret x 0,767229 USD/kg [17]

kg ret cyl: kg. promedio devuelto por cilindro
% filling: average filling percentage per returned cylinder

Based on the results presented in Table 1, the following can be stated:

- The difference between the values for users of 15 kg cylinders in the columns $ US ret vs. $ US ret real*, is because the $ US ret represents the value of the remaining gas returned by the user, but this is not a real value because this user should pay the industrial fare, result shown in the column $ US ret real*.

- There is remaining gas returned in all cylinders, which is money that the user has paid in advance.

- Among the users of 15 kg cylinders, N° 1 returns the least fuel (2.18 kg/cylinder), and N° 8 returns the most fuel (5.13 kg/cylinder).

- The average amount of fuel returned in 15 kg cylinders was 3.82 kg per cylinder, which represents 25.49 % of its capacity.

- Among the users of 45 kg cylinders, N° 15 returns the least fuel (6.45 kg/cylinder), and N° 12 returns the most fuel (12.72 kg/cylinder).

- The average amount of fuel returned in 45 kg cylinders was 9.69 kg per cylinder, which represents 21.54 % of its capacity.

3.2. Security

Figure 5 shows the quantitative results of the security inspection performed to the 20 users, according to the criteria established in the current legal framework in Ecuador [26]. The letter in the abscissa represents the violated criterion, and the number on the bar represents the number of users that violate that criterion.

It is important to remark that in the numerical criteria regarding installed capacity, the individual capacity, given in kilograms, of all cylinders in the storage area is added.

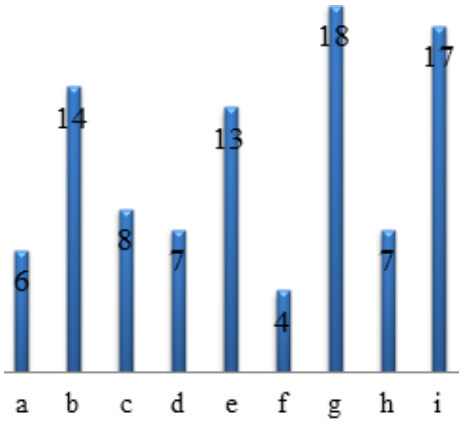

Figura 5. Users of LPG systems that violate security criteria.

a. Security distances to third parties: 6 users had the containers very close to open flame sources or spark generators. The Technical Regulation establishes a minimum security distance with respect to third parties that may be potential risks of fire generation or incentive [28].

b. Ventilation of the storage area: 14 users had the containers in areas without ventilation (Figura 6a).

c. Number of cylinders in storage: The regulation establishes a maximum number of 15 kg and 45 kg cylinders, which may be located for supply as well as for reserve. 8 users exceeded the maximum number of allowed cylinders.

d. Presence of gas leaks: 7 users exceeded the maximum allowed by the measuring device (1.93 % of LPG in the air). A probable cause of this situation is the wear in the connecting couplings, which are constantly connected and disconnected during the replacement of the cylinders.

e. Availability of fire extinguishers in storage area: 13 users did not have fire extinguishers.

f. Validity of extinguishers: Of the 7 users who did have extinguishers, 4 of them had them expired.

g. Availability of gas leaks detectors: The installation of detectors is recommended as an alternative measure to detect possible gas leaks in the surroundings of the storage. These detectors emit a high-pitched sound when the amount of fuel in the environment is close to the lower explosion limit. 18 users did not have this device.

h. General condition of accessories (valves, regulators, hoses) in the storage area: The accessories have a service life recommended by the manufacturer, according to treatment received [29]. 7 users had accessories that exhibited signs of excessive wear (Figure 6b).

i. Availability of emergency plans in the facility: In case of emergency with fuel leaks and fire, it is recommended to count with an emergency handling plan that considers the actions to be taken during such emergency. This plan should specify the people responsible of leading these actions, and should be always readily available. 17 users did not have emergency plans nor people responsible for handling such emergencies.

3.3. Users that have replaced cylinders by stationary tanks

Users that have opted to replace the system with cylinders by stationary tanks have seen the benefits immediately. Some of these benefits include:

- Zero gas remaining, because there is no return or replacement of the container; therefore, there is no return of fuel to the marketer.
- Since there is no LPG remaining, there is a saving of money that can be invested in other activities related to the commercial or industrial business.
- The storage is concentrated in a single space, which enables focusing the security and prevention efforts in a single point [30] (Figure 7a).
- More secure systems, since they are inspected by the competent authority and they should comply the current technical regulation for their approval and operation [26].
- Easy monitoring and control of the amount of fuel in reserve, since stationary tanks have measuring and control devices. If the system is connected to several users, the billing is done individually placing meters or counters for each user (Figure 7b).
- Comply the current legislation for commercial and industrial use (without subsidy) of LPG, and elimination of the use of the residential LPG for users that usufruct it.
- Minimum maintenance of the facilities, since there is no manipulation during the discharge because it is not necessary to disconnect couplings during the replacement [31].
- Comfort, since no personnel is required to take away and transport empty cylinders.
- The transportation of cylinders produces bumps and dents on structural parts of the building; these are eliminated with stationary systems.
- Flexibility for the installation of containers in hard-to-access areas, such as terraces [32].

a) b)

Figura 6. a) Tanks in an area without natural ventilation. b) LPG cylinder with the connecting valve in bad condition.

a) b)

Figura 7. a) Stationary LPG tanks. b) Meters of LPG consumption.

Equation 2 gives an expression to determine the time in which a facility with stationary tanks may be paid, considering the money that is not paid to the marketer as remaining fuel.

$$Recov = \frac{Facility\ cost}{\$US\ ret\ real} \tag{2}$$

Where:

Recov: is the time for recovering the investment on a new facility with stationary tanks.

Facility cost: Approximate cost of the facility.

$ US ret real: Monthly average of returned USD.

On the other hand, Table 3 shows the times for recovering the investment for the monthly averages of remaining gas, estimating an initial installation value of 1500 USD for a system with 15 kg cylinders and 2500 USD for a system with 45 kg cylinders.

Tabla 3. Recovery of the investment for a facility with stationary tanks

Cyl	$ US ret real*	Recov
15	99,58	15,06
45	213,14	11,73

Obviously, this will depend on the size of the facility and the number of accessories, pipes and stationary tanks that are placed, for the initial cost of such facility. However, considering reference values according to the reality of the market, the recovery time of the investment in 15 kg cylinders facilities is 15 months, and 12 months for the case of 45 kg cylinders facilities.

4. Conclusions

The replacement of a conventional system with cylinders by stationary tanks, generates saving to the user because there is no payment for remaining fuel. This can be seen immediately after the new system is put into operation, since no fuel is returned to the marketer.

As the consumption is greater, so will be the need to have a stationary gas system with tanks, since the payment for not utilized remaining fuel could be avoided.

There will always be return of remaining gas in a cylinder. For the cases considered, the averages were 3.82 kg/cyl. (25.49 %) for users of 15 kg cylinders and 9.60 kg/cyl. (21.59 %) for users of 45 kg cylinders.

The initial investment that could be made for replacing a system with cylinders by one with stationary tanks, is recovered in short time (15 months in 15 kg cylinders and 12 months in 45 kg cylinders) because there is no payment for the remaining gas; this time may vary depending on the size of the facility and on the fuel consumption.

In a system in which LPG is stored, there will always be physical and human risks. A system with stationary tanks does not eliminate this risk, but minimizes it compared to the system with returnable cylinders.

A gas storage system minimizes the risk in a commercial or industrial facility; however, the user is responsible for maintaining the level of security in the system, and may start with small routines such as:

- Revise the general condition of the accessories.
- Verify leaks with soapy water in the joints of the accessories.
- Request talks about prevention, and periodic inspection to the system by qualified personnel.
- Count with protection systems such as: extinguishers, leak detectors, fire alarms.
- It is necessary to have an evacuation and emergency plan.
- Request inspection and permission for operating the system to the competent authority.

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