DEVELOPMENT OF A SAFETY FRAMEWORK FOR BULK & COMMERCIAL LPG SUPPLY SYSTEMS IN COMMERCIAL BUSINESSES

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Degree of Master of Science

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Thesis submitted in partial fulfilment of the requirements for the degree Master of Science in Safety and Health Management

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ABSTRACT

The purpose of this project is to analysis the commercial & bulk LPG supply systems in Sri Lanka and to develop recommendations the safe LPG supply distribution considering market demands in commercial applications. This covers all the LPG supply systems practiced in Sri Lanka by identifying customer's current perception and level of satisfaction with the traditional Gas withdrawal commercial 37.5Kg LPG cylinders and bulk storage LPG bullet tanks.

LP Gas is potentially hazardous from the point of production until it has been safely used and the combustion products have been properly disposed of. The term LP Gas describes a range of products which have much in common on safety concerns during distribution. Safety concerns are the understanding the behavior of LP Gas and keeping it under control during distribution.

The research findings reveal that industry currently follows unsafe practices that limit its ability to take full advantage of market developments and opportunities, particularly compared to bulk LPG supply system. This finding alone justifies the need for the LPG industry to find ways to work with LPG suppliers, distributors and dealers to develop commercially sustainable safe business models for supplying across the country's full consumer market. According to the study new liquid withdrawal cylinders or bulk tanks are to be introduced to the current model to minimize the risk. To enhance the knowledge of users, there is a requirement of comprehensive door to door training progress. Following up available standards, set controls on LPG installations and continuous safety audits can ensure the safety of current commercial and bulk LPG supply systems.

The level of challenges that exist will however likely lead to the commercial industry experiencing growing pains as it wrestles with securing market opportunities and reacting to the increasing competitiveness showed by bulk LPG suppliers. This research has summarized the problems of existing commercial & bulk LPG supply systems and it has shown the opportunity for implementing further safe systems to cater to the demand of industrial LPG requirements like in other many developed countries.

***Key Words**: LP Gas, Safe, Supply Systems, Risks, Distribution*

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LIST OF ABBREVIATIONS

Abbreviation	Description
ASTM	- American Society for Testing and Materials
BLEVE	- Boiling Liquid Expanding Vapor Explosion
CBSL	- Central Bank of Sri Lanka
CPC	- Ceylon Petroleum Corporation
CSC	- Customer Service Center
ECV	- Emergency Control Valve
ESD	- Emergency Shut Down
GDP	- Gross Domestic Product
GSIUR	- Gas Safety Installation and Use Regulations
HEMP	-Hazard & Effect Management Process
HSE	- Health Safety & Environment
ICTAD	- Institute of Construction Training and Development
LGLL	- Litro Gas Lanka Limited
LOT	- Liquid Off Take
LPG	- Liquefied Petroleum Gas
NFPA	- National Fire Protection Agency
NRV	- Non Return Valve
OPSO	- Over-Pressure Shut-Off
OSHA	- Occupational Safety & Health Administration
PRV	- Pressure Relief Valve
QA	- Quality Assurance
SLS	- Sri Lanka Standard
SLTDA	- Sri Lanka Tourism Development Authority
UPSO	- Under-Pressure Shut-Off
WLPGA	- World Liquefied Petroleum Gas Association

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CHAPTER 01-INTRODUCTION

1.1 Background

Sri Lanka Standards 712:1998 mentions that LPG (propane or butane) is a colorless liquid which readily evaporates into a gas. Originally it has no smell, to help detect leaks it will normally have an odor added.

When mixed with air, if it meets a source of ignition the gas can burn or explode. LPG vapour is heavier than air, so it tends to sink towards the ground. Due to its high density LPG can flow for long distances along the ground, and can collect in drains, gullies and cellars (Gamas, Diaz, Rodriguez, López-Salinas, Chifter & Ontiveros,2011).

To keep it liquefied, LPG is stored in pressurized tanks. These tanks can be installed above or below ground. They are strong and not easily damaged, but liquid or gas leaks can occur from valves and pipe connections. LPG liquid can cause cold burns to the skin (Bandhavi & Rao,2012).

"A high combustion efficiency fuel gas obtained from a saturated gas produced by pumping petroleum gas to a light oil composed of butane, pentane, hexane, heptane, and octane"(Chem,2001).

"The users have to ensure that LPG tanks are located in a safe place and have all the necessary safety accessories to protect the tanks, pipework and any LPG appliances attached to them. However continuous follow up and the maintenance of equipment is essential" United Kingdom Health and Safety Executive. (2016, April). Safe use of liquefied petroleum gas (LPG) at small commercial and industrial bulk installations [Brochure]. Retrieved from http://www.hse.gov.uk/gas/lpg/safeuse.pdf.

As per the research outcome of Blake & Roland (1995) the combined processes of unburned, uncontrolled leakage and incomplete combustion of LPG due to wrong air fuel ratio play a significant role in causing the excessive ozone characteristic of

many cities. Reductions in ozone levels should be possible through LPG supply system follow up, changes in LPG composition and lowered rates of leakage.

“It is specially odorized by adding Ethyl Mercaptan at refineries for easier detection of gas leakage in case of a leakage. When 1 liter of LPG is liquefied, under normal conditions, It reaches 250 liters of gas volume. Unlike natural gas, as LPG is heavier than air, it precipitates and accumulates at the bottom in case of a leakage”(Urhan,2015). Mixed LPG used in our county is generally 70% butane, 30% propane.

According to Hatanaka(1960) while LPG cylinders are commonly employed to package for the small consumer, it is usually much more economical for both small and large users to maintain relatively bigger supply tanks such as 2000Kg horizontal bullet tanks and to have them filled from time to time, as required, from transport delivery vehicles, such as LPG bowser trucks.

“When working with LPG, first the risk has to be identified. Risks are categorized as product related and process related. Risk of product is due to leak in LPG distribution system or primarily loss of primary containment. LPG leaks can lead for vapor cloud explosions or fire. Liquid LPG is much more danger than vapor. Because it can create 12500 times higher flammable mixture. Regular maintenance and audits help to ensure the safety of pipelines of LPG supply system United Kingdom Health and Safety Executive . (2016, April). Safe use of liquefied petroleum gas (LPG) at small commercial and industrial bulk installations [Brochure]. Retrieved from http://www.hse.gov.uk/gas/lpg/safeuse.pdf.

According to Urhan(2015) LPG, liquefied petroleum gas is a colorless, odorless, heavier than air and category 2 flammable gas which is obtained during distillation of raw petroleum at refineries or produced by extraction of natural gas found over oil reservoirs and liquefied under pressure. “Interest in Hydrocarbon fuels such as liquefied petroleum gas ("LPG") has increased in recent years due to the inherent cost and environmental advantages over other fuels”(Bennett,1994).

“LPG is a fuel that consumers can safely use when they comply with all the basic standard requirements of use”(Urhan,2015). When mixed with air, the gas can burn or sometimes can be exploded when it meets a source of ignition. It is heavier than air, so it tends to sink & flow towards the ground. In some cases LPG can flows for long distances along the ground, and collect in drains, gullies and cellars.

LPG is stored in controlled pressurized containers to keep it liquefied. “Pressure compact mini containers are used in both industrial and domestic areas. The bullet tanks can be installed above or below ground” (Urhan,2015). As per Boyer(1997) LPG storage tanks are manufactured to engineering standardsand not easily damaged, but liquid or gas leaks can occur from accessories such as valves and pipe connections. The leak LPG liquid can cause cold burns to the skin.

According to SLS 1196(2000) every tank should be separated from a building, boundary, or fixed source of ignition, to:

a. In the event of fire, reduce the risk of fire spreading to the tank and
b. Enable safe dispersal in the event of venting or leaks.

Tanks should be situated outdoors, in a position that will not allow accumulation of vapour at ground level. Ground features such as open drains, manholes, gullies and cellar hatches, within the separation distances given in standards should be barricaded, sealed or trapped to prevent the passage of LPG vapour.

International Energy Agency Statistics 2016 publication shows that LPG use as a fuel for a wide range of industrial, commercial and agricultural industries including:

- Commercial and residential heating fuel
- Fleet vehicle fueling by school districts, government agencies and public transit companies
- Agricultural: crop drying, vehicle fuel and weed control
- Redundant fuel source for hospitals and other institutional, commercial and industrial properties
- Standby Electric Generators

- Distribution for Consumers
- Auto Gas

Bulk LPG storage bullet tanks are used in several types of facilities. They store large amounts of LPG to help industries to meet the demand. As per Hatanaka(1960), bulk facilities can be used to distribute LPG to industrial and commercial consumers. These horizontal vessels are typically designed to load bobtails.

Based on the expected maximum daily/monthly consumption of LPG, LPG supplier has to design the vapor withdrawal system to cater to the equipment's demand. According to the applicable standards such as SLS 1196 & NFPA 58 for LPG installations cylinder series have to install outside the building with maximum of 1000Kg storage at the cylinder manifold. There is no limit for bulk installation tanks.

Hence the maximum number of cylinders a system can include is 26 numbers with a separation of 13 each cylinders in a single side of the manifold.

During the daytime a single cylinder LPG can evaporate a maximum of 2Kg/Hr rate whereas it declines upto the level 0.5Kg/Hr during night. Commonly used bulk LPG storage tanks are 2MT,4MT,8MT,12MT 35MT and 65MT. The natural vaporization rate depends on the factors like Outer Temperature, Wind and Surface Area of the liquid phase in the cylinder. This leads to fluctuations in LPG supply during the night time.

Most of 24 hours operating entities must keep a second option of supplying LPG demand during the night operations with cylinder manifolds. Currently in Sri Lanka all the customers are using vapour withdrawal systems with commercial cylinders. When it comes to bulk they have both vapour and liquid withdrawal systems.

As per George E. Totten, (2003), Liquefied Petroleum Gas is considered green fuel, an environmentally friendly fuel due to its lower carbon emissions. Unlike some other fuels in Sri Lanka, LPG does not receive heavy government subsidies. In a world where governments are moving away from subsidized fuels, LPG can be the premium alternative.

According to the development policy framework of government of Sri Lanka (2016), The government of Sri Lanka is engaged in improving the infrastructure, promoting tourism, trade, which will eventually result in economic prosperity in the future. It has seen rapid urbanization in many areas in Sri Lanka where new hotels, restaurants, commercial establishments and industries being set up. These types of economic activities will lead to increase in demand for clean, environmentally friendly, cost effective and sustainable energy source. LPG can be ideal choice and energy solution in marching forward for a strong economic growth as it is versatile, efficient and cost effective.

In Sri Lanka cylinders replacement is done though the agent nominated in the demography on customer request. There are two LPG suppliers in the market as Litro Gas Lanka Limited & Laugfs Gas .According to the annual report of Litro Gas Lanka limited 2016, LPG Market share of Litro Gas is 72%.

1.2 Problems in current LPG supply system

High rate of LPG leak incidents are observed in the industry. Standards are available for LPG installations. But proper follow up of existing standards is required. Most of the commercial LPG consumers are seen unplanned increase in number of cylinders proportion to consumption. Also there is certain number of customer complaints due to drop in efficacy and pressure and temperature. Consequentially cylinder Handling issues are seen due to high frequency of replacements. This is mainly non application of correct calculations and guidance for cylinder sizing.

1.3 Research Objectives

1. Identify the customer problems and hazards in the existing LPG commercial supply systems used in Sri Lanka.
2. Identify possible causes for deviations from standards when installing LPG supply systems for commercial operations (37.5Kg Cylinders)
3. Identify the willingness of the customers to migrate from using commercial cylinders (37.5 Kg) to bulk supply tanks.
4. Propose Safety framework to mitigate the risks associated with current LPG bulk & commercial supply system.

Research method adopted can be illustrated as below.

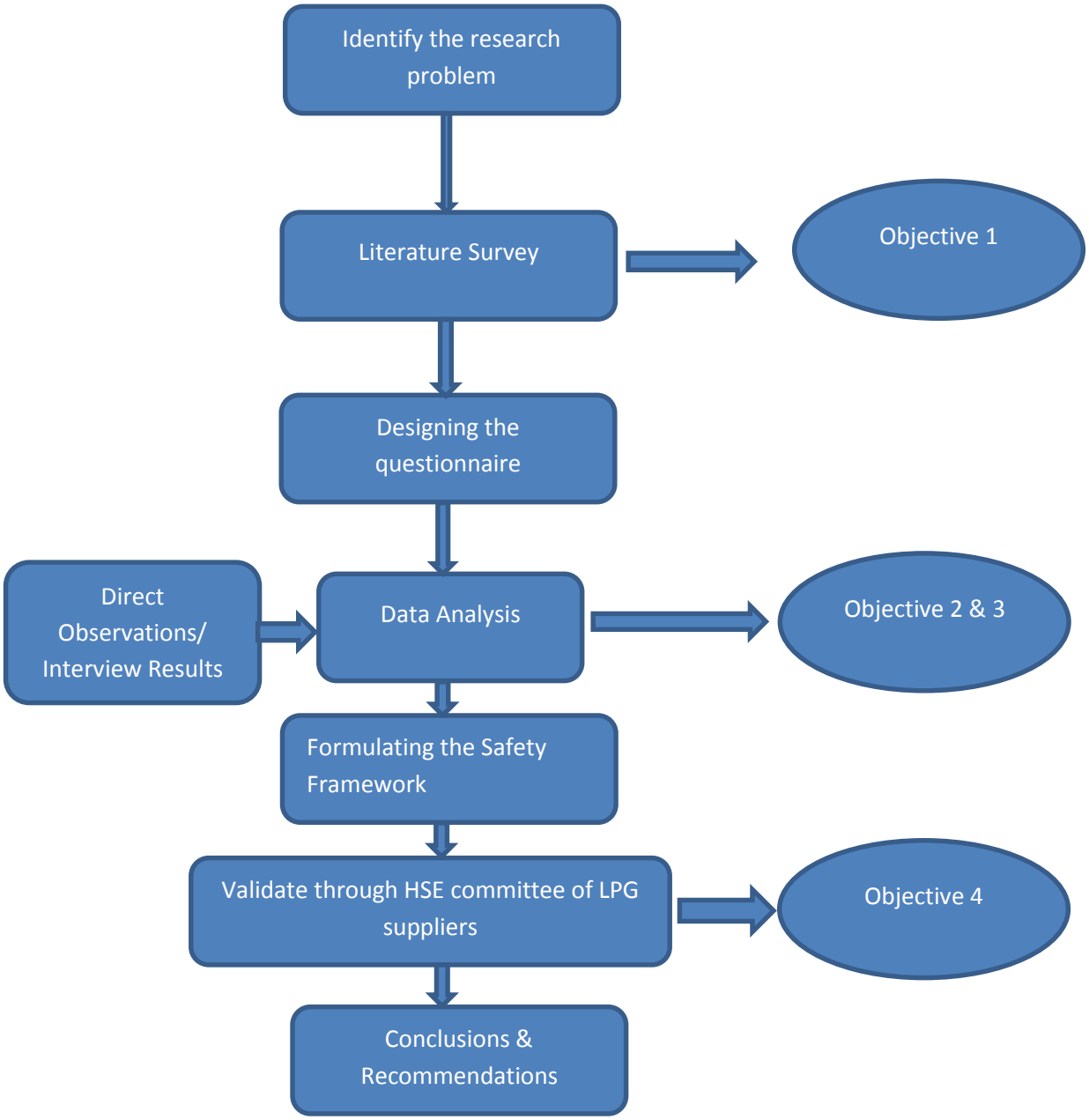


Figure 1: Research Methodology

1.4 Research Methodology

In this study existing customer's LPG supply system will be comprehensively studied/ analyzed and looked for recommendations to achieve the objectives. Here both primary and secondary data will be required to have the overall picture on assessing the opportunity to introduce safe LPG supply system.

1.4.1 Collection of Primary Data

1.4.1.1 Questionnaire

A questionnaire of twenty basic technical & consumer behavior related items were formulated along with a checklist and executed among 5 customers of each of different identified segments. These items were formulated to gather opinion and information regarding problems of existing system of having 37.5Kg cylinders for the commercial applications. A part of the questionnaire had a Likert scale to measure the effectiveness of the LPG supply systems. The questions consisted of both open ended and closed questions. The questionnaire was administered personally.

1.4.1.2 Interviews

After getting the answers for questionnaire, one Engineer and a Technician of all above selected customers were interviewed. For this purpose an interview guideline was prepared with ten items to gather more information which could not be gathered through the questionnaire.

1.4.1.3 Observations

At least one system from each segment was personally observed by the researcher to collect information regarding the various problems and issues of existing systems throughout the clock.

1.4.1.4 Collection of Secondary Data

A documentary survey was carried out to get data relate to the study through immediate years.

Sri Lanka Energy Balance Figures

Annual Reports of LPG suppliers/ Customer Service Database of LPG suppliers

SLS 1196 , REGO Service Man Manual & NFPA 58 LPG Design Standards.

Table 1: Summary of Data Collection

Data Collection Method	**Numbers**
Questionnaire	39 questions
Interviews	39 interviews
Direct Observations	39 direct customer visits

1.5 Data Analysis Techniques

The data and information collected through the research instrument were triangulated and analyzed using quantitative statistical techniques. The analysis was used to formulate findings and recommendations for liquid withdrawal system. Bar charts, Tables, Percentages and trend analysis were used in presentation.

1.6 Significance & Limitations of the Study

In Sri Lanka, studies conduct in this area is seen minimal. Therefore this research will be a base for future research in this commercial LPG supply area. The outcome of this research will be guidance for innovations in this field of study. This study will contribute to find solutions to actual practical issues facing in the existing LPG supply systems in commercial & bulk customers in Sri Lanka.

Although some selected customers issues were highlighted throughout the study, the findings of the study generalized to represent the requirement of new safe LPG Liquid & vapour withdrawal system to the industry.

Introducing liquid withdrawal cylinders along with external fired would be a solution for above issues with maximum customer satisfaction. Introduction of a larger size liquid withdrawal cylinder will be confined to 5000kg per month.

1.7 CHAPTER BREAKDOWN

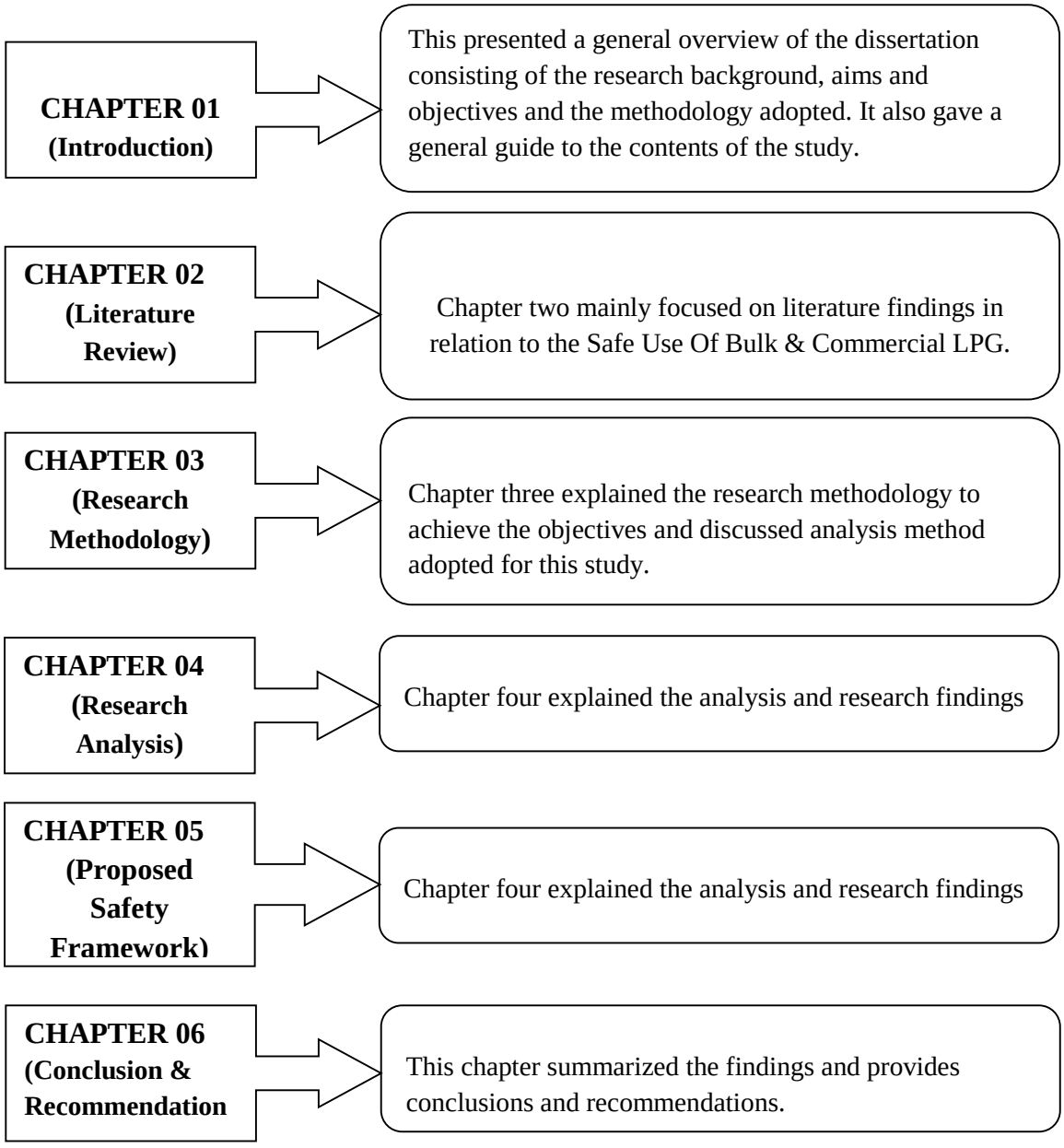


Figure 2: Chapter Breakdown

CHAPTER 2- LITERATURE SYNTHESIS

Under this chapter, current issues faced by commercial users are highlighted. All the research problems identified initially are based on available publications. Identification of customer problems and hazards in the existing commercial liquefied petroleum gas industry is mainly from literature and the answers from questionnaire. Possible causes for deviations from standards and their willingness of migrate from using commercial cylinders to bulk supply tanks are discussed under this chapter.

2.1 Status of Commercial LPG Installations

"Gas Cylinder Manifold is a high pressure structure specially fabricated for interconnecting two or more numbers of cylinders to a common gas supply line when consumption of gas is high. Manifold interconnects two or more number of cylinders for the purpose of availability of more gas at source "Anonymous (2014).

"A manifold is rigidly connected to the valve. The manifold has a gas passage there through in gas ccommunication with the passageway through the valve when the valve is open. The manifold has a plurality of device connectors in gas communication with the manifold passage. Each device connector has a check valve and is configured to connect to a flexible tubular gas line"(Steininger,2009).

Manifolds comprise a regulator, pigtail and an isolation valve and a pressure relief valve.

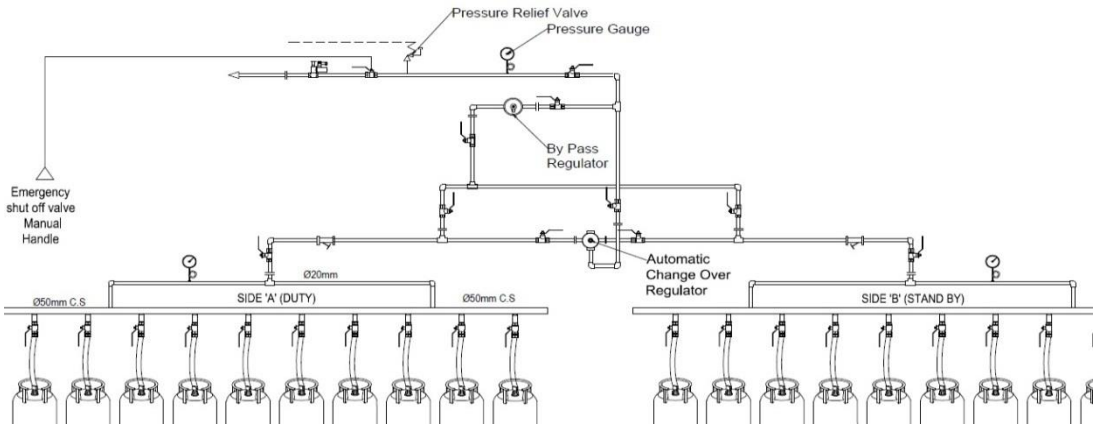


Figure 3 : Basic commercial LPG manifold

The leaflet issued by the British Compressed Gases Association (Revision 5: 2015) has identified the basic principles for all cylinders and bulk LPG storage and their safe operation are bound to;

- Sound design and construction.
- Consideration of usage of adjacent land and property.
- Good housekeeping.
- Minimum stocks held.
- Trained staff.
- Clearly displayed work instructions.
- Non-combustible construction materials.
- Clear of other flammables and combustibles etc.
- Easy access.
- Adequately separated from residential accommodation, commercial and industrial development, vulnerable populations etc.
- No cellars, open drains etc.
- Open area with good ventilation.
- Good security (to protect against vandalism)

Rizuwan & Wahab (2010) has identified and evaluated the Practical Problems of present cylinder manifolds. They are;

- Limitations in consumption rate
- High replacing frequency
- Cylinder sweating
- LPG Left over cylinders
- Non availability of liquid withdrawal facility
- Due to high rate of regulator replacement, high rate of accessory damages
- Barriers to increase number of cylinders in the manifold.
- Vulnerability for leaks in the system

The maximum number of cylinders a system can include is 26 numbers with a separation of 13 each cylinders in a single side of the manifold.

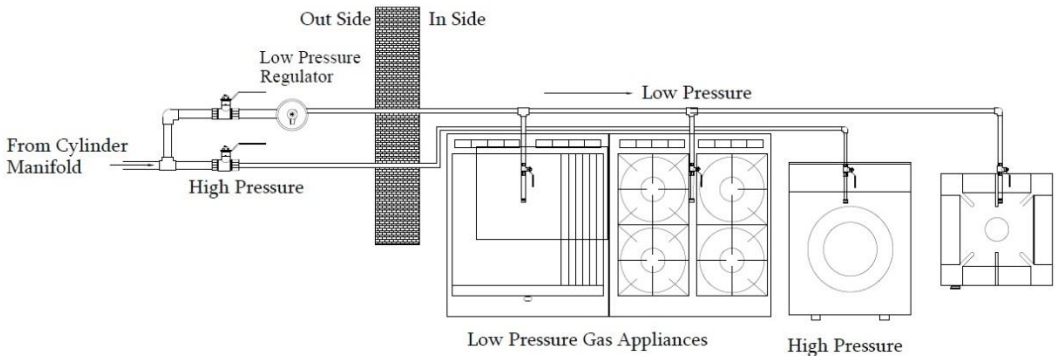


Figure 4: LPG Cylinder Manifold Accessories

2.2 Overview of LPG Consumption in Sri Lankan industries

Currently LPG imports from Middle East. Small quantity of LPG is issued to the LPG suppliers in Sri Lanka through the CPC refinery byproduct scheme. Following is the table of secondary data for total LPG used in Sri Lanka since 2007.

Table 2: Total LPG demand in Sri Lanka

Item	**2007**	**2008**	**2009**	**2010**	**2011**
Refined Products Imports (MT'000)	132	128	154	171	164
CPC Production (MT'000)	16	13	14	16	16
Item	**2012**	**2013**	**2014**	**2015**	**2016**
Refined Products Imports (MT'000)	223	208	211	298	388
CPC Production (MT'000)	24	23	24	17	20

Source: Economics & Social Statistics of Sri Lanka 2016

(Central Bank Of Sri Lanka) & Sri Lanka Customs Import Data Base

LPG demand in Sri Lanka in 2016 was 388,000 Metric Tons and Local industries (Commercial & Bulk) contributed 24% to the local demand in 2016.

Sri Lanka's LPG consumption for different segments are plotted in below pie chart.

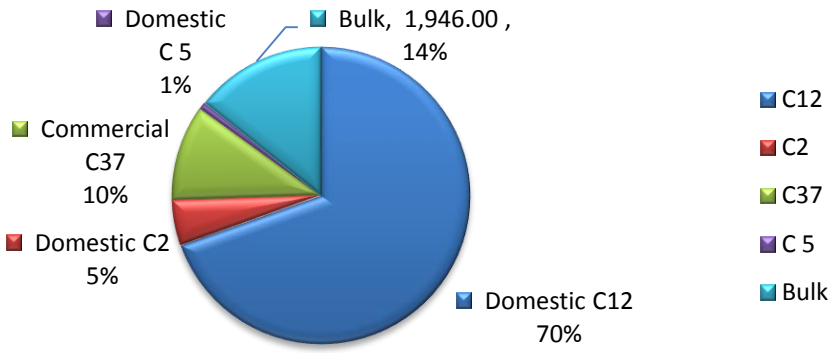


Figure 5: Sri Lanka LPG demand breakdown

Source: (*Annual Report of Litro Gas Lanka Limited 2016*)

Commercial application's energy requirement is fulfilled by using 37.5KG LPG cylinders and Bulk LPG storage tanks installed in factory premises. Due to space constraints and large capital cost involvement in bulk installations.In Sri Lanka Vapour withdrawal 37.5KG cylinders are used in mainly in industries such as Ceramics, Textiles & Printing, Hotels/ Confectioneries, Rubber, Metal, Battery, Glass processing and negligible quantity in AutoGas.

Table 3: Industry Segment wise LPG demand

Industry	**Percentage of LPG consumption**
Ceramics	59%
Confectionery	16%
Rubber/Plastics Manufacturing	14%
Metal Industry	5%
Textiles & Printing	3%
Hotel	1%
Battery	1%
AutoGas	1%

Source: (Annual Report of Litro Gas Lanka Ltd; 2016)

2.3 Literature Synthesis Practical Problems of Existing Commercial LPG Supply Systems

2.3.1 High rate of LPG leak incidents

"In Sri Lanka most of the industries run as a central energy supply system where they like to have the Cylinders in an isolated designated outdoor location for cylinder bank and from there onwards a branched system of distribution to the application" Annual Report Litro Gas (2016). A leak starts with a loss of primary containment. So due to high pressure applying in the accessories, the probability of getting a leak is very higher. In most of LPG supply systems we can see and feel leaks due to design, accessories, supply and demand mismatch and bad handling practices.

2.3.2 No proper follow up of existing standards.

In Sri Lanka we do not have any enforcing body to follow up LPG related standards. But when designing a system they used to follow standards guided by LPG suppliers. SLS 1196, NFPA 58, Fire guide lines are very important for correct design.

2.3.3 Unplanned increase in number of cylinders proportion to consumption

When the cylinder manifold is down sized and operate in high demand applications, natural vaporization will not be sufficient for exact supply. Then it tries to get the heat from the surrounding for evaporation. At these points there can be sweat outside the cylinders and tend to drop the pressure due to reduction in efficiency in the system. Finally certain amount of LPG can be remaining in cylinders by the time of replacements. Due to lack of knowledge they put these cylinders to hot baths etc. to increase flow rate of gas sully system.

2.3.4 Customer complaints due to drop in efficacy and pressure and temperature

During the night operations surrounding weather condition changes can lead to have slower in natural vaporization. So when the rate of vaporization getting reduced, both the pressure and the required temperature parameters will not be achieved.

Hence there can be large number of system failures and ultimate production losses due to machine cut offs.

2.3.5 Cylinder Handling issues due to high frequency of replacements

In most of the sites, they do not have vehicle access to the cylinder banks area. So manual handling is required. When it has to replace frequently, another extra dedicated human resource allocation needs to run the system continuously.

2.3.6 Non application of correct calculations for cylinder sizing

It is very difficult to find the correct calculation for consumption. As a guide Rego Serviceman Manual, NFPA 58 and SLS 1196 can be used. But there are also only propane related calculations available for references.

2.4 Possible causes for deviations from standards in LPG installations based on the literature survey findings & Safety Framework to mitigate the Risk.

2.4.1 Safety of LPG commercial installations

According to Chen,Lin & Chao (2004) Liquefied petroleum gas (LPG) is a very important highly flammable fuel and chemical feed stock as well; however, the this highly flammable hydrocarbon has been involved in many major fires and explosions. One of these accidents is boiling-liquid, expanding-vapor explosion (BLEVE). These consequences leading to result from the sudden release from confinement of a liquid at a temperature above its atmospheric-pressure boiling point. The differential pressure results in the explosive vaporization of a fraction of the liquid and a cloud of vapor and mist with the accompanying blast effects. BLEVEs are involved in flammable liquids, and most BLEVE releases are ignited by a surrounding fire and result in a fireball.

“Safety distances kept in pipelines transmitting LPG and pressurized LNG are determined considering the possible outcomes of an accidental event associated with fuel gas release from pressurized transmission systems”(Sklavounos & Rigas ,2005).

Code of practice 1 given in SLS 1196 highlights that the user of the LPG (ie the person operating the site) does have responsibilities in relation to the LPG installation including:

- Siting of the LPG cylinder tanks
- Ventilation and conditions around the cylinders
- Replacement tanker access
- Security of LPG supply system
- Impact protection of the installation
- Emergency arrangements

The legal framework provides more information on the background to these responsibilities.

2.4.2 Issues in Siting of the tanks

This was a basic deviation observed during LPG installation site visits. The installers haven't gone through the standard requirements in most of the cases. As per SLS 1196 part 2(2010) & NFPA 58 (2014) separation distances have to be kept for LPG installations. Distance from tanks to nearest buildings or source of ignition is very important to reduce the fire risk. Proportion to the capacity of storage, minimum safety distances have to be maintained. Firewalls are made to reduce the safety distance. These walls are specially arranged to withstand to fire. The height of a wall is around 180 cm.

According to BS 3360, There should not be any drains or gullies near to the tank unless a water trap is provided to prevent gas entering the drains. "This is because LPG is heavier than air and if a leak was to develop from the tank or its controls or pipework or when it is being filled then the vapour could accumulate by flowing in an un trapped drain or gully. Ignition of these LPG vapours could then lead to fire/explosion" Moodie, Cowley, Denny & Small,(1988).

"The tank should also not be painted in any colour other than originally supplied as this may increase the amount of heat it absorbs from the sun" (NFPA 58 - 2014).

According to Khan& Amyotte (2002) in considering location and separation distances the principle must be considered that a well-designed and operated installation is unlikely to create a hazard.

Findings of Chen,Lin & Chao (2004) shows that the separation distances are measured from the surface of the vessel to any building or property boundary. They are provided to reduce the impact of an incident and most articles indicate that the risks to the immediate surroundings from an LPG tank are from a gas cloud or jet flame.

"Standard design can substantially reduce LPG leaking risks by reducing the potential leak points and ensuring that all leak sources can be rapidly shut down in the event of an incident. The lowest probable worst case scenario for an LPG tank is the BLEVE (Boiling Liquid Expanding Vapour Explosion) and this can only occur when the tank has a jet flame directly impinging on it or when the tank is engulfed in a pool fire for a long time period" (Birk 1996).

According to the investigation report issued by Park, Mannan, Jo, Kim & Keren(2006) good design, where less pipework joints or equipment are located where a failure could result in a jet flame impinging on the tank or a pool fire occurring under the tank, will achieve significant risk reduction.

Locate above ground tanks in the open air according to the separation distances required in local Fire regulations, but with a minimum separation distance as listed in Table 1 of SLS 1196 part 2:2000. Ensure that there is a good airflow around the tank.

As per SLS 1196 (2010) If more than one vessel is installed they must be separated by a distance of ¼ of the sum of the diameters of adjacent vessels with a minimum distance of 1 metre.

Ex: If vessel Diameter is 2m then separation distance in between 2 tanks will be- (2+2)/4= 1m

All separation distances are based on tank installations that are fully compliant with this standard with the minimum of joints and flanges in pipework and a rigorous asset integrity management regime applied.

At the design stage selecting LPG tank farm ground underneath or next to connections into LPG tanks or LPG ancillary equipment must be concreted or compacted and free from depressions, pits, culverts or drains. LPG tanks are installed in horizontal parallel manner. If all connections are joined in a single side, it may only be necessary to compact or concrete under the connections. The ground inside the required separation distances must be free from flammable sources , substantially level and as flat as possible (except under the tank where it must be sloped away approximately 1:50 such that any spillage of LPG can evaporate and disperse safely in a separate area not under the tank).

"Care must be taken to avoid siting tanks in locations where the surrounding ground slopes towards vulnerable features e.g. other tanks, buildings, houses, drains etc., even though these may be outside normal separation distances. Adjacent tanks must be spaced according to specific site conditions and what is necessary for safe installation, testing, maintenance and removal"(Litro Gas Standard 1, 2011).

According to Melchers & Feutrill (2001) adjacent tanks must be spaced according to standard requirements & specific site conditions and what is necessary for safe installation, testing, maintenance and removal. If the frequency of delivery to a customer's premises is high e.g. autogas, consideration must be given to increasing the separation distances and/or providing additional fire protection.

Table 4: Minimum Safety Distance for Storage of LPG In Bulk

Tank Water Capacity (litres)	Minimum Separation Distance to a Building, Boundary or Permanent Source of Ignition
0-7600	3.0
7601- 114000	15
114001-265000	23
265001 upwards Perform a Risk Assessment	

Source: (January 2011 Standard 1 : Litro Gas Lanka Limited)

Cross Reference with S Sklavounos, F Rigas - Journal of Loss Prevention in the Process Industry, 2006

Note

Based on NFPA 58 Liquefied Petroleum Gas Code, by the National Fire Protection Association. This edition of NFPA58 was approved as an American National Standard on January 16, 2004. Table 6.3.1 refers to minimum separation distances and the column for aboveground containers is used here.

2.4.3 Issues in Ventilation and conditions around the tank

"In case of leaks there should be plenty of area around the tanks to ensure good air flow ventilation so that dense LPG vapors cannot build up around them" Cippitani (1996).

"It is also very important to keep the area around the tank clean, free of rubbish, particularly if it is combustible or could reduce the levels of ventilation. It is recommended to keep weeds and grass cut down around the tank. If a weed killer is used, then should not use something that is chlorate-based (as this can make the dead plants easier to ignite)" (Edjekumhene, Owusu, Ampong 2007).

2.4.4 Tanker access Issues

As per SLS 1196 Part 2: 2000, it is recommended to have a dedicated flat parking area for the tanker delivering LPG. During the time of LPG transferring, clear instruction posters have to be displayed in the site. Additionally area has to be barricaded to avoid trespassing of unauthorized personnel.

Properly maintained clear instructions have to be displayed during the time of LPG transferring. Any instruction followed; have to be monitored by the site personnel and the LPG supplier as well.

"Liquefied Petroleum Supplier must ensure that their drivers are trained to face any emergency situations followed by the delivery" (Ratcliffe, Sleen, 1996).

2.4.5 Security Issues

According to Marston (1982) People who are not involved or not trained with the LPG piping, visitors who visits the site, contractors who do not engage with the

direct business , should be kept well away from it. Since LPG is highly flammable all the ignition sources have to keep away from the storage. It is recommended to remove the grass around the tanks manually unless the grass cutter is explosion proof.

NFPA 58 :2014 describes

Essentially all the bulk storage tanks are kept in an isolated area from buildings. A trash barrier is made for security from moving traffics. Normally all the tanks are kept in a single area by keeping the safe distance. In addition to that a mesh is constructed for further security. Two security lockable gates are made to protect from un authorized access. These gates are opened outwards. In Sri Lanka, the LPG supplier gives the instructions to construct the safe tank farm. Essentially a security fence, two lockable outwards opening gates, trash barrier are made to ensure the safety of the tank farm. When installing tanks near public places such as schools, hospitals etc. there is a defined safety zone. Based on the density of the population around the tank farm, another standard distance applies to keep the tanks away from people. There is a top cover to keep the valve assembly secured.

2.4.6 Impact protection

All the tanks installed inside the premise has to be followed the required safety distance given by NFPA 58. If it is closer to the public road, a fire wall has to be constructed to prevent the expose to the public. Tank farm needs to be protected by bollards and crash barriers. Instruction sinages have to be put in order to aware the risk to the public. Double yellow lines and instruction notices such has " Highly flammable LPG, No Smoking, Bowser Delivery Procedure" have to fixed to the tank farm. These basic parameters are discussed in detail by Droste & Schoen(1988).

2.4.7 Emergency arrangements

As per Tiemin (1999) The LPG tank will have printed on it the supplier's emergency number that should be called if there is a leak. If a fire breaks out then the user should have in place an emergency plan with contact numbers which includes evacuating people from the premises. In general, leave tackling any fire near the

tank to the fire brigade unless it is judged that it can be put out without endangering anyone. In the event of an emergency, and where it is safe to do so, the emergency shut-off valve on the top of the tank (A remote operated pneumatic valve) and the emergency control valve (ECV) should be closed.

2.4.8 Service pipework

As per the Factories Ordinance Part 3, Owners of service pipework therefore have some important responsibilities and should consider the following:

- Installation route
- Materials of construction
- Pressure
- Inspection and maintenance
- Replacement
- Entry into the premises

LPG supplier provides more information on the background to these responsibilities.

2.4.9 Installation route

"In November, 1984, an enormous disaster involving an LPG installation occurred in Mexico City and resulted in the deaths of over 500 people" , Pietersan (1988).Ideally LPG tank farm installation pipelines are done in guage 80 carbon steel pipelines. Those are kept above ground. The colour of identification is white. All the fire water lines are painted in red colour. After the tank farm area to the burners, all the lines are painted in yellow colour. Mostly for extra security, they are kept underground wrapped in denso tapes. These lines have to be marked in above ground with arrows for identifications.

Tiemin(1999) explained If it is not possible to run the pipework above ground, then it can be buried underground wrapped with denso tapes and, in such cases, it is important to know its route and to mark it so that others are aware of it. When traffic

or other heavy loads pass over the pipe, protection should be provided, such as load-bearing slabs or covers.

As per supplier instructions, an audit to cover all the accessories of the piping system to be conducted frequently. All the corrosion patches and other potential risk points have to be identified and addressed to secure the system. Loss of Primary Containment or simply a leak in the system can lead for vapour cloud explosions and sometimes a BLEVE condition as well.

2.4.10 Materials of construction

According to Mohitpour, Golshan & Murray (2007) The Pipeline material used in LPG installation can be either one of the following;

- Steel pipes
- Copper pipes
- Yellow brass pipe
- Ductile iron
- Aluminum pipe
- PVC/PE pipes

As per SLS 1196 part 2: 2000

> "Buried pipework installed within the last 15 years is likely to be made of non-corroding material, such as polyethylene. Older installations, though, may have buried metallic pipework. In these cases, the pipework is likely (but not always) to have some form of corrosion protection provided (for example it may have been wrapped in a special protective tape). This protection will not last indefinitely and the pipes will corrode over time. This may also happen more quickly in certain types of soil, for example waterlogged clay soil. If buried pipework is metallic then it will need to be replaced".

2.4.11 Pressure

As per Mohitpour, Golshan & Murray (2007) When it comes to LPG tanks pressure, there are three important parameters. They are Design Pressure, Test Pressure and working Pressure. There is a safety relief valve installed in the tank for extra safety in case of abnormal pressure increase. Ordinarily, minimum standard ratings for pressure in relief valve require a differential between design pressure and maximum product vapor pressure that is adequate to allow blow down of the pressure relief valve.

As per API guidelines,

- The number of joints of any type between the vessel and the first block valve shall be minimized.
- Welded joints shall be used where practical.
- The number of flanged joints shall be minimized.
- Joints in pipe NPS 2 or larger shall be welded or flanged.
- Joints in pipe smaller than NPS 2 shall be socketwelded, butt-welded, or flanged. Piping gaskets shall be of the self-centering or confined type and shall be resistant to LPG.
- Threaded connections shall be minimized to the extent practicable and shall be between NPS 3/4 and NPS I' /2, inclusive.

2.4.12 Inspection and maintenance

Proactive maintenance is required in LPG industry in order to protect and ensure the system runs with confidence. A maintenance schedule is to be kept for all LPG related appliances. Pipeline and LPG storage tanks have to be tested certified frequently to minimize the risk of leaks. The owner of the pipeline needs to define initially. LPG supplier or the user has to get the clear understanding about the maintenance. Usually the user needs to ensure the system fulfils the minimum health safety and environment parameters.

According to LPG Service Man’s Manual(2014), there has to be a separate dedicated team for LPG supply system maintenance. An external audit will also help to ensure

the safety of the system. Each day morning at the toolbox meetings, the pipeline visual inspection report has to be discussed. Any observations about the status of the piping have to be reported to the team. A potential risk, incidents recording methods have to be introduced.

Difficult to access places such as underground tanks are monitored by using Cathodic Protection system. Underground tanks need to be removed and replace all the accessories once in 20 years.

2.4.13 Replacement

"LPG suppliers and users always monitor the performances of LPG supply system. Replacement of all the accessories based on the proactive maintenance schedule. Essentially all the accessories in LPG pipeline have to be replaced for every 10 years. Annual inspections, pressure tests and other specific tests mentioned in NFPA 58 have to be carried out. Pipelines are replaced if there is an observation of corrosion. " LPG Service Man's Manual(2014).

2.4.14 Valves

As per Litro Gas Standard 1 (2011);

A **pressure relief valve** directly connected to the vapour space and usually used in conjunction with a suitable automatic shut-off valve to enable removal for testing and servicing. No other fittings to be positioned between the PRV and the tank.

An installation is subject to the standardizing such as Gas Safety Installation and Use Regulations (GSIUR) over-pressure shut-off and under-pressure shut-off valves which provide back-up protection should the regulator tested for performances.

OPSO (over-pressure shut-off valve) – This extra safety device must be re-set only by the gas supplier if it trips out and shuts off the gas supply when over-pressure conditions exist.

UPSO (under-pressure shut-off valve) – This other extra safety device may be re-set by the gas user if it trips out and shuts off the gas supply when the gas pressure drops below its set pressure value.

A pressure relief valve (PRV) is a valve fitted to the top of a bulk tank or any LPG container to relieve internal pressure within the tank if this were to increase due to external influences, such as thermal radiation impact from a fire.

Emergency control valve (ECV)
As per Tiemin (1999) An ECV is intended to allow the LPG user to shut off the supply of gas in the event of an escape. Control Valves are required under GSIUR but recommend that these are fitted also at factory premises.

In this case there has to be proper communication and display of ESV locations to the fire teams and other emergency teams.

2.5 Safety framework to Mitigate Risks

The installer must ensure that LPG tanks and pipework are located in a safe place and have all the necessary safety devices to protect the tanks, pipework and any LPG appliances attached to them (Factories Ordinance Part 3). However continuous monitoring of LPG installation reduce the risks. In particular should take the required precautions:

2.5.1 Fire Fighting Measures

"All LPG storage sites must have enough of the correct capacity of portable firefighting equipment to extinguish fires next to LPG tanks and prevent escalation of any incident. The 'correct' equipment comprising fire extinguishers, fire monitors and access to water will be defined by local or national fire protection standards or codes of practice, which will also specify an appropriate 'mix' of equipment, plus location, maintenance and levels of capability" ICTAD Fire Regulations & Occupational Safety and Health Administration (OSHA)

Table 5:Fire Guidelines for LPG storage system.

Water Capacity Litres	**Nominal LPG Capacity Tonnes**	**Precautions**
Less than 150 – 4,000 (Domestic tank capacity)	Less than 1.1	Water supply for fire brigade use up to 100m away
Less than 150 – 4,000 (Commercial & Industrial tank capacity)	Less than 1.1	Water supply for fire brigade use up to 100m away Two 9kg dry powder extinguishers.
Greater than 4,000 to 56,250	Greater than 2 to 25	Water supply for fire brigade use up to 100m away. Two 9kg dry powder extinguishers
Greater than 15,750 (Liquid offtake tank capacity with remotely operated shutoff)	Greater than 7	Water supply. Two 9kg dry powder extinguishers
Greater than 15,750 *(Liquid offtake tank capacity without remotely operated shutoff)*	Greater than 7	Water supply. Fixed and / or portable monitors. Two 9kg dry powder extinguishers
56,250 to less than 112,500	25 to less than 50	Water supply. Fixed and / or portable monitors.. Two 9kg dry powder extinguishers
112,500 or more	50 or more	Water supply. Fixed and / or portable momitors. Two 9kg dry powder extinguishers

Source: Table 13 of SLS 1196 part 2,1998

2.5.2 Training Requirements

It is the responsibility of management to make sure that all staff involved in LPG operations clearly understands the characteristics of LPG and its associated risks. Staff must be regularly trained and assessed in the knowledge and practice of normal operations, including as appropriate:

- Product knowledge.
- Safety in day to day operations.
- Use of personal protective equipment.
- First aid.
- Loading / unloading.
- Emergency procedures and shut-down.
- Fire-fighting.
- Inspection and maintenance.

To be effective, training must be continuous, with a rolling schedule of refresher courses and where appropriate at least an annual emergency procedure practice.

2.6 Introduction to Bulk LPG storage tanks

Wikipedia identified the fact that safe, quick and simple to install, mini bulk tanks have fast become the most economical way to enjoy all the advantages of bulk gas from LPG tanks. LPG tanks are small, compact and at the heart of cleaner-burning LPG home-supply system. These under ground or aboveground storage tanks are kept supplied by regular road tanker bowser deliveries. "The potential reduction of risk in LPG road transport due to the adoption of passive fire protections has identified" (Paltrinieri,Landucci,Molag,Bonvicini,Spandoni & Cozzani,(2009).

As per SLS 1196, part ii ,1998

All bulk tanks must install in compliance with all local Health & Safety regulations. And ensure all LPG tanks are the optimum distance from the application point and its boundaries; positioned for best protection from accidental damage; easy access for LPG refilling vehicles.

2.6.1 Storage tank options

According to National Fire Protection Agency Liquefied Petroleum Gas Code – NFPA 58 There are varieties of bulk tank options to suit the requirements.

As per Rego Service Man's Manual for LPG, Rate of vapourization Vs. Tank Sizes are summarized below.

Table 6: LPG vapourization Vs. Tank Sizes

Standard Tanks Sizes	**Maximum Rate of Natural Vapourization**
2MT	32 Kg/Hr
4MT	38 Kg/Hr
10 MT	54 Kg/Hr
12 MT	72 Kg/Hr
35 MT	168 Kg/Hr

Source: Rego Service Man's Manual

The assessment of the safety spacing between tanks was also discussed by Chen,Lin & Chao (2004).Most households and businesses would find that an above ground LPG tank is suitable; however due to aesthetic demands a lot of industries install underground tanks as well. Retrieved from (http://www.avantigas.com/storage-and-supply/).

At the planning stage trained representatives and engineers can help every step of the way from advising on the size of tank to the best position for tank dependent on requirements.

2.6.2 Above Ground Tank Option

According to Myers(1997) this is the horizontal bulk tank that sits on a concrete base in a carefully selected area of garden or land. There is less preparation work needed but special attention is required to the surrounding with this option compared to the underground tank. Correct height concrete base the tank sits on needs to be flat and level with the ground and in accordance with current legislation. The dimensions for the base on a typical 1410 sized tank are 2mx1.5mx150mm.

As per SLS 1196 part 2 (2010) there also needs to be a minimum separation distance between the tank, buildings, boundary and fixed source of ignition proportional to the size of tanks for safety reasons.

The only other work to be carried out for above ground tank is a trench for the pipe work. Once the preparation work has been carried out correctly, the pipe work and tank can be easily installed and once this is done customers are ready to take delivery of LPG. With the above ground tank can screen it should the customer wish to.

Materials that can screen the tank with include evergreen shrubs such as laurel and holly or a non-flammable open branched, ranch style fence. A screen is only allowed on one side of the tank and should be 1M away (for tanks sized 5,000 liters or below), so consider carefully which side would work best for whilst still complying with safety regulations(NFPA 58,2014).

2.6.3 Underground Tank Option

According to Myers(1997) customers selects underground tanks for aesthetic qualities. This involves more ground preparation work for the installation of the tank, but once installed will be out of sight .Options of underground tanks starts from 2MT.

As per Sri Lanka Standard Institution Code 1196(2010),The scale of excavation needed in order to install a typical underground tanks would need to analyze the soil condition and size of tanks, water bed depth etc.

“The representative will also agree the most practical and shortest route for underground pipework that will need to go from the end of the base to the premises” (Wikipedia,2016).

2.7 Basic Liquid Withdrawal LPG Systems

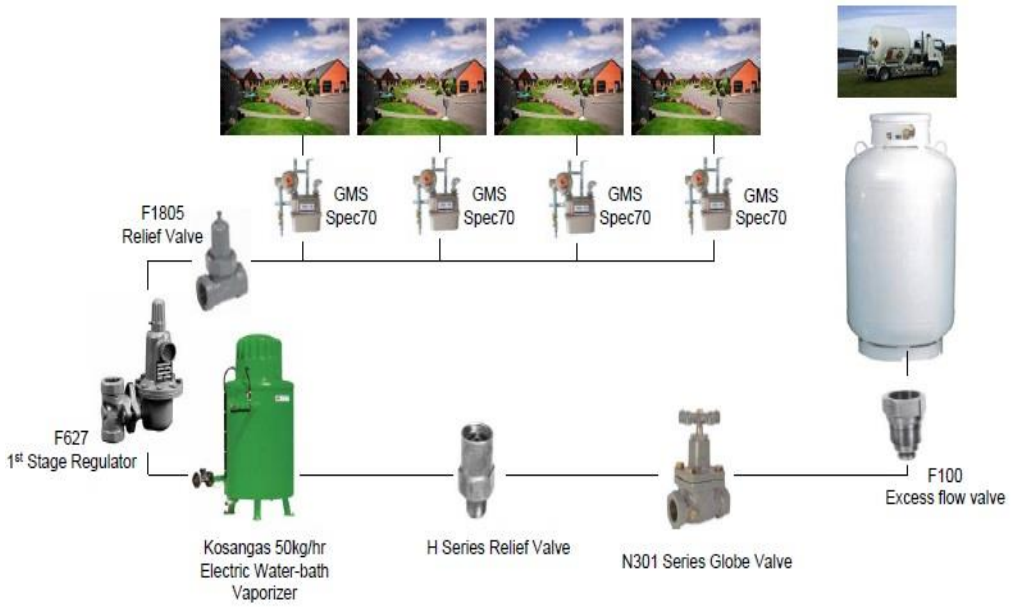


Figure 6: Basic LPG Liquid Withdrawal System Block Diagram

Liquid Off-take (LOT) LPG systems have become popular in commercial & Industrial usage of LPG in most of the countries. This system offers the strength of Bulk LPG Installation and easy functionality as that of cylinder manifold. LOT LPG System withdraws Liquid LPG using the LOT valves.

The LOT System can cater to Volumes up-to 250Kg per Hour and occupies less space. They are easy to handle and provided with high safety standards. The LOT LPG systems are highly cost effective as there is no residual loss. Advantages of this system would be; Constant Pressure–Application pressure less than 18 Psi.

Regulators use to adjust pressure

- Very convenient to handle
- Cost Effective
- No loss on account of residue
- Requires Lesser Space

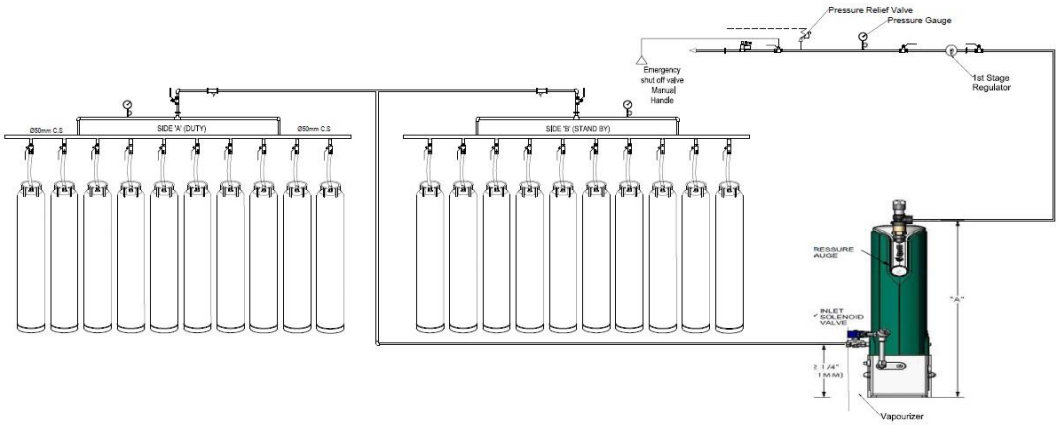


Figure 7: Drawing of Basic Liquid Withdrawal system

Rate of Evaporation based on theoretical calculations in vapor off take cylinders.

Table 7: Evaporation rate in LPG Mixture in different environment conditions

Product	Cylinder Size Kg	Temperate		Tropical	
		Continuous	Intermittent	Continuous	Intermittent
Propane	12.5	0.5	1	1	2
	50	1	2	2	4
Butane	12.5	0.35	0.6	0.6	1.2
	50	0.7	1.2	1.2	2.4

Source: (NFPA 58)

According to the table 12, it shows that the maximum flow rate that a LPG commercial cylinder can generate is 2Kg/Hr. But it vary with the environment conditions.

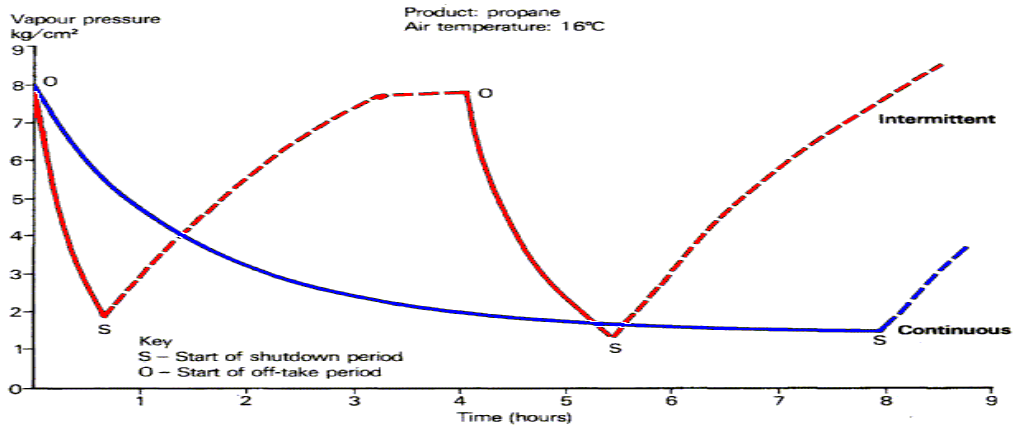


Figure 8: Vapour pressure variation with time based on the observations

Vapor pressure continuously reduces in cylinders proportion to the cylinder liquid levels. At a break of shut off, the vapour get accumulate in the cylinder and create the pressure and again pressure drops with the operation.

Table 8: Rate of vaporization in cylinders in different environment conditions

Season	Type of Load	Evaporative Capacity (Kg/Hr)
Winter	Continuous	0.5
	Intermittent	1-1.5
Summer	Continuous	2-2.5
	Intermittent	2.5-3

Source: (NFPA 58)

Above table shows the rate of vaporization in cylinders in different environment conditions. So in our actual observations we have recorded the pressure drops in night operations proportionally.

Table 9 : Pressure drop along the pipeline

Pressure		Capacity of 30 meters of pipe (000s kcal/hr)			
Inlet	Pressure Drop	Copper Tubing		Steel pipe	
		6mm	10mm	12mm	15mm
300 mm WC	7 mm	3	7	9	16
300 mm WC	15 mm	5	9	12	23
0.35 kg/cm2	0.017 kg/cm2	23	42	55	100
0.7 kg/ cm2	0.035 kg/cm2	37	70	91	166
1.05 kg/cm2	0.14 kg/cm2	78	149	196	353

Source: (NFPA 58)

These charts shows the theoretical pressure drop along the pipeline. But the designers had not considered such parameters in most of the commercial installations. So the data analysis results shows that they haven't followed the standard calculations at the design stage.

Table 10: Number of cylinders Vs. Evaporation capacity

	Capacities in 1000s of Kcal/Hr					
Number of Cylinders required	Evaporation Capacity in Kg/Hr/ Cylinder					
	0.5	1.0	1.5	2.0	2.5	3.0
1	5.5	11.0	16.5	22.0	27.5	33.0
2	11.0	22.0	33.0	44.0	55.0	66.0
3	16.5	33.0	49.5	66.0	82.5	99.0
4	22.0	44.0	66.0	88.0	110.0	132.0
5	27.5	55.0	82.5	110.0	137.5	165.0
6	33.0	65.5	98.0	131.0	164.0	196.5
7	38.0	76.5	115.0	153.0	191.0	229.5
8	44.0	87.5	131.0	175.0	219.0	262.5
9	49.0	98.5	148.0	197.0	246.0	295.5
10	54.5	109.0	163.5	218.0	272.5	327.0
11	60.0	120.0	180.0	240.0	300.0	360.0
12	65.5	131.0	196.5	262.0	327.5	393.0
13	71.0	142.0	213.0	284.0	355.0	426.0
14	76.5	153.0	229.5	306.0	382.5	459.0
15	82.0	164.0	246.0	328.0	410.0	492.0

Source: (NFPA 58)

If the burners maximum evaporation rate is given, we can get the practical number of cylinders for the manifold. Let's say if our requirement is 175,000 Kcal/ hr then at a rate of 2Kg/Hr we need 8 cylinders in the manifold to get the requirement.

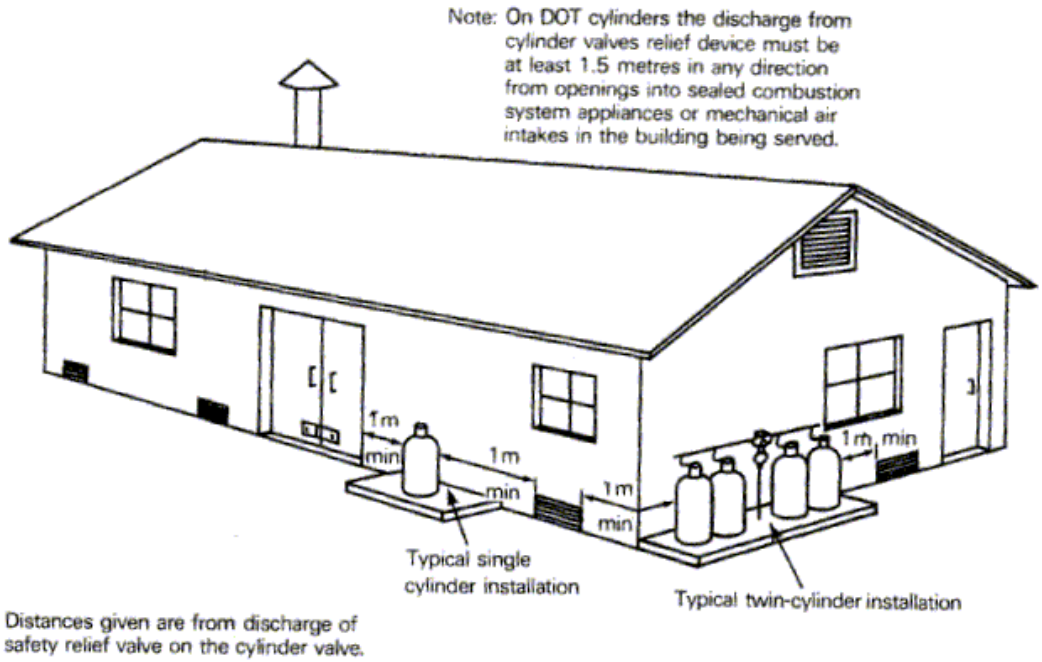


Figure 9: Basic Cylinder manifold install in a building

Source: (NFPA58, Appendix 1, Pg 13)

Prior to any LPG manifold system installation, plan approval must be obtained from fire department if the consumption is more than 100Kg. Upon completion of LPG installation, installed system must be checked by Registered Inspector (RI), prior to application of Fire Safety Certificate (FSC). This Can only start operating LPG manifold system after the appropriate approvals are obtained.

2.8 Major defects of Commercial Cylinders

Table 11: Cylinder Defects Analysis based on customer service data base of LPG suppliers.

Defect	2014	2015	2016
Body leak	1	1	1
Neck leak	2	7	1
Relief valve leak	18	1	1
Shrink seal not in tact	1	1	3
Valve leak	1	2	7
Valve spindle leak	3	2	7

Defect	2014	2015	2016
Body damage	5	2	1
Burnt cylinder	15	16	13
Can't fix the regulator.	226	318	333
Damaged rubber gasket	5	8	4
Gas leak	571	708	806
Package related	61	67	102
Product issues – lpg (sludge)	85	64	89
Regulator fixed gas not coming	54	66	51
Shrink seal intact empty cyl/ shw	65	89	148

2.8.1 Regulator related issues

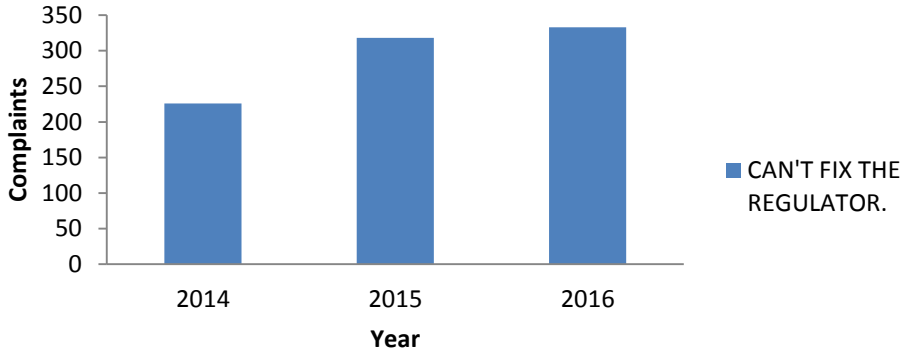


Figure 10: Commercial customer's Major regulator fixing defects in cylinders

If the customers shift from commercial to bulk, these issues will be minimal.

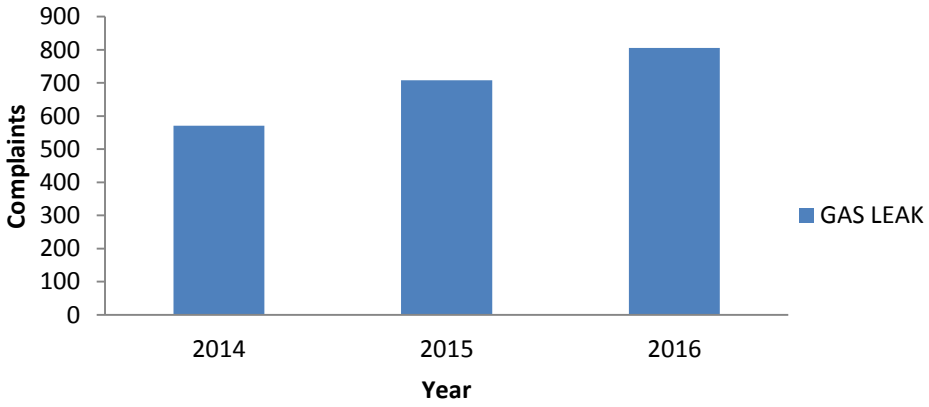


Figure 11: Commercial customer's Major gas leak defects in cylinders

2.9 Calculations and Recommendations

In most of the above observation Cylinder sweating was reported.
If we get a commercial 37.5Kg cylinder there is a maximum limit of vapour withdrawal.

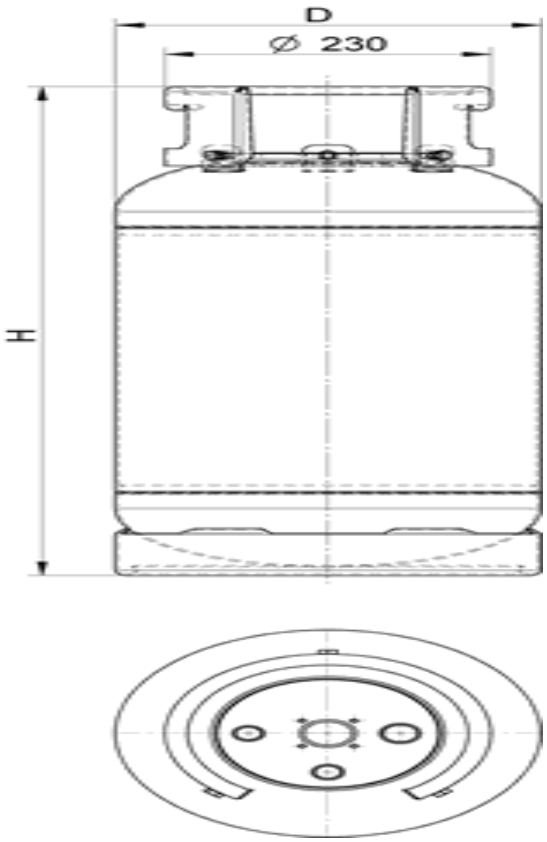


Figure 12: Cross section of a commercial cylinder

LPG Content Propane 30% Butane 70%

D = 300 mm H = 1386 mm

Area of Liquid Contact $A = \pi r^2$

= (22/7) * .15 * .15

= .0707 m2

Rate of vaporization = Diameter (D) * Liquid Surface Length * Factor

= 2 Kg/Hr

Average rate of vaporization based on practical experiences = 0.6 Kg/Hr

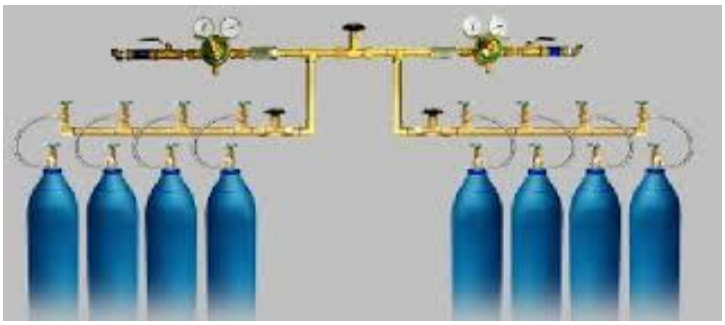
According to the standards maximum cylinder storage capacity = 1000 Kg

Total number of cylinders = 1000/37.5

= 26.66

So we can keep only 26 cylinders in a manifold.

Keeping one **stand by** and one **in operation**



Standby **In Operation**

Figure 13: Standby & Operation cylinders

Maximum number of cylinders can install in the single side of the manifold is 13.

So the maximum vapour flow rate a single manifold can give = 13 * 2 Kg/Hr

= 26 Kg/Hr

But when the liquid level goes down in a cylinder the flow rate also goes down proportionally.

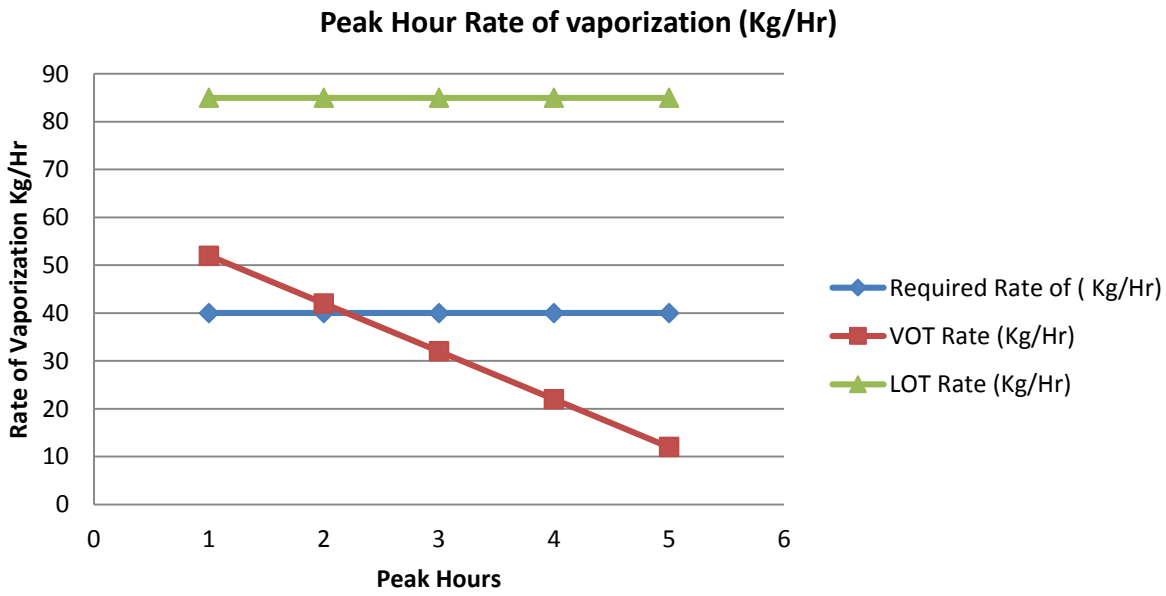


Figure 14: Rate of vaporization in peak hours

So if they run both sides of the manifold they will be able to get 52 Kg/Hr rate at 85% of the cylinder liquid level. This also gradually reduces when the cylinder tank level goes down.

When the application demand is higher than the natural vaporization rate, liquid tries to get the heat from the outside environment. Then due to heat absorption from the air, it gets condense the air and moisture deposits on the surface of the cylinder metal. Because of this Pressure reduction in the system can be observed.

2.10 Answers from Liquid Withdrawal System

Liquid withdrawal system is an advance concept in multi cylinder installations which overcomes lots of demerits of Bulk LPG system & conventional cylinder Manifold systems. This system is widely used in commercial & industrial applications only where high pressure is required & not for domestic purpose. Liquid withdrawal system withdraws liquid LPG using Liquid withdrawal valves & is converted into vapour using a vaporizer.

LPG off take per cylinder can go up to 10kg/hr which is comparatively much more than the normal Vapour off take cylinder of 0.6 kg/hr. The system offers the efficiency of Bulk installation and easy functionality of cylinder manifold system. Liquid withdrawal systems are compact, safe & highly cost effective as liquid is completely drawn from the cylinder and there is no residual loss.

Liquid withdrawal Systems that are known for their compact design and safe usage. The systems offered comprise connecting hoses, NRVs, valves, piping system, LPG vaporizer with all safety fittings, pressure regulating stations, filters and gauges. We offer indigenously manufactured vaporizers with electrically heated water bath design and world class dry type vaporizer. These can ideally be operated on single phase power without the need of any water inlet / outlet connections. we also offer to our clients metering systems, gas leak detection systems, remote operated control valves and other instruments.

2.10.1 Key Elements of Liquid Withdrawal Cylinder System

Based on the literature survey results, below accessories are found to be the basic elements of a liquid withdrawal cylinder manifold.

- Staggered Cylinder Connecting Arms
- Isolation Valves
- NRV
- LPG Hoses
- Pressure Regulators
- Pressure Guages
- Safety Valve
- Piping System
- LPG Distribution Piping
- Isolation and regulation points
- Vaporizers
- Ball Valve

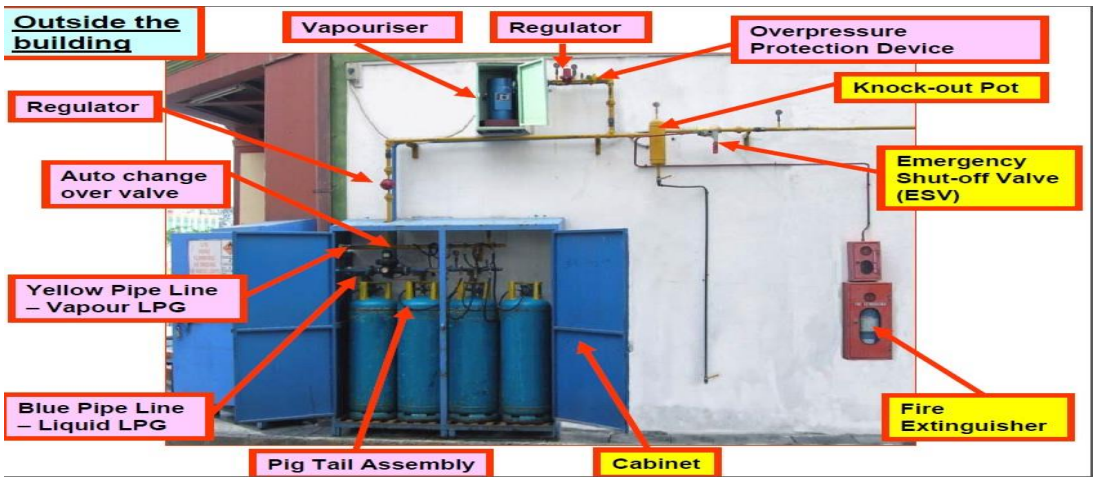


Figure 15: Basic Liquid Withdrawal LPG system

Out of the above list of accessories, NRV & Vaporizers are the additional items compare to vapor off take system.

Figure 16: LOT Valve

Figure 17: Liquid withdrawal manifold with Vaporizer

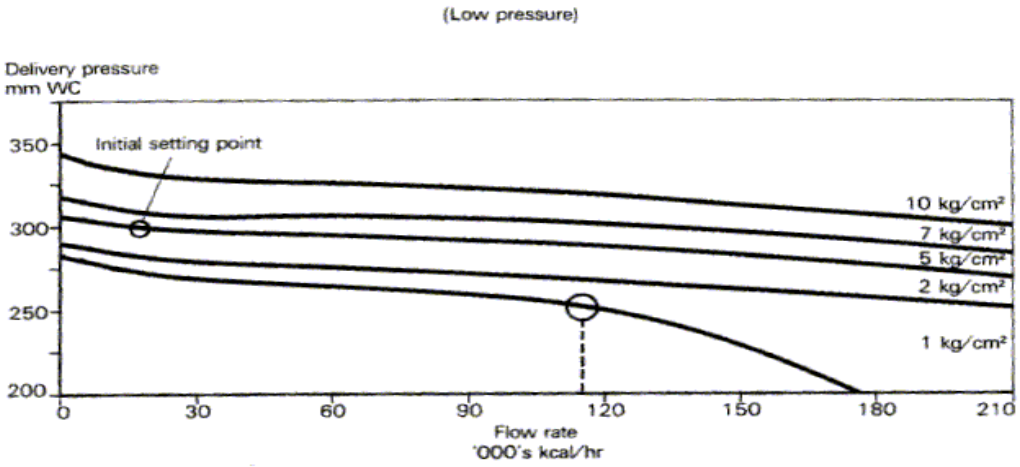


Figure 18: Pressure Vs LPG flowrate (NFPA 58)

All the vaporizers shall not be installed be inside the building and it should not be installed inside the steel cabinet or within the housing of the of LPG cylinders. Wall--mounted vaporizers shall be at least shall 1.8 m above the ground.

Proper installations of LPG manifold system, coupled with regular and proper maintenance program for the system can go a long way to ensure safety of such system.

At least one approved portable B:C rating dry chemical fire extinguisher with minimum capacity of 9 kg (in (working condition) shall be provided in this Liquid withdrawal systems.

2.11 Research literature synthesis conclusions

1. Identified customer problems and hazards in the current commercial LPG supply systems are;
    a. High rate of LPG leak incidents
    b. No proper follow up of existing standards.
    c. Unplanned increase in number of cylinders proportion to consumption
    d. Customer complaints due to drop in efficacy and pressure and temperature
    e. Cylinder Handling issues due to high frequency of replacements
    f. Non application of correct calculations and guidance for cylinder sizing

CHAPTER 3 - RESEARCH METHODOLOGY

In this study existing customer's LPG supply system will be comprehensively studied/ analyzed and looked for recommendations to achieve the objectives. Here both primary and secondary data will be required to have the overall picture on assessing the opportunity to introduce safe LPG supply system.

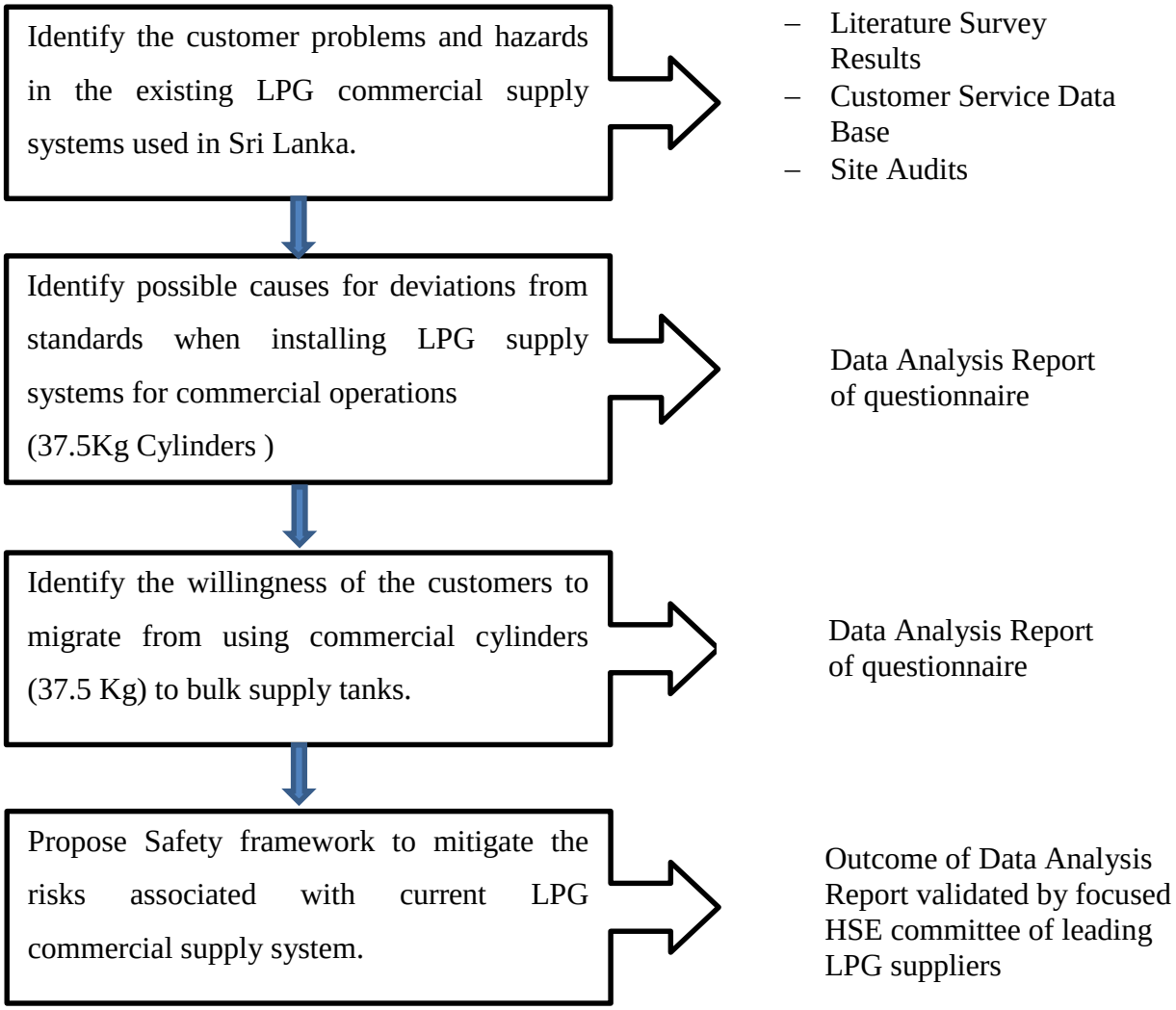


Figure 19 - Research Methodology

3.1 Collection of Primary Data

Since my research based on a practical issue, Personnel interview with questionnaire was selected to collect data. For the experimental based study I used the most flexible method of data gathering with identifying the respondent and supervision. So this is wider and more representative coverage. When choosing and developing primary research, we must consider the most appropriate method, to include its reliability, validity and practicality.

There are many comments over what is and is not reliable within research. Within the natural sciences, data are seen to be reliable, as they can be tested by different people at different times to find out the same or similar information.

Researching society and the people, systems and institutions that make up society does not offer the same guarantee for the same standard of reliability, however, when choosing which research method, we can go about being as reliable as possible - in the methods one chooses, being as objective as possible and applying and demonstrating rigorous collection and analysis methods and systems.

When starting the methodology following common issues were focus to find out the solutions to the existing system deviations.

- Availability of existing data
- Practicality of collecting data
- Gatekeepers...who are the gatekeepers? Is there a group of people you would like to research but can't as they are difficult to gain access to / or are they unwilling to participate in research? - how might you get around this?

Since observation involves sensitive human interactions, it cannot be reduced to a simple set of techniques.

- Choosing a research site
- Gaining access in setting and taking role
- Jotting down notes
- Formulating analysis

By considering the above, basically prepared a basic questionnaire to understand LPG consumption patterns and emailed to their engineering department head. At the first stage 237 copies of the initial questioner was emailed to all of the below segment customers. All the completed responses were received within 5 days.

3.2 Analyze and selection of the sample population of the study

Table 12: Total population of commercial LPG consumers in Sri Lanka

Industry	Considered Population Density
Ceramics	28
Confectionery	43
Rubber/Plastics Manufacturing	24
Metal Industry	12
Textiles & Printing	37
Hotel	69
Battery	11
AutoGas	19
Total	**243**

Source: Annual Reports of Leading LPG suppliers in Sri Lanka

For the study, the commercial LPG customers were categorized into the following three categories based on the monthly LPG consumption.

Less than 250Kg's of Monthly Average Consumption , Less than 1000Kg's and more than 250 Kg's of monthly Average Consumption & more than 1000Kg's monthly LPG consumption.

3.2.1 Selecting the Customers for administrating the questionnaire

The sample population for the study was picked using the segment wise 13 from each consumption group. So the total sample size was 39 customers.

Category 1 C < 250	Category 2 250< C < 1000	Category 3 1000 < C
13 Customers	13 Customers	13 Customers

CHAPTER 4: DATA ANALYSIS

4.1 Standard Follow up issues in the current LPG installations

Based on the research questionnaire and site visit results, the below results are found and summarized in the analysis.

4.1.1 Number of Cylinders in the manifold

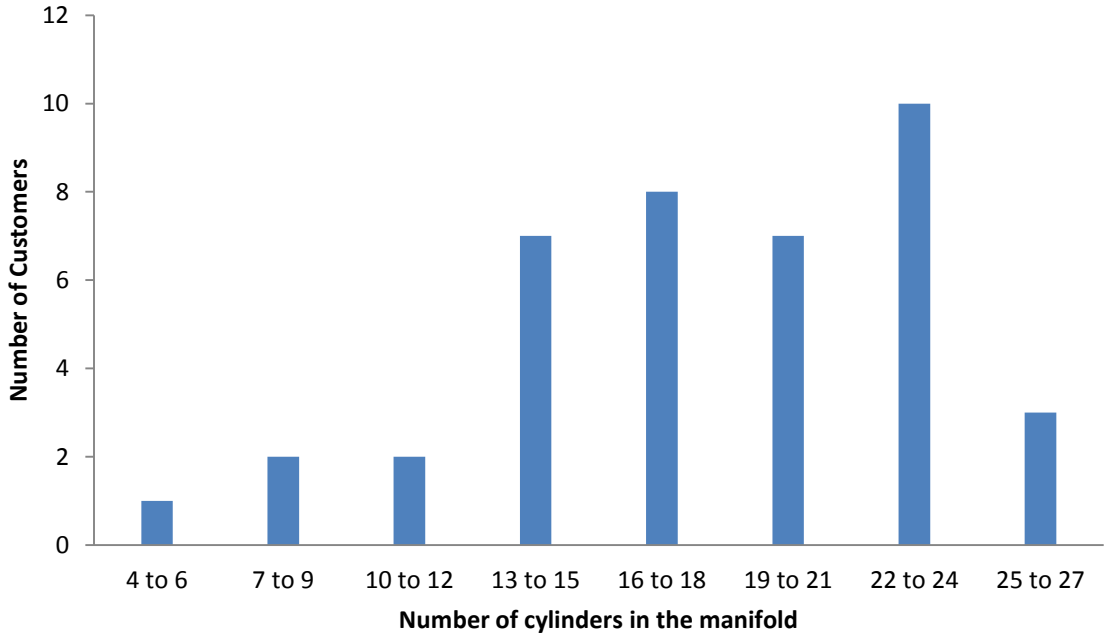


Figure 20: Cylinders in the manifold

As per the data analysis it shows most of the cylinder manifolds are incorrect with the minimum number of cylinder calculations. If the hourly consumption of LPG is 12Kg, Then there has to be at least 6 cylinders in the manifold as per the literature findings. But it was observed that industries even try to run this by having only 3 cylinders.

As a major issue of this vapor withdrawal system we found out cylinder sweating throughout the operation in many places.

4.1.2. Answers to the standards follow up during design stage of the installation

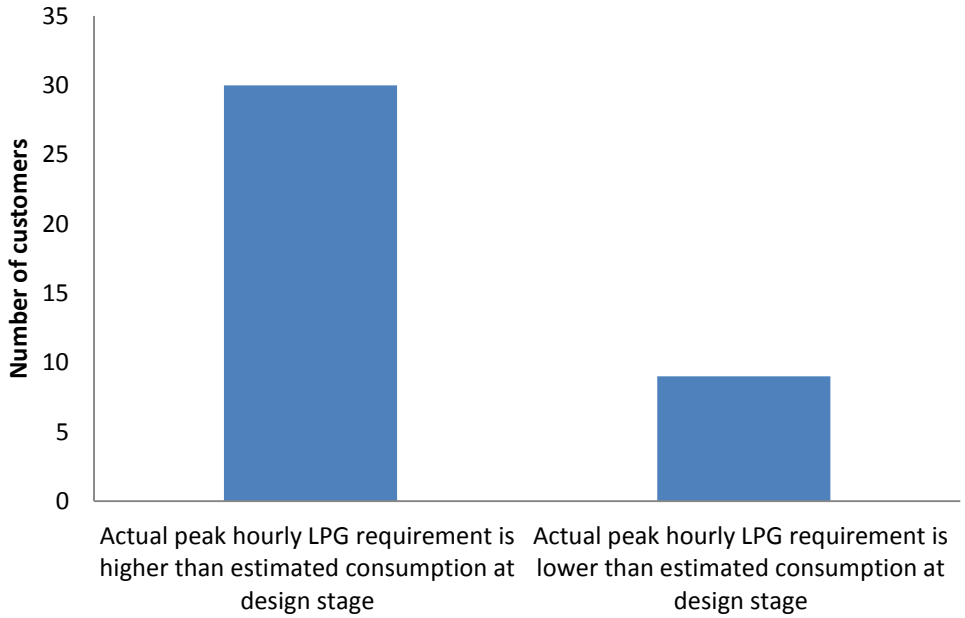


Figure 21: Status of Standard follow up at design stage

It was concluded only 15% of survey commercial LPG users had followed the standards at the early stage of LPG supply system design.

4.1.3 Cylinder sweating During Operation

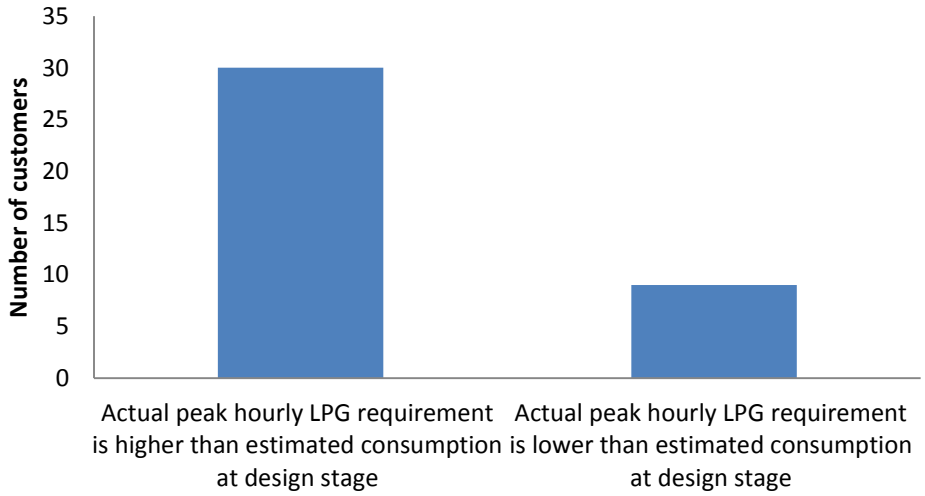


Figure 22: Cylinder Sweating During Operation

32 Consumers out of 39 were seen sweating during the operation. So it has 82% having problems of the existing system. This is due to design failures.

4.1.4 Pressure Drop in the system

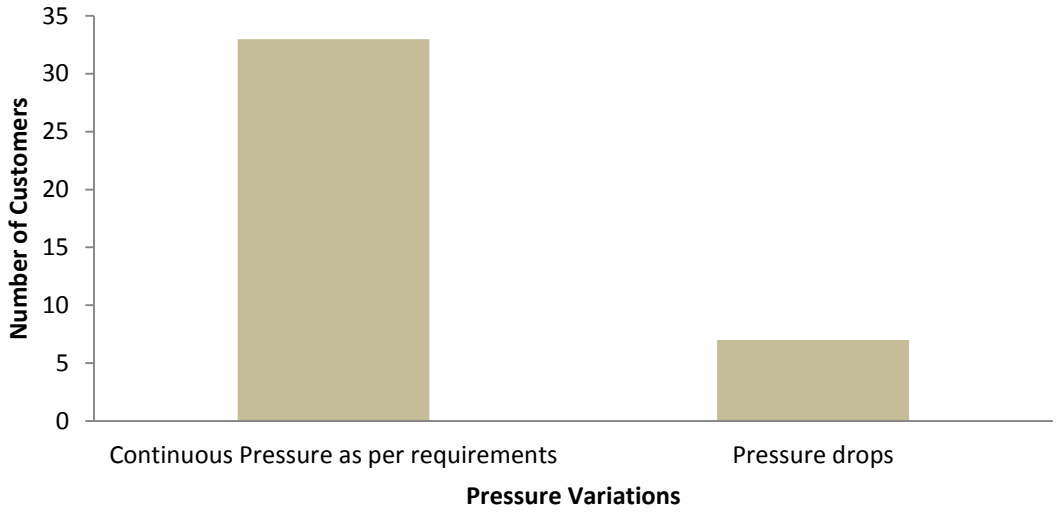


Figure 23: Pressure Drop in the system

In most of the users in commercial cylinders they required less than 18 psi pressure to run their ovens. But still around 17.5% of research consumers face pressure drop incidents.

4.1.5 Flame fluctuations

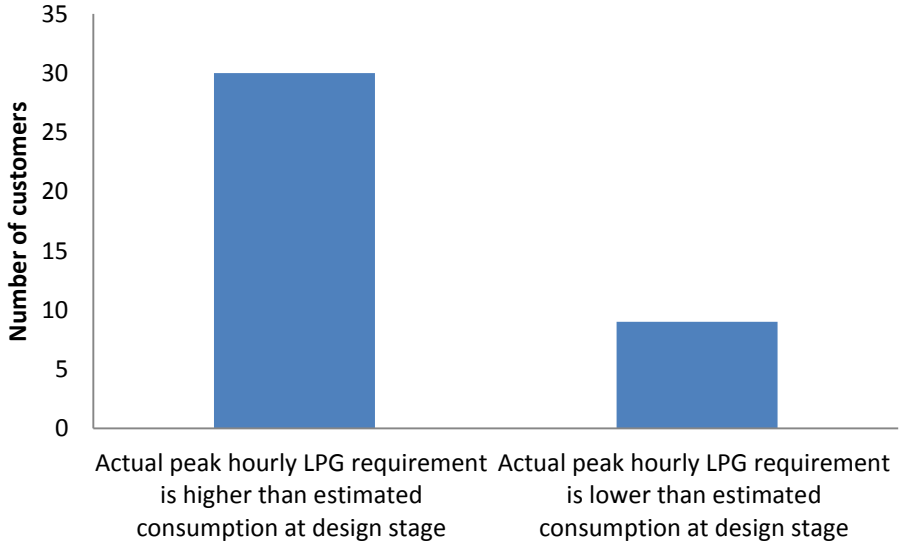


Figure 24: Uncontrolled flame conditions

Almost 72% of the consumers facing flame uncontrolled conditions where it can directly affect the oven auto shut off systems. So this can be eliminated by using liquid withdrawal cylinders.

4.1.6 Separation Distance Constraints

4.1.6.1 Area Availability for further expansions

Based on the site visits and answers to the questionnaire, commercial LPG suppliers ability to expand the current LPG storage area is plotted below.

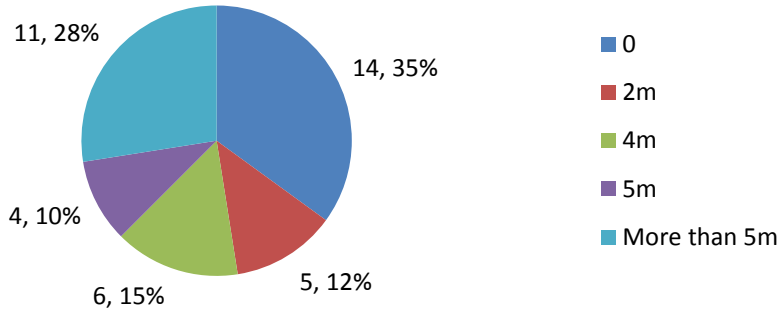


Figure 25: Space availability for further expansions

Distance from manifold to the nearest building was analyzed. Only 28% of the total sample customers have more than 5m space availability for further expansions.

4.1.7 Actual and estimated peak LPG consumption

Q1: Actual peak LPG requirement / hr (In Kg or in heat values)

Q2: Estimated peak LPG demand at the design stage

When designing a basic LPG supply system, it is recommended to use peak hour consumption rather than average consumption.

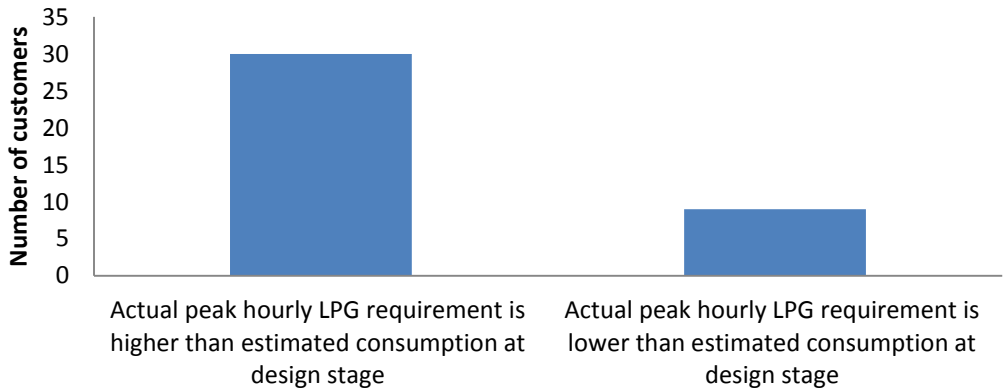


Figure 26: Hourly peak LPG consumption

Actual Hourly LPG consumption requirements and system designed hourly LPG consumptions are shown varied in many places. 77% of sample commercial customers were having highest hourly LPG consumptions than the design stage LPG consumptions.

4.1.8 Distribution issues of Cylinders

Q1: Internal road ways to cylinder area : Sufficient area for truck movements
Q2: Approximate distance from nearest Distributor
Q3: Approximate distance from Colombo

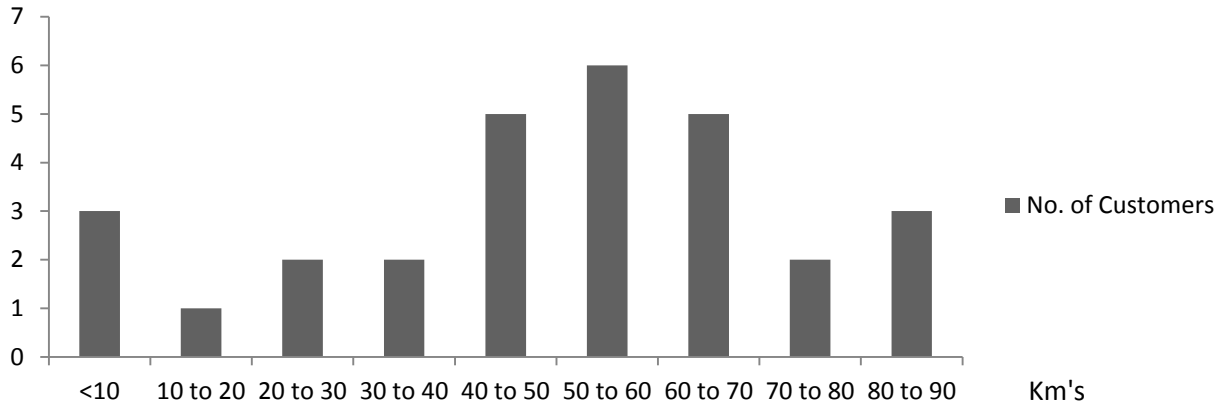


Figure 27: Distance to the nearest LPG distribution hub

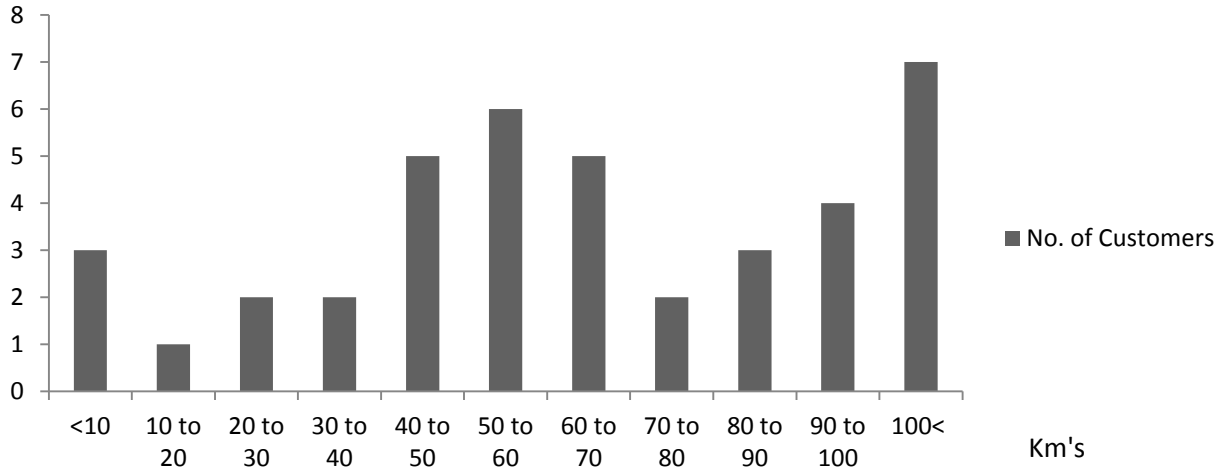


Figure 28: Customer distance from Colombo

Above two tables shows that all the commercial customers are located within a radius of 6Km from the dealer point. So stock management is not so complex as per the above analysis. If they convert to bulk from commercial cylinders, there is an issue of delivering bulk LPG in case of an emergency requirement.

From the questionnaire, customers have recorded their advantages and disadvantages for shifting the vapour withdrawal traditional LPG cylinders to liquid withdrawal cylinders.

4.2 Advantages raised by the customer

- No sweating in cylinder surfaces
- No pressure drops in the system
- Continuous same flame conditions
- Minimum intervention
- Less space requirement
    - Area Required for 26 cylinders 18 Meters * 4 Meters
    - Area required for 6 cylinders 6 Meters * 4 Meters
- No burner failures

4.3 Disadvantages raised by the customer

- Additional Cost of Vaporizer installation

Based on the current market price of 100 Kg/Hr. vaporizer, additional cost of Rs.325, 000 will have to bear for this LOT system.

- Additional electricity cost for vaporizer

4.4 Data Analysis Conclusion

Identified causes for deviations from standards in LPG installations are;

- Issues in Siting of the tanks & safety distances
- Issues in Ventilation and conditions around the tank
- Tanker access Issues
- Security Issues
- Impact protection
- Emergency arrangements
- Service pipework and construction material issues

Migrating to mini bulks and liquid withdrawal LPG system is found to be the best option to mitigate the risks in current LPG supply systems as per the data analysis.

CHAPTER 5

Based on the data analysis results and direct site observations, the following framework is proposed to HSE committees.

5.1 Proposed Safety Framework for LPG installations

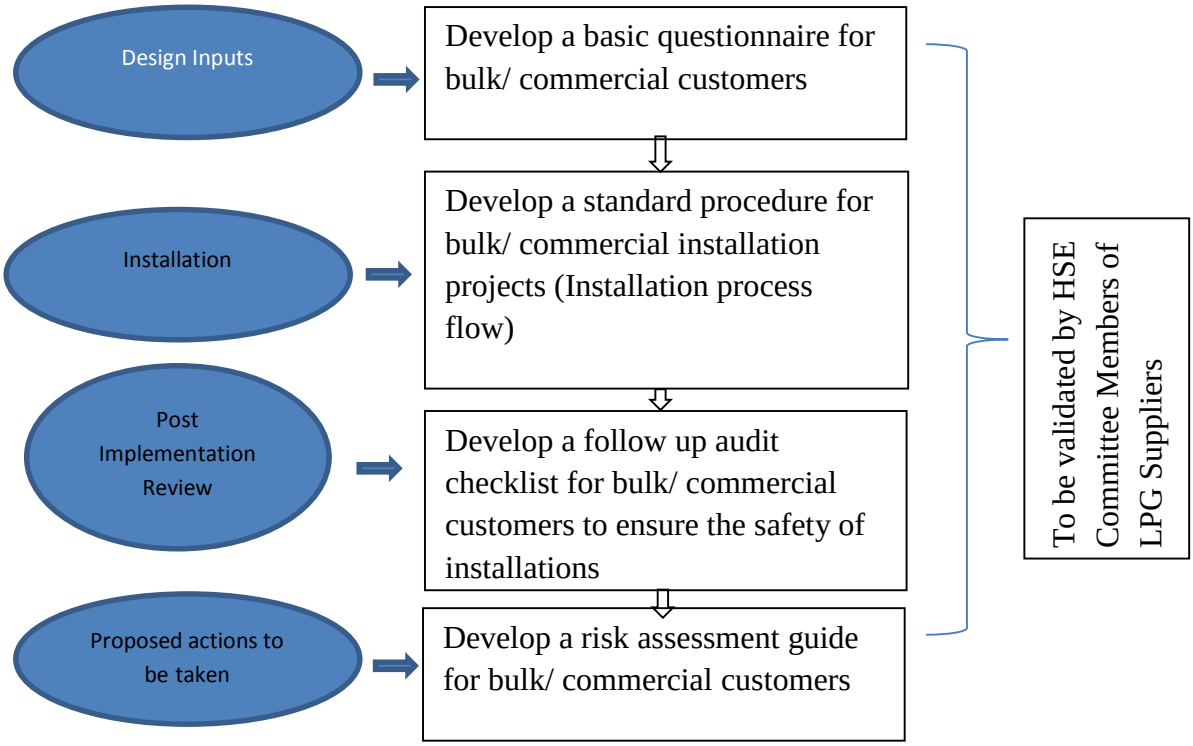


Figure 29: Proposed Safety Framework Development Stages. Approved by the HSE committee of LPG suppliers;

A basic questionnaire will helpful to use as a data for LPG supply system designs. Customers will have to give their future estimated correct values at the design stage in order to minimize under estimated designs.

A follow up audit will help to rectify operational related deviations and ensure the safety of operations. Risk Assessment can be used as a guidance to control hazards and bring down the level of risk to a minimum stage.

When installing a new LPG supply system consumption data has to be collected for future expansions as well. The following format will help in reducing the risk of fluctuations from actual requirements.

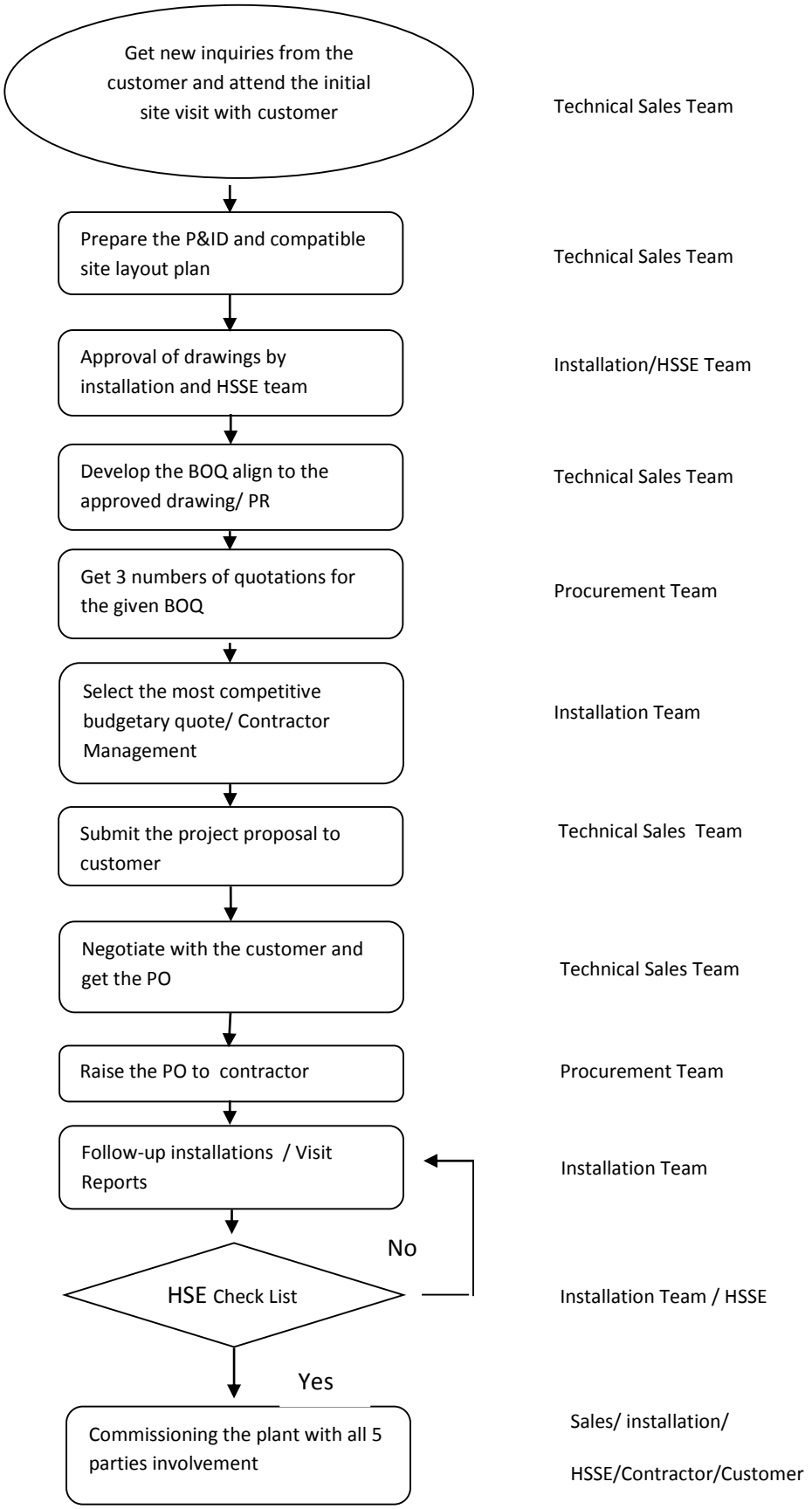
Table 13: Basic Questionnaire for Bulk/ Commercial Customers

(Validated by HSE Committee of LPG suppliers)

No	Item	Units	Customer's Request	Any Future Expansions	LPG supplier Recommendation
1	LPG requirement / hr (In Kg or in heat values)	Kg or K.cal	…….. ……		…… ……..
2.	Estimated Peak Hour Consumption	Kg or K.cal/Hr	…….. …….		…….. ……
3.	Number of hrs in operation /day	Hrs	…….		…….
4.	Monthly LPG requirement	Mt	……..		……
5.	No .of supply points & size	Nos. mm	…….. ……		…… ……..
6.	Working Pressure & capacity of each point	Psig	…….		……
7.	Estimated Annual LP Gas requirement	M.T	…….		…….
8.	Proposed Number of Tanks & Capacity	Nos:	……		……
9.	No of Vaporizers & Capacity	Nos: Kg/Hr	.....		....

No	Item	Units	Customer's Request	Any Future Expansions	LPG supplier Recommendation
10	First stage regulator capacity & no's required	Nos:	……..		…….
11	Minimum area required for the installation (Tanks area)	Met^2	…… ……		…… ……
12.	Internal road ways to tank area : Sufficient area for truck movements	Yes No	…… ……..		…… ……
13	Fire Fighting equipment & fire water requirement : 9.8 lt/m^2/min (Tanks with road tanker)	Yes No	…….. ……..		…….. ……..
14	Equipment supply by the Customer 1st ,2nd & Intermediate regulator	Yes No	…….. ……		…… …….
15	Equipment to be supply by LGLL Tanks, Vaporisers	Nos:			
16.	Approximate distance from Colombo	Km Miles	…….. …….		…… …….

5.2 Proposed Bulk/Commercial installation procedure



5.3 Safety Audit questionnaires for commercial LPG installation system

A safety audit questionnaire was prepared based on the research findings as outcomes of site visits. This will help to create the safety framework for LPG installations.

Table 14: Proposed Safety Audit Checklist

		Yes	No
1	Are safety separation distances in compliance with SLS 1196?		
2	Locate LPG cylinder storage in WELL-VENTILATED, normally OPEN AIR positions		
3	Stored below ground level, e.g. in cellars, basements or pits.		
4	Escape and access routes from the premises AND the neighboring premises blocked or obstructed		
5	LPG storage areas must always have level floors		
6	Adjacent material storage does not block or limit ventilation of LPG storage areas.		
7	Minimum recommended separation distances always maintained		
8	The store protected against tampering, theft or vandalism		
9	Any kind of flammable material to accumulate within the cylinder store and/or separation distances.		
10	LPG storage area clearly identified and notices displayed		
11	Control barriers to prevent un authorized access and accidental damage within the LPG storage area.		
12	All cylinders stored with valves uppermost		
13	All used cylinders capped		
14	Gas tight protective plugs or caps in place during storage, handling and transportation.		
15	LPG cylinders checked for signs of leaks, damage and stack stability		
16	Any electrical equipment, including wiring, cabling and enclosures used in hazardous areas confirms to the appropriate standard for the zone classification.		
Out Door Installations			
17	Are emergency contact telephone numbers displayed at the site?		
18	LPG cylinder storage area planned and arranged, according to the total quantity of LPG being stored and the maximum cylinder stack size		
19	Adjacent ground sloped or bund walls or diversion channels provided to divert any spillage away from the LPG storage.		
20	Fire walls constructed to maintain acceptable separation distances.		

21	Cylinder storage areas not located within 2 m of any doors or openings into cellars, buildings or pits,	Yes	No
23	Are all tanks equipped with a vacuum prevention measure where necessary?		
24	Are all tanks equipped with a pressure gauge?		
25	Are all tanks equipped with a temperature gauge (if required for stock reconciliation)?		
26	Are pressure relief valves set and sized to protect the tank from more than 120% of the design pressure?		
27	If a tank has an internal diameter more than 1.5m and is bigger than 5 m3, are there vent pipes fitted to the tank's PRVs, at least 1.8m above the tank?		
28	Are all drain connections no greater than 50 mm nominal bore diameter?		
29	Are all drain connections fitted with two fire safe, quick acting ball valves in series?		
30	Are all drain connections discharging safely outside the shadow of the vessel?		
31	Are drain pipes and second valves removable?		
32	Are liquid service valves fire safe, quick acting ball valves?		
33	Are logical markings and /or color codes used to indicate flow direction, contents and whether vapor or liquid?		
34	Are liquid fill couplings right-hand Acme threaded for commercial grades of odorized LPG?		
35	Are vapor connections greater than 8 mm diameter and liquid connections (including drains) greater than 3 mm diameter, protected with an excess flow valve, non-return valve or a remotely operated ESD valve?		
36	Where fitted, are ESD valves actuated automatically, operating in a controlled manner?		
37	Where fitted, are ESD valves installed in all liquid service connections having a nominal internal diameter greater than 25 mm ?		
38	Where fitted, are ESD controls located at strategic positions over sites and clearly indicated?		
39	Where fitted, does the ESD system include automatic trips on the LPG pumps, as well as to the emergency alarm and water fire protection system?		
40	Are all tanks above 2,500 litres water capacity permanently bonded to an effective grounded earthling point (clean, unpainted and free from corrosion)?		
41	Is there electrical continuity between tank transfer connections and earthling points/ bonding connections through to the tanks and are there records of the checks?		

42	Do pipelines, fittings and hoses used for liquid phase LPG transfer have electrical continuity and are they reliably connected to earth ?	Yes	No
43	Are electrical bonding straps fitted across connecting joints?		
44	Is all electrical equipment mounted near the vessel suitable for use in Hazardous Areas?		
45	Is all pipework carrying vapour, below 5 bar, carbon steel, copper up to 35mm diameter or polyethylene (if underground)?		
46	Is all pipework carrying vapour, above 5 bar, seamless carbon steel or copper (up to 15mm diameter)?		
47	Is all pipework carrying liquid seamless carbon steel		
48	Is all pipework over 50mm nominal bore seamless carbon steel?		
49	Is all pipework routed above ground where practicable, in the open air and adequately supported?		
50	Where pipework is buried underground, is it inherently resistant to corrosion?		
51	Are hydrostatic relief valves fitted in any pipework in which liquid LPG may be trapped?		
52	Do regulators comply with a recognised standard and are they produced by reputable manufacturers?		
53	Are first stage regulators located as close as practicable to the tank / vaporiser connection?		
54	Are second stage regulators located on the exterior wall of the supplied premises? If installed inside buildings are the vent and any relief valve piped to the outside of the building?		
Fire Protection			
55	Are appropriate fire precautions, according to LPG tank capacities and calculated fire risk, installed?		
56	Is there a water supply available at all sites to supply 9.8 litres per m2 per minute over the entire tank surface for no less than an hour?		
57	Are all fire extinguishers within the test date?		
58	Are water-sealed interceptors put where necessary to prevent LPG entering drains and sewers?		
59	Does the design/location of fixed drench and hydrant systems allow control of water flow from safety distances greater than specified in SLS 1196?		
60	Is the fire protection equipment at all LPG storage sites approved by the enforcing authorities and a fire risk assessment carried out?		

5.4 Developing a Risk Assessment to address issues

Table 16: Hazards and Effects Management Process (HEMP)

Identify (From Questionnaire)	Are people, environment or assets exposed to potential harm?
Assess(From Questionnaire)	What are the causes and consequences? How likely is loss of control? What is the risk and is it ALARP?
Control (From Literature Survey)	Can the causes be eliminated? What controls are needed? How effective are the controls?
Recover (From Literature Survey)	Can the potential consequences or effects be mitigated? What recover measures are needed? Are recovery capabilities suitable and sufficient?

Risk Assessment for Bulk/Commercial LPG facility

(Validated by the HSE Committee of LPG suppliers)

No.	Threat	Control Measures	Consequences	Mitigation/Recovery Measures
1.	Failure of transfer hose	• Correct hose selection and handling facilities • Site staff training programme (induction and refresher) • Maintenance staff training programme (induction and refresher) • Daily supervisor site inspection • Visual inspection of hose before use • Clear display of work instructions • Adherence to procedures/work instructions • Periodic hose testing • Fault reporting system • Availability and use of protection and housing for hoses • Site audit system Correct hose procurement, specification & QA	• Product leak • Fire / explosion • Asset damage / loss - company / contractor / third party Injury / fatality	• Safety distances to facilitate dispersion without ignition • Leak detection by Operator • Fire detection by Operator • Introduce ESD system • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Communication • Site exits (for emergency) • Hazardous Zone definition and discipline • Hose Testing • Gas detector in vicinity

No.	Threat	Control Measures	Consequences	Mitigation/Recovery Measures
2.	Static electricity build-up and discharge (spark)	• Site staff training programme (induction and refresher) • Maintenance staff training programme (induction and refresher) • Clear display of work instructions • Adherence to procedures/work instructions • Regular 'toolbox' meetings • Regular safety committee meetings • Vehicle maintenance program of delivery Vehicle • Regular check of electrical continuity of delivery vehicle, transfer hoses and pipe work. • Regular check of bonding wire continuity. • Battery master (isolating) switch on delivery vehicle. • Unsafe act auditing system • Fault reporting system • Site audit system • Correct tyre procurement, specification & QA • Correct clothing • Control of pumping speeds / Delivery of Fuel	• Fire / explosion • Asset damage / loss - company / contractor / third party • Injury / fatality	• Fire detection system • Introduce ESD system • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Communication • Site emergency exits • Hazardous Zone definition and discipline • Use temporary barricade to restrict vehicular movements.
3.	Vehicle moving with hose connected	• Driver training programme (induction and refresher) • Site staff training programme (induction and refresher) • Clear display of work instructions • Adherence to procedures/work instructions • Vehicle interlock system • Use of wheel chocks • Unsafe act auditing system • Incident feedback • Vehicle maintenance programme	• Damage to facilities • Product leak • Asset damage • Fire / explosion • Injury / fatality	• Safety distances to facilitate dispersion without ignition • ESD system • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Communication • Site emergency exits • Hazardous Zone definition and discipline

No.	Threat	Control Measures	Consequences	Mitigation/Recovery Measures
4.	Spilled gas at Tank loading point / Cylinder Valve area	• Operator training programme (induction and refresher) • Maintenance staff training programme (induction and refresher) • Maintenance contractor selection & appraisal processes • Use of drip trays • Daily/Weekly supervisor site inspection • Site maintenance programme • Fault reporting system • Unsafe act auditing system • Site audit system • Regular 'toolbox' meetings • Regular safety committee meetings • Incident feedback	• Personal injury • Environmental pollution	• Use of PPE (especially non-slip shoes) • Availability and use of absorbent material for spillages • Efficient first aid medical response • Filling point to be located appropriately. • Introduce a proper barricade system around the unloading facility. • Restrict vehicular movement in area.
5.	Poor housekeeping (flammable waste, long grass/shrubs, canteen waste, office waste, etc.)	• Maintenance staff training programme (induction and refresher) • Briefing to ground maintenance staff • Daily inspections and walks • Daily/Weekly supervisor site inspection • Unsafe act auditing system • Site audit system • Regular 'toolbox' meetings • Regular safety committee meetings • Incident feedback	• Fire / explosion • Injury / fatality • Asset damage / loss - company / contractor / third party	• Dispenser ESD system • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Site emergency exits • Hazardous Zone definition and discipline
6.	Failure of pipe work, gaskets, gauges, fittings,hoses etc.	• Correct specification & Quality Assurance of parts. • Maintenance staff training programme (induction and refresher) • Maintenance contractor selection & appraisal processes • Adherence to procedures/work instructions • Site maintenance programme • Fault reporting system • Daily/Weekly supervisor site inspection • Site audit system	• Product leak • Fire / explosion • Injury / fatality • Asset damage / loss - company / contractor / third party	• Safety distances to facilitate dispersion without ignition • Product stock reconciliation process • Fire detection • Dispenser ESD system • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Site exits (for emergency) • Hazardous Zone definition and discipline

No.	Threat	Control Measures	Consequences	Mitigation/Recovery Measures
7.	Failure of storage vessel, cylinder, gaskets, gauges, fittings, etc.	• Correct specification & Quality Assurance of parts. • Maintenance staff training programme (induction and refresher) • Maintenance contractor selection & appraisal processes • Adherence to procedures/work instructions • Site maintenance programme • Fault reporting system • Daily/Weekly supervisor site inspection • Site audit system	• Product leak • Fire / explosion • Injury / fatality • Asset damage / loss - company / contractor / third party	• Safety distances to facilitate dispersion without ignition • Leak detection through product stock reconciliation process. • Fire detection • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Site emergency exits • Hazardous Zone definition and discipline
8	Security	• Barricade the LPG tank farm and cylinder manifold area • In/ Out logs • Security register • Auto shut down systems • Check devices • Duty assignments • Trainings to security staff	• Vandalism • System breakdown • Fire/ Explosions	• Site ESD • Safety distances to facilitate dispersion without ignition • Leak detection through product stock reconciliation process. • Fire detection • Site firefighting facilities • Site Emergency Response Plan/Procedures • Site Medical Response Plan/Procedures • Emergency Services • Site emergency exits • Hazardous Zone definition and discipline

CHAPTER 6

6.1 CONCLUSION AND RECOMMENDATIONS

Technical and safety standards should be established, maintained and enforced for LPG appliances, installations appliances and for consumer installations as per WLPGA requirements. Only qualified installers and servicemen should be permitted to undertake LPG installation work. Public safety awareness program should be introduced to address potential hazards in using LPG and about the safety features of appliances and their installation. Consumers should exercise due care in the use of LPG. Consumers should insist that LPG installers and servicemen are properly qualified for such work.

As per the literature survey findings, there are many practical issues in current commercial LPG installations. As per Rizuwan & Wahab (2010) the major practical problems of present cylinder manifolds are;

- Limitations in consumption rate
- High replacing frequency
- Cylinder sweating
- LPG Left over cylinders
- Non availability of liquid withdrawal facility
- Due to high rate of regulator replacement, high rate of accessory damages
- Barriers to increase number of cylinders in the manifold.
- Vulnerability for leaks in the system

Literature survey finding shows that sound design and construction helps to prevent many risks in LPG installations. SLS 1196, NFPA 58, REGO guidelines are useful in design. Many internal standards are also available with LPG suppliers for LPG installations. Consideration of usage of adjacent land and property at initial stage will definitely address the issues of area constraints.

Good housekeeping is a requirement in handling LPG. Ventilation sources have to be maintained with regular audits. Non-combustible construction materials/ Clear of

other flammables and combustibles and maintaining easy access are essential in commercial LPG installations.

Proper stock management system will also required in answering to the issues related to the commercial LPG supply system. This includes planning storage cylinder quantities, space managements, regular audits, efficient replacements etc.

Knowledge barrier is the main cause for deviation from standards. LPG suppliers have to mainly focus on the training of commercial cylinders users. There is a gap of required knowledge on standards and safe work practices. Behaviors based safety observations will definitely help in inculcating the proactive safety culture. It was observed that even though a LPG safety leaflet has been issued by the LPG supplier, it is not properly distributed to the end customers.

Clearly displayed work instructions are required for LPG maintenance team. Adequately separated from residential accommodation, commercial and industrial development, vulnerable populations etc. & good security (to protect against vandalism) are the areas for improvements.

Staff must be regularly trained and assessed in the knowledge and practice of normal operations, including as appropriate:

- Product knowledge
- Safety in day to day operations
- Use of personal protective equipment
- First aid
- Loading / unloading
- Emergency procedures and shut-down
- Fire-fighting
- Inspection and maintenance

As per the study, It shows most of the customers with more than 3000 Kg's of monthly LPG consumption, are willing to transfer from commercial cylinders to Bulk & liquid withdrawal systems. Their interest areas of shifting from cylinders to bulk are; easy to maintain, no manual handling in LPG replacements, less cost for

LPG, simple configuration in LPG distribution system, less number of valve fittings etc. But there are issues like area constraints, cost of initial installation and additional security also.

In summary the underlying basic principles for all bulk/commercial storage and its safe operation are required:

- Sound design and construction
- Consideration of usage of adjacent land and property
- Good housekeeping
- Minimum stocks held
- Trained staff
- Minimum number of joints and potential leak paths
- Clearly displayed work instructions
- Non-combustible construction materials
- Clear of other flammables and combustibles etc
- Easy access
- Adequately separated from residential accommodation, commercial and industrial development, vulnerable populations, etc
- No cellars, open drains etc
- Open area with good ventilation
- Good security (vandalism and theft)
- Access to authorized personnel only
- Clearly visible hazard/warning notices
- Emergency procedure and telephone number displayed
- Appropriate firefighting equipment
- No smoking or naked lights
- Appropriate electrical equipment for hazardous areas
- Safeguarding and mitigation systems
- Rigorous asset integrity regime in place

It is not recommended to carry out any modifications which may affect the LPG installation, such as altering walls or erecting sheds or fences, or installing electrical equipment near the tank. Always it has recommended get the guidance from the installer about the minimal safety requirements of LPG installation.
The best way to alert the visitors on LPG installation is to have signage around the tank farm area. Always follow standards when installing the LPG distribution system. Do not follow shortcuts and follow only the standard procedures.

Fire department approval is a requirement for bulk LPG installations. After installing the LPG supply system regular safety Audits have to be conducted in order to ensure the safety of the system.

Proposed process flow will help to make controls on LPG installations. Initial Customer questionnaire and the commercial LPG installation audit format will definitely make the initial framework of safety in commercial LPG installations.

Risk assessment can be used as a tool to recognize risks involved in commercial LPG supply system and to reduce the risks by applying control measures. This has to be updated with incidents regularly.

6.2 Recommendations

1. It is highly recommended that the proposed safety framework to be implemented in new installations.
2. New Liquid withdrawal cylinders or Bulk identified to be introduced through the existing LPG suppliers in the commercial market. New range of cylinders along with Liquid withdrawal special valve assembly to be fixed to the cylinder. Additional cost will incur in configuration for this modified valve assembly.
3. Handling of Liquid is more hazardous than the vapour since it can make 12,500 times higher flammable air mixture. Special site based trainings have to be introduced enhancing the knowledge.
4. Convince customers to add additional Vaporizers to the existing system with additional cost & Find out innovations for dry type vaporizers to fix in vertical walls along with cylinders.
5. Align to special safety standards given in SLS 1196 & NFPA 58.
6. Introduce essential fire department approval process for commercial LPG installations.
7. Annual inspection of LPG installations by authorized agent to ensure the safety of bulk & commercial LPG installations. Thereby introducing a licensing system for commercial & bulk LPG installation systems.

6.3 Directions for Future Research

- The outcome of this research will be guidance for innovations in this field of study. This study will contribute to find solutions to actual practical issues facing in the existing LPG supply systems in commercial customers in Sri Lanka.
- Each and every issues highlighted in our study have a root for in depth analysis. In this research I have gone through the issues as a whole to find out whether we can give solutions from existing market available models. A technical research can use to analyses each and every issue by taking as a

single research. Introducing a bigger size LPG storage cylinder will give a good topic for further research. The results found from the study can be taken as a reference to a future project.

- The developed business model can further analyses in detail to find another chain of applications in this fast moving world. This study only surveyed commercial customers. The transferability of the study findings could be further strengthened by surveying and interviewing bulk customers to gain a more comprehensive understanding of the issues suggested by industrial customers in this survey.
- The survey, as designed, generated a large number of open-ended responses of more qualitative data. The questions that emerged were telling, but also raised more questions about the process of operations. Thus, a final, but worthwhile, direction for future research would be taking a case-study approach to exploring the experiences of factory engineering staff.
- The analyses of issues within a common analytical framework and using comparable methods as outlined in these volumes has ensured greater consistency and comparability in evaluating and using scientific evidence on major operational issues in the existing system.
- All the calculations and data analysis shows a clue for the pointed objectives and these can be further refined to have mini studies in LPG system studies.
- Design of LPG withdrawal manifolds, increasing the evaporation rates in cylinders, Inter-fuel conversions in different segments, Studying the improvements for vapor off take cylinders etc. can take as further studies from this research topic.

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