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MINIMIZING PROBLEMS IN CONVENTIONAL LPG CYLINDER MANIFOLDS USED IN APARTMENT BUILDINGS IN SRI LANKA

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Abstract
Apartment users are heavily depended on conventional type LPG supply systems for their cooking purpose. However, this system identified many drawbacks in terms of user safety. This finding alone justifies the need for the LPG industry to find ways to work with LPG suppliers, distributors and building contractors to develop commercially sustainable safe business models for supplying across apartment buildings. Alternatively, liquid withdrawal LPG cylinder manifolds are recommended as safe, effective and efficient system for apartments. In the same time the proposed system can be shown as a solution for limited space in apartments for storage of cylinders. The paper discusses existing issues in conventional LPG cylinder manifolds and presents a liquid withdrawal compact LPG supply system for apartment buildings as a solution for issues in conventional LPG supply systems

Keywords: *LPG supply system, Safety, Apartments, Risks, Liquid Withdrawal LPG cylinder manifolds*

Introduction

Liquid Petroleum Gas (LPG) have been identified as the most economical and environmentally sustainable fuel over other fuels (Amuzuvi & Ashilevi, 2016). Electricity and gas are found to be the dominant fuels used by urban residential apartments (Kim, Cho and Kim, 2019). The use of LPG has seen a tremendous increase in recent years for residential buildings due to its inherent cost and environmental advantages (Wan & Yik,2004). In Sri Lanka, cylinder manifolds are used as a common system of LPG supply. In this system, two or more cylinders are interconnected together to a common gas line in a cylinder manifold to use in higher LPG consumption applications (Mariani & Vallerotonda,2008). As seen in Figure 1, Carbon steel or Galvanized Iron pipes, regulator, pigtail, isolation valves and pressure relief valve are identified as critical accessories of a manifold to regulate the safety of the system.

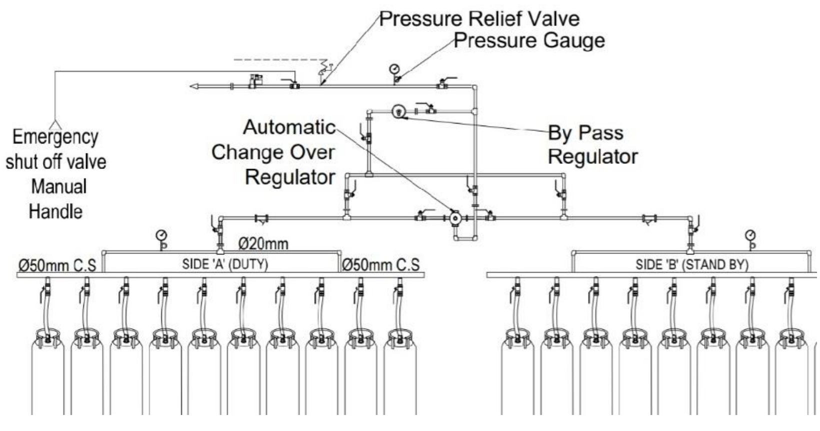


Figure 1: Typical LPG manifold of an Apartment Building

LPG manifolds have their inherent safety risks and thus fire hazards in apartment buildings are at a greater level. Loss of primary containment (LOPC) arise from spillage of liquid from a pressurized container or from a pipeline resulting in instant total dispersion and evaporation, is identified as the main fire risk causing factors in the LPG distribution system (Rasbash,2010). LPG leak creates risks for occurrences of "Vapor Cloud Explosions (VCE)", "Flash Fire" and "Boiling Liquid Expanding Vapour Explosions (BLEVE)" as illustrated in Figure 2 (Tasneem & Abbasi, 2006).

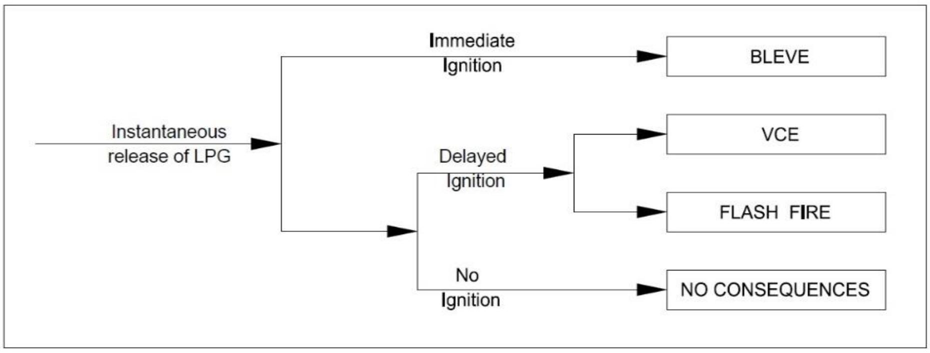


Figure 2: Consequences of LPG leaks
Source: Jung, Ng, Laird & Mannan,2010

To understand the issues in apartment LPG distribution systems, factors such as geographical location of the LPG supply system and surrounded environmental information (Poon, Tsz-ho, William,2008), Plot plan, Process and Instrumentation Diagrams (P&IDs), Process Flow Diagrams (PFDs) (Islam & Sultana, 2017), Installation layout, Operation procedures, physical and Chemical specification of the material, (Dormohammadi, Zarei,Delkhosh and Gholamib,2010) etc., are to be examined. Safety distances kept in storage and pipelines transmitting LPG is determined considering the possible outcomes of an accidental event associated with fuel gas release from pressurized transmission systems (Sklavounos & Rigas, 2012). According to SLS 1196(2000) every LPG manifold should be separated from a building, boundary, or fixed source of ignition and 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.

Existing Problems of Conventional LPG Supply Systems in Apartments

Despite the benefits of the LPG, high rates of LPG leak incidents are reported in apartment buildings, increasing the risks of causing explosions or fire(Beheshti, Dehghan,Hajizadeh, Jafari & Koohpaei,2018; Bruce et al., 2015; Nisanci, Yildirim and Erbas,2009). Further, direct exposure to LPG vapour gases, cold burn due to contact of liquid LPG to the skin are critical secondary impact of those leakages (Chatier et al.,2016). Among them, fire is the most common hazard, while explosion is more critical in terms of its potential damage (Faisal I. Khan, S.A. Abbasi,2002).

Barriers to increase number of cylinders in the manifold to cater to the demand due to space constraints (Spyros Sklavounos, Fotis Rigas,2006), limitations in maximum LPG evaporation rate of a cylinder (Tauseef1, Abbasi, Thiruselvi and Abbasi,2017), high cylinder replacing frequency(Inkoon & Biney,2010), cylinder sweating (Malviya &Rushaid,2018), design and installation failures, LPG left over cylinders (Santoli,Paiolo,Basso, 2017), non-availability of liquid LPG withdrawal facility (Stawczyk,2002), high rate of regulator replacement (Krzysiak et al, 2017), high rate of accessory damages (Demichela, Piccinini & Poggio, 2004), vulnerability for leaks in the system are identified as common practical problems of present cylinder manifolds for enhancing safety of the system (Rizuwan & Wahab , 2010). As per LPG supplier's complaint records, more than 100 LPG leak incidents have been reported in last year leading to 4 major fire incidents in apartment buildings in Sri Lanka.

Lack of awareness among users regarding safety measures, poor knowledge on safety procedure and lack of authority involvement are identified as common root causes for accidents (Paliwal, Agrawal ,Srivastava, Sharma ,2014;Wahab,2010) reported relate to LPG supply systems of apartments.

Methodology

Forty apartments were randomly selected from 72 apartments which use LPG from a central manifold in Colombo district for data collection. Those apartments have been built between 1997 and 2019. Monthly average consumption of LPG was obtained from the records of central manifold meter readings.

To assess the level of safety risk in LPG supply systems of selected apartments, interviews were conducted with the respective maintenance managers. Additionally, site surveys were conducted to view the site conditions. As per the literature findings on safety issues of LPG systems, following aspects were studied during the data collection as follows;

- Insufficient number of cylinders in the manifold (Armenakis & Nirupama ,2011),
- Cylinder sweating during operation (Quedat, Guarnieri, Gablino & Rigurd ,2015),
- Pressure drop in the system (Kimemia & Annegarn ,2016),
- Flame fluctuations & yellow flames (Gallab et al.,2017),
- Constraints in separation distance,
- Lack of LPG storage and manifold area utilization
- Lack of provisions for further expansions (Erameh and Iruansi ,2014),
- Mismatches in hourly LPG consumption analysis (Boult,2000),
- Non-availability of liquid withdrawal LPG systems,
- Insufficient distance to the nearest ignition sources (Ono & Silva,2000)

Criticality levels of those safety issues were calculated using the mean rating of Hazard Rating Index $(HRI)_{apartment}$ as follows;

$$HRI_{apartment} = HCN * \text{Existing Level of Risks} \quad (1)$$

$$\text{Where } HCN = \left(\sum_{k=1}^{n} W_k\right)/N \quad (2)$$

N= number of experts
W= given Likert scale ¥= 1,....5

Twelve (12) experts were interviewed to establish “Hazard Critical Number (HCN)” which was derived from 1-5 Likert scale. These 12 expert’s committee is a composition of more than 10 years industrial experienced engineers in the field of LPG and petroleum. Based on their individual scoring, HCN numbers were derived for all existing issues in conventional LPG system.

Existing levels of risk were calculated based on the finding of field observation data calculation and results are discussed in below.

Results and Discussion

Existing issues of LPG system

Seven existing common issues were analyzed using the equation 1 and ranked according the their HRI (Table 1).

Table 1: Existing issues in conventional LPG system

Issue	HCN	Risk level	HRI	Rank
Insufficient storage space for safe operations	5.0	0.72	3.6	1
Non Availability of Area for further Expansions	4.0	0.90	3.6	1
Cylinder sweating During Operation	4.0	0.80	3.2	2
Insufficient number of cylinders	3.0	0.50	1.5	3
LPG Supply and demand mismatch	2.0	0.67	1.34	4
Yellow Flame	2.0	0.5	1.0	5
Pressure Variations	3.0	0.175	0.525	6
Flame Fluctuations	1.0	0.425	0.425	7

- **Insufficient storage area for operations**

As per SLS 1196 part 2 the maximum LPG capacity store in a well ventilated single location is 1000Kg. 70% of selected apartments had a dedicated location for LPG storage. Area allocated for LPG storage was not enough for 72% of apartments and risk level is considered as 0.72. Firefighting measures were not available in 40% of apartments. Empty and filled cylinders were kept adjacent to the cylinder manifold area those who didn’t have a storage facility.

- **Non Availability of Area for further expansions**

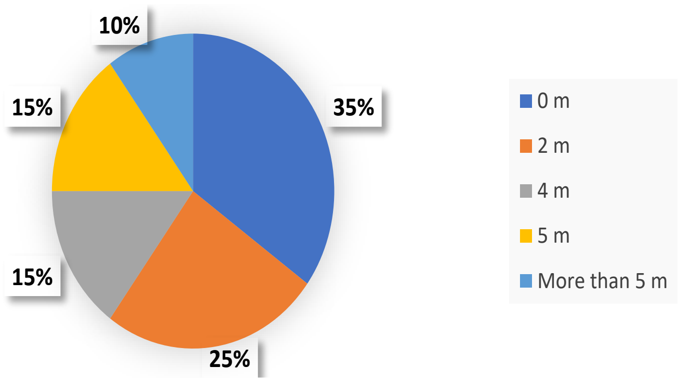


Figure 3: Space availability for further expansions

Figure 3 represents the availability of area for further extensions in LPG manifold installation area. Area availability is a compulsory requirement for manifold installations. As per SLS 1196 there is a minimum distance requirement to install a cylinder manifold from a source of ignition. Thus, at least 5m distance to be kept free to have a smooth manual operations of cylinders. Thus, the existing risk level 90% is a result of calculation based on 5m minimum separation distance.

In addition, ventilation issues were commonly seen in storage areas due to congested storages. Impact protection and emergency access to LPG facility is a compulsory requirement identified at risk minimization stage.

- **Cylinders Sweating During Operation**

Due to supply and demand mismatch, the phase conversion of the LP gas from liquid to gas absorbs heat from the surrounding area and makes the tank colder where it contacts the liquid inside the tank. Sooner the tank gets below dew point; it'll start to see condensation on the side of tank which is termed as sweating. Due to supply and demand mismatch, out of 40 apartment manifolds, 32 (i.e. 80% of risk level) were seen sweating mainly during the night operation. Figure 4 further illustrates period of occurrences of the sweating.

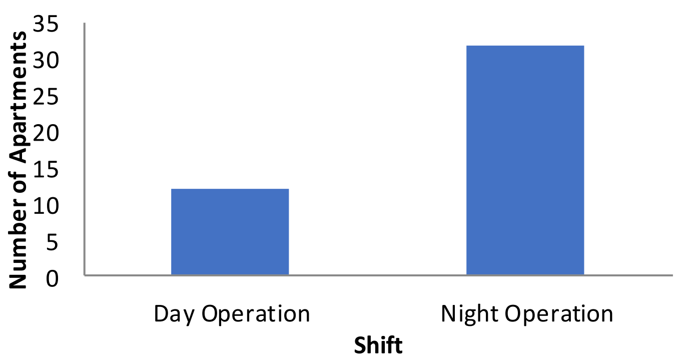


Figure 4: Cylinder Sweating During Operation

Sweating is resulted due to design failures, use of partial standards at the design stage and neglect of basic design parameters such as operational pressure, temperature, ambient environment conditions, maximum demand which leads to pressure fluctuations, incomplete burning and system inefficiencies.

- **LPG Supply and demand mismatch**

Hourly peak LPG consumption in all 40 apartments are shown in Figure 9. There are 5 apartments who has more than 50Kg/Hr.

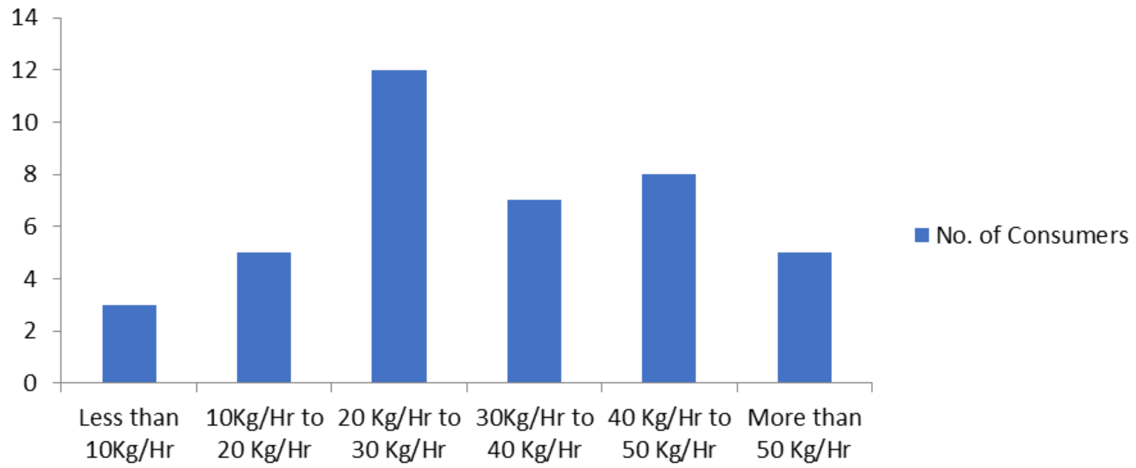


Figure 5: Hourly peak LPG consumption

Peak hourly LPG consumption vary from 40 to 50 Kg were taken for further evaluation. 6 apartments who had 40Kg/Hr consumption data were further evaluated and below required vs actual LPG supply data are presented in figure 6. Actual Hourly peak LPG consumption requirements and system designed maximum hourly LPG consumptions are shown varied in many places. 67% of under designed manifolds are operating in selected 6 apartments who had 40Kgs/Hr peak LPG consumption.

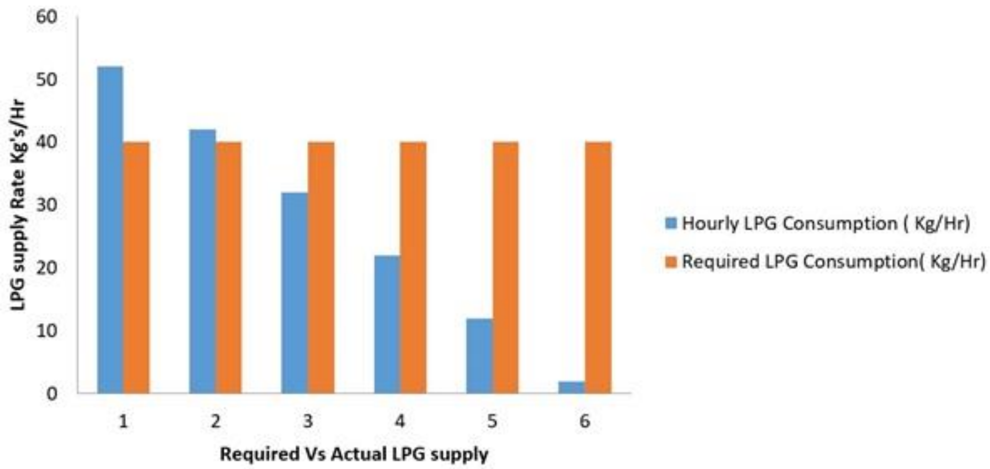


Figure 6: Hourly actual vs required LPG supply rate

- **Insufficient number of cylinders in the manifold**

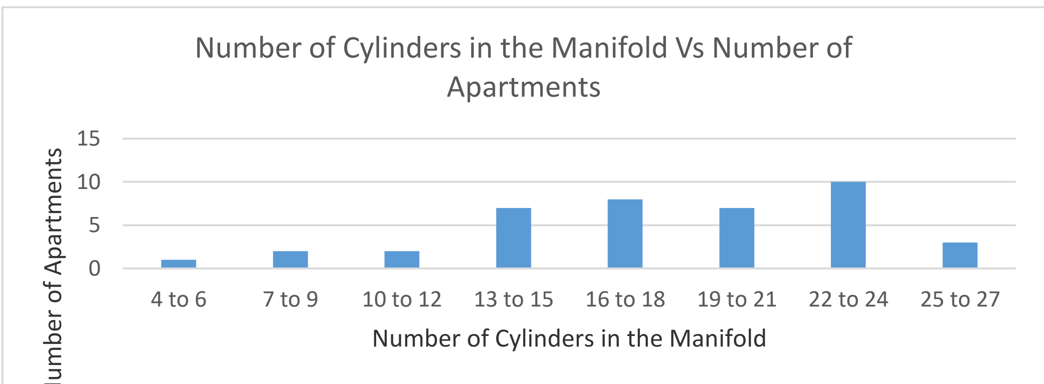


Figure 7: Number of cylinders in the manifolds installed at apartments

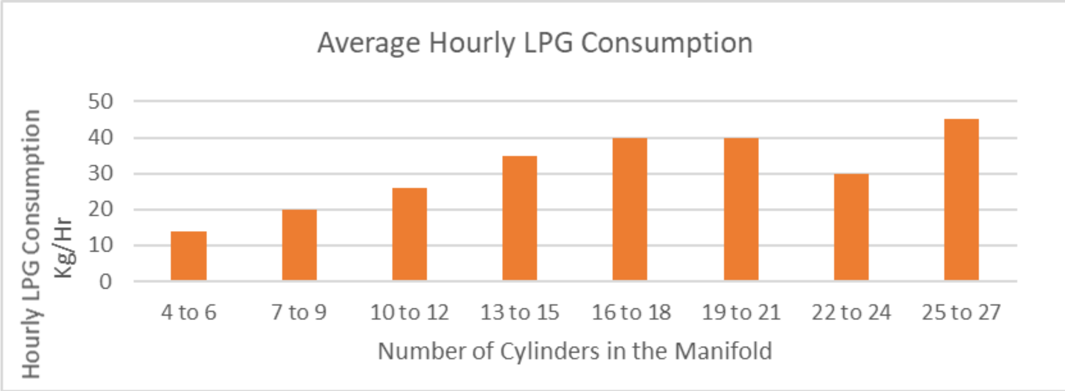


Figure 8: Hourly LPG consumption Vs number of cylinders in the manifold

Figure 6 and 7 illustrates number of cylinders in the manifolds and the average hourly consumption in the apartments. As per the NFPA 54 standard/guideline, industrial and domestic cylinder can produce a maximum of 2Kg/hr LPG demand. Figure 7 illustrates number cylinders in manifolds. Thus, the % of insufficient cylinders in apartments is 50% (i.e. 20 apartments) which leads to many operational issues such as cylinder sweating, flame fluctuations, yellow flames, pressure drops etc.

In some apartments, LPG consumption have been increased from its planed consumption after fixing. and the number of cylinders have not increased proportionally.

- **Pressure Drop during peak operations**

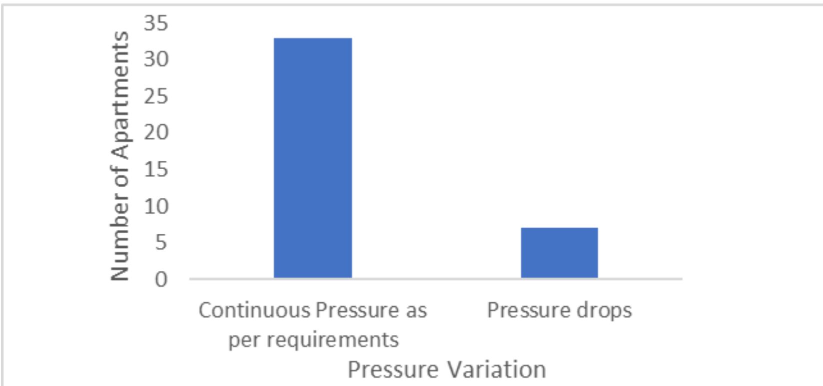


Figure 9: Pressure Drop in the system

Average operating pressure of domestic oven is .5psi. Due to design failures, 7 apartments out of 40 face pressure drop incidents between the peak hours. Long cooking cycle time, Burner switch off, High fuel consumption due to incomplete combustion are the consequences of this.

- **Flame fluctuations & yellow flames**

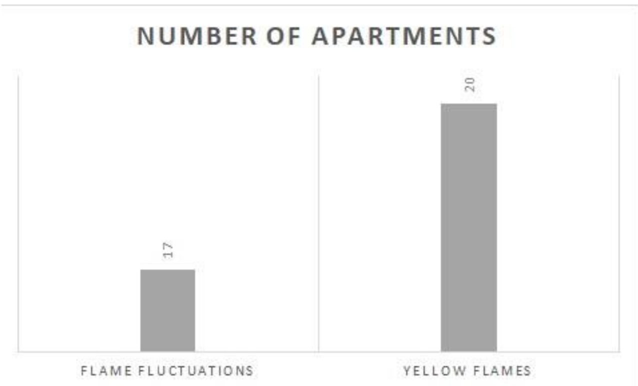
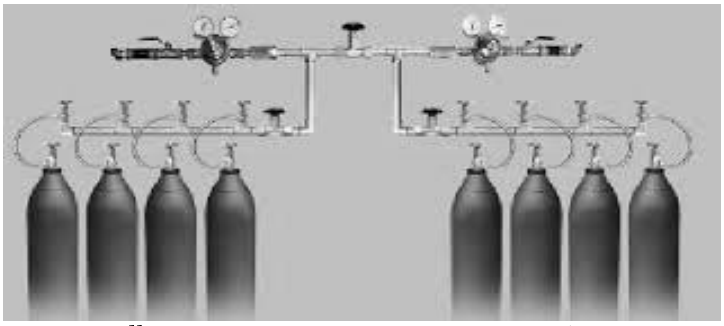


Figure 10: Uncontrolled flame conditions

Almost half of the households of apartments facing flame uncontrolled conditions (Figure 10). Yellow flame generates due to partial and this is caused by lower supply rate. This is also a consequence of design failure of manifolds. Under sized manifolds supply lower than the required rate of LPG demand. This can directly affect the cooking cycle time.As per the key findings of the survey the main issues of conventional LPG vapour withdrawal are summarized as higher area reservation for LPG storage and operations, limitations in consumption rate, high replacing frequency, cylinder sweating, LPG Left over cylinders, non-availability of liquid withdrawal facility, high rate of accessory damages, barriers to increase number of cylinders in the manifold, vulnerability for leaks in the system.

In most of the above observation Cylinder sweating was reported. As per expert field verification data, the maximum evaporation rate of 1 feet diameter cylinder for a tropical country like Sri Lanka is 2Kg/Hr. As per SLS 1196 part 2 (2000), the maximum LPG cylinder storage in capacity of a facility is 1000Kg's. To maintain this standard, maximum of 26 cylinders are recommended to install in a LPG supply system by keeping one stand by and one in operation



Standby In Operation

Figure 11: Standby & Operation cylinders

Maximum number of cylinders can install in the single side of the manifold is 13.
So the maximum vapour flow rate produce by a single manifold = Max. No. of Cylinders * Flow Rate (3)
Which equals to 26 Kg/Hr.
But as per observations of the survey, when the liquid level goes down in a cylinder the flow rate also goes down proportionally as given in figure 12 below.

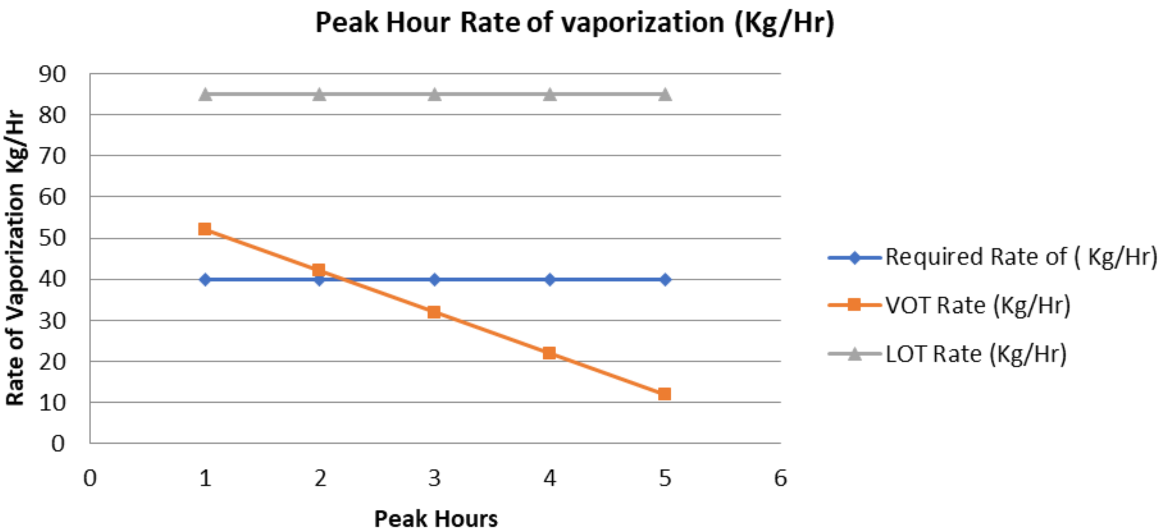


Figure 12: Rate of vaporization in peak hours

There is a requirement of a liquid offtake system which can produce the continuous rate of vapour demand. Another issue is that 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. This can create a barrier for heat transfer and leads to pressure fluctuation of the system.

Average area requirement for 13-cylinder manifold is 20.4 square meters. Due to high demand for lands in urban areas finding a considerable area for LPG supply system is a big challenge.

Proposed Liquid Withdrawal System

Liquid withdrawal system is an advance concept in multi cylinder installations which overcomes lots of demerits of conventional cylinder Manifold systems. 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. Liquid withdrawal systems are compact, safe & highly cost effective as liquid is completely drawn from the cylinder and there is no residual loss.

Liquid Off-take (LOT) LPG systems have become popular in apartment buildings 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.), convenient to handle, cost Effective, no loss on account of residue, requires lesser space etc.

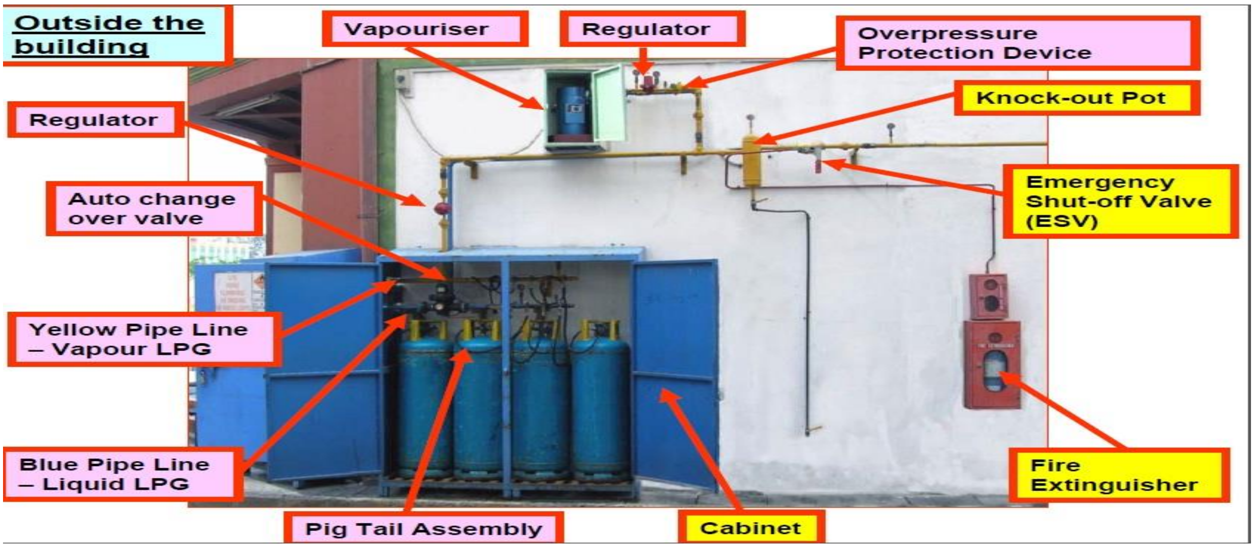


Figure 13: Typical Liquid Withdrawal LPG system

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

Figure 14: Liquid withdrawal manifold with Vaporizer

By addressing the issues of the conventional LPG vapour withdrawal systems, proposed liquid withdrawal cylinders have the advantages such as No sweating in cylinder surfaces, No pressure drops in the system, Continuous same flame conditions, Minimum intervention, No burner failures and specially less area requirement as given below.

Less space requirement for liquid withdrawal LPG supply system

a. Area Required for 13 cylinders 20.4 m2 (a)
b. Area required for 4 LOT cylinders for same demand 9.6 m2 (b)

Space utilization with the new liquid withdrawal facility (a – b)/ a * 100 (4)
equals to 53%.

Additional cost for vapourizer installation and electricity cost at the time of operation are identified as the demerits of proposed liquid withdrawal cylinder installations.

Summary of Safety Features of new Liquid Withdrawal Cylinder Manifolds are given in Table 2 below.

Table 2: Comparative advantages of LPG liquid withdrawal system

Issues of Conventional LPG Vapour Withdrawal System	Solutions From New LPG Liquid withdrawal System
1. Non Availability of Area for Operations and Expansions	Comparative less space requirement. High space utilization
2. Cylinder sweating During Operation	Only liquid withdraws from cylinder
3. LPG Supply and demand mismatch	Select the correct vaporizer capacity
4. Insufficient number of cylinders	Require less number of cylinders 13 reduce to 4 cylinders.
5. Pressure Variations	Set the required pressure after vaporizer
6. Yellow Flame	Blue flame due to efficient supply
7. Flame Fluctuations	Pressure control features of vapourizer out flow

Conclusion

As per the research findings, there are many practical issues in current apartment LPG installations. The major practical problems of present cylinder manifolds identified in the survey are; Higher area requirement for LPG supply facility, Limitations in consumption rate, High replacing frequency, Cylinder sweating, LPG Left over cylinders, Non availability of liquid withdrawal facility, High rate of accessory damages, Barriers to increase number of cylinders in the manifold and Vulnerability for leaks in the system. Theoretically there is a maximum limit of vapour supplied by natural vapourization which creates barriers to cater to peak demands of many apartments. There is a need for continuous steady vapour supply system like in a liquid withdrawal cylinder manifold system to minimize safety hazards in the existing conventional systems. It identified as a safer system than the conventional LPG supply system. In the same time the proposed system can be shown as a solution for limited space in apartments for storage of LPG cylinders.

When considering the urban demand for space, liquid withdrawal cylinder option that utilize small space gives the best solution to the apartments. The propose system requires approximately 9.6 m2 space to install 4 cylinders which is a has a capacity of 13 cylinders that utilize 20.4 m2 space, in the conventional gas withdrawal LPG systems. Thus, it reduces the utilization space by 53%. Thus, propose system could be a novel solution for future apartment developments in highly dense areas in Sri Lanka

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