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DOMESTIC EXPLOSION HAZARDS FROM SMALL LPG CONTAINERS

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Summary

LPG is likely to be present in many domestic premises, either as a fuel or as an aerosol propellant. This paper considers the potential hazards to life and property that may arise if the contents of small LPG containers should leak and subsequently ignite. A short programme of experimental explosions aimed at examining the problem is described.

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1. Introduction

When quantities of flammable gases are released and ignited inside buildings, the explosions that result can cause injuries, fatalities and damage to property (in extreme cases the complete destruction of the building involved).

Piped mains gas supplies account for the majority of the total number of domestic explosions reported ($\sim$200 per year) but a considerable number of domestic gas explosions arise from other cases, particularly portable appliances containing Liquified Petroleum Gases, (LPG). This paper reports the initial stages of an investigation to examine the hazards associated with the use and storage of LPG in domestic premises, with particular reference to small containers.

2. Background

Several factors, such as energy costs and the more widespread availability of LPG as fuel for heating appliances, home improvement and camping applications, as propellants in 'aerosol' containers and as a source of heat for other small domestic appliances has resulted in the presence in domestic dwellings of containers of LPG covering a wide range of sizes. Table 1 indicates the available range of appliances using LPG and the quantities involved.

TABLE 1

LPG Application in domestic dwellings

Application	Quantity (kg)
Portable space heating	5 –15
Portable cookers	0.1 – 5
Blowlamps	0.2 – 0.5
'Aerosols' and refill containers	0.02– 0.5
Cigarette lighters etc.	~0.005

2.1 Domestic LPG usage

The bulk of LPG used domestically is for space heating. However, substantial amounts enter domestic dwellings in small containers. Aerosols for household and personal use increasingly incorporate LPG as propellant, which can be between 20% and 95% of the contents. Some disposable fuel cartridges, used, for example, in blow torches and camping equipment, contain commercial butane. In addition, LPG is increasingly being used as a heat source in small domestic appliances e.g. cigarette lighters, hair curlers, irons etc., together with suitable containers for refilling purposes.

It should be noted that whereas containers of LPG intended for use as a fuel often bear warning labels marked with details of the contents and with warnings as to its flammable nature and safe usage, the same is not necessarily true of all aerosol products. Although such products also carry warning labels [1], in general, these have been found to be less explicit with regard to the contents. Those which contain less than 40% flammables may not carry any 'flammable' warning although at least one explosion is known to have resulted from the overheating of such a product (see incident 1). All aerosol products manufactured in the UK carry a general warning about safe storage and disposal of the cannister.

The flammable nature and the explosion hazard associated with the use and storage of LPG in industry is well known by those who are familiar with the product, but the same may not be true of domestic consumers. In view, therefore, of the increasing domestic use of LPG, it was considered that the hazards, particularly of explosions, arising from these products should be examined in more detail.

3. The current investigation

This investigation has been divided into three areas:

(1) a consideration of the manner in which LPG might leak from a container during use, or following misuse, accidental damage or rupture.

(2) an examination of available statistics to examine the pattern of occurrence of incidents and their effects, coupled with a sample study of actual incidents.
(3) measurement of the pressures generated in a sealed but vented compartment (i.e. one containing a panel which will break at a relatively low pressure and relieve the explosion) resulting from the ignition of small quantities of LPG released from ruptured containers.

Future work will be concerned with the hazards of LPG released by leakages from storage cylinders and associated appliances. The broader significance of LPG explosions for the structural stability of buildings is outside the scope of this paper, but is being addressed separately.

4. Mechanisms of leakage

The leakage of LPG from containers falls into the following general categories:

(i) relatively slow leakage from equipment using large containers, specifically arising from required manipulation of valves, joints, hoses etc. Such leakages may arise from the deterioration of equipment or from its maloperation and could be up to 2 m^3/h.
(ii) an uncontrollable leakage from camping and home improvement equipment which generally do not have protective devices and interlocks. In this case safety is much dependent upon correct manipulation and adequate engineering, e.g. the threaded connections on certain types of container have been known to shear off during replacement, due to overtightening of the new container. Corrosion may also increase the risk of leakage if the container is stored either for long periods or in a hostile environment. Leakages of this type may have rates several times greater than the leaks described in category (i) but would also tend to be of correspondingly shorter duration.
(iii) Instantaneous releases of the total contents from containers ruptured by mechanical damage or overheating. The latter can occur in a fire or if the container is placed close to a source of heat such as a fan heater, domestic fire or cooker.

5. Statistical evidence

Fire brigade attendance at fire and explosion incidents in the UK is always accompanied by the recording of important details from which the UK Fire Statistics are compiled by the Home Office.

Statistics for the three years 1982–1984 were studied [2–4]. A total of 297 individual fire brigade reports were examined, related to incidents in domestic dwellings in which LPG containers including aerosols were implicated. The totals for each year are shown in Table 2.

TABLE 2

LPG Incidents from UK fire statistics 1982–1984

	1982	1983	1984
LPG	92	84	75
Aerosol	13	15	18
TOTAL	105	99	93

Total for three years = 297.

TABLE 3

Reported causes of LPG leakage from containers, 1982–1984

Size of Container	Reported cause of leakage				
	Leak from fault in equipment e.g. valve	Human use or abuse	Overheating by fire or other means	Doubtful	Total
< 0.5 kg	21	74	33	13	141
0.5–5 kg	13	7	1	2	23
5–20 kg	35	17	3	7	62
> 20 kg	6	6	1	3	16
Unknown	—	—	—	—	55
	75	104	38	25	297

An examination of the distribution of incidents showed that incidence was higher in the spring and summer. Few explosions occurred between 0200 hours and 0800 hours, the majority of incidents occurring between 0800 and 2300 hours with a peak at 1500 hours. The explosions resulted in 188 casualties including 7 fatalities.

The size of container involved and the reported cause of the leak were both analysed, the results are shown in Table 3. In addition there were 55 incidents where the size of container was unrecorded.

From the information it has been possible to assess the extent of the damage sustained by the building in which the incidents occurred: the following criteria have been used:

(i) *Severe:* cracking displacement or other major damage to brick walls and major damage to solid partition walls.
(ii) *Moderate:* window breakage, damage to doors and light partitions.
(iii) *Slight:* minor damage to contents but none to the building.
(iv) *None:* no damage reported.

It should be noted that the fire brigade reports did not allow an assessment of the extent to which the structural integrity of the building had been threatened

TABLE 4

Distribution of the effects of reported explosion in buildings

Source	Effect	No
LPG	Severe	41
	Moderate	65
	Slight	86
	None	32
	Unknown	27
Aerosol	Severe	8
	Moderate	17
	Slight	20
	None	1
	Total	297

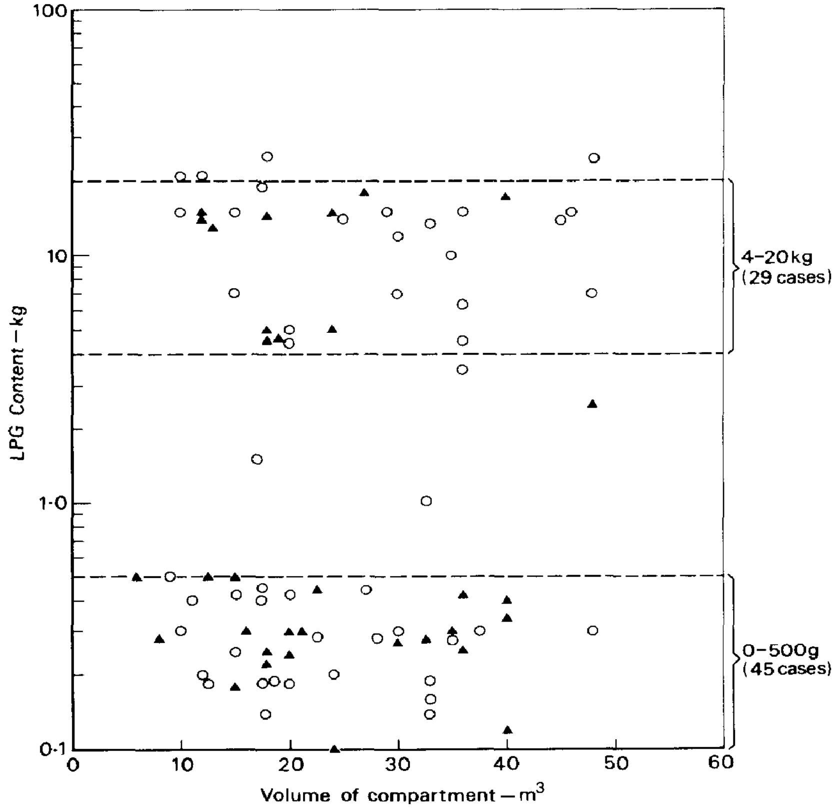

Fig. 1. The distribution of moderate (▲) and severe (○) explosion with respect to container capacity and volume of compartment.

by any incident. The distribution of the effects of explosions are shown in Table 4.

It was also possible to correlate container size and compartment volume with explosion severity as shown in Fig. 1. For moderate and severe damage it can be seen that most incidents involved either containers less than 0.5 kg capacity or in the range 4–20 kg capacity. It can also be seen that there is little apparent corelation between container size, volume of compartment and explosion severity except that damage resulting from leaks from large containers mainly occurred in rooms less than 25 m^3 in volume.

These apparent divisions may simply reflect the current availability of these products and their most common locations of use within domestic premises.

6. Investigation of incidents

In order to complement the statistical evidence, a series of domestic LPG explosions, which occurred during the period of this study, were examined in detail. All of the incidents occurred in the West Midlands Fire Service area and were examined by their Fire Investigation Team.

A total of six incidents were examined. All occurred over a period of five months during the investigation and involved small quantities of LPG (up to 200 g); all were aerosol products. Table 5 refers to the type of dwelling and room in which the incidents occurred. Table 6 lists the type of product involved, the estimated LPG content, the cause of the leak, the ignition source and the category of explosion as defined in Section 5. Table 7 summarises the extent of damage caused by each explosion.

TABLE 5

Details of buildings involved in explosion incidents

Incident No.	Dwelling type	Construction	Room of origin	Approx. volume of room m^3	Approx. window vent as % cross section	Vent* coefficient K
1	Flat (for elderly)	Modern, 2 storey	Bedroom	25	10%	10
2	House Semi-detached	Modern, timber framed, brick clad	Kitchen	25	20%	5
3	House Terraced	Pre 1920 brick No cavity	Bedroom	30	15%	7
4	Flat High-rise	17 Storey block	Lounge	35	90+%	1
5	House Terraced	Brick	Lounge	35	N/A	N/A
6	Shop Terraced	Brick	Shop	30	90+%	~1

N/A-Not available.
*Where K is defined as the ratio of the area of the wall containing the vent to the area of the vent itself.

TABLE 6

Products involved and explosion conditions

Incident No.	Product	Can volume ml	Estimated LPG content g	Cause of leakage of LPG	Ignition source	category* of explosion
1	Aerosol Air freshener	200	30	Overheating by small accidental fire	Fire in radio/ cassette recorder	Severe
2	Aerosol Paint spray	400	50	Overheating by gas cooker	Gas cooker	Severe
3	Aerosol Air freshener	300	150	Overheating by electrical fan heater	Fan heater	Severe
4	Aerosol Air freshener	200	180	Overheating by small accidental fire	Candle flame and small fire	Severe
5	Aerosol Hair spray	440	60	Can punctured with scissors	Gas fire	Moderate
6	Aerosol Air freshener	225	200	Fire	Fire	Severe

*As defined in Section 5.

TABLE 7

Damage to the building caused by LPG explosions

Damage to:	Incident Number					
	1	2	3	4	5	6
Contents	✓	✓	✓	✓	✓	✓
Window glass		✓	✓	✓	✓	✓
Window Frame		✓	✓	✓		✓
Doors/Door Frames	✓	✓				
Ceilings	✓	✓	✓	✓		
Roofs	✓					
Walls (Light Panels)		✓				
Walls, Solid internal cracked	✓					✓
Walls Internal major displacement	✓			✓		
Walls external cracked		✓	✓			✓
Walls external major displacement		✓	✓	✓		
Personal injury					* ✓	# ✓

*Hospitalisation with 30% Burns.
Fire service personnel hit by flying glass.
✓ Damage occurred.

It can be seen from Table 6 that in most instances the cause of the LPG release was overheating and in only one case was the vapour released by mechanical puncturing. The former may be considered as analogous to the BLEVE (Boiling Liquid Expanding Vapour Explosion) involving a sudden release of vapour followed by ignition of highly turbulent vapour/air mixture. The latter, involving a slower but still rapid release of vapour, produced the least damage to the building, but it is interesting to note that it also caused the only serious personal injury – to the person who punctured it.

In all cases the quantity of LPG involved was less than 200 grams and the smallest no more than 30 grams. In each case manufacturers claimed that the LPG gas involved was butane although this may have been a generic name for proprietary propellant mixtures containing butane and other LPG gases such as propane.

Because of the small number of incidents involved, no attempt was made to correlate the damage caused with important factors such as the amount of LPG and the size and ventilation characteristics of the room. However, the study provided clear evidence of the damage potential of explosion from small quantities of LPG in domestic premises. The buildings involved were of a wide range of ages and construction type and the rooms in which the explosions occurred contained windows with a range of sizes representing from 10% to over 90% of the total cross sectional area of the room (Vent coefficient, K, in the range 1–10 – see Section 7.2; eqn. (1)).

The damage to the building caused by the explosions ranged from breakage of windows to cracking and displacement of external walls including small areas of brickwork completely ejected (Table 7).

7. Experimental assessments

In order to simulate the most severe incidents, i.e. the BLEVE, a series of experiments were designed and undertaken. These were carried out, firstly in an open space and then in a vented compartment.

7.1 Open space experiments

Using several different sizes and types of aerosol and gas cartridge, experiments were carried out to qualitatively assess the severity of explosions produced under various conditions of heating and ignition. The heat sources used were: (i) A hot plate, (ii) A radiant bar fire, (iii) A hot air stream and (iv) A small wood fire.

The ignition sources were placed at various distances from the canister upto a maximum of 3 metres. The ignition sources used were: (i) An electrical spark, (ii) A small bunsen (naked) flame, (iii) A radiant bar fire and (iv) A small wood fire.

Measurement of the canister wall temperature showed that rupture occurred when that temperature of wall exceeded approximately 70 °C. Upon ignition, a fireball of up to 3 m diameter formed. The exact shape and size of the fireball depended on the size of container and the manner in which it burst and was therefore quite variable. As expected, the larger canisters tended to give larger fireballs.

If ignition occurred adjacent to the canister and within a few milliseconds of rupture the explosions were perceptibly more pronounced.

7.2 Explosions in a 22.5 m³ compartment

The investigation of incidents had shown that the BLEVE type of situation could lead to an explosion causing 'severe' damage (as defined earlier) from only a small quantity (<200 g) of LPG released from a container. Experiments were, therefore, carried out to determine the explosion pressures that could be achieved by this type of release and ignition in a room-sized compartment, volume 22.5 m^3.

Three product groups were investigated:

Group 1 Aerosol products for personal and household use carrying a 'flammable' contents warning, with LPG as propellant. The estimated full content of these canisters ranged from 100–180 g.

Group 2 Aerosol products for personal and household use not carrying a 'flammable' contents warning with LPG as propellant. Estimated LPG content was up to ~ 30 g.

Group 3 Disposable cartridges containing LPG as a fuel. These cartridges contained from 90–480 g of commercial butane.

A single canister was used in each experiment. Heating of the canister was achieved by either a small hot air blower or small wood fire and ignition obtained from one of the ignition sources described earlier, in most cases a second wood fire. Rupture of the canister normally occurred within five minutes. On most occasions the experiments were designed to give an ignition immediately after the canister burst, this being the expected worst case. However, the effects of changing the ignition position and of delayed ignitions were also investigated.

The area of relief vent incorporated in the compartment had a vent coefficient (K) of either 8 or 4, as defined by eqn. (1)

$$K = A_s / A_v \tag{1}$$

where A_s is the area of the wall incorporating the vent, and A_v is the vent area. The vent covers were constructed from 12 mm thick, medium density fibreboard, which has a bursting pressure similar to that of a single, 4 mm thick, glazed window of equivalent area.

7.2.1 Experiments with a Relief Vent Coefficient, $K=8$

For vent areas with $K=8$ (equivalent to 12.5% of the wall area), explosions could be categorised into four distinct types.

Type (A) The vent had a limited effect on the development of the explosion in that the maximum pressure was significantly greater than the vent bursting pressure. These explosions occurred with canisters containing more than 160 g of LPG.

Type (B) A less severe form of Type (A) in which the vent had a greater relieving effect although the explosion pressure still exceeded the vent bursting pressure.

Type (C) Pressure was limited to the value at which the vent ruptured. Explosions of this kind were therefore less severe, often involving those 'aerosols' containing a small quantity of LPG, or where ignition was delayed.

Type (D) Explosions which did not rupture the vent, a weaker form of Type (C).

A quantitative summary of the results is given in Table 8.

It can be seen from Table 8 that the general trend is for both P_{max} and P_{vent} to decrease in the order Type (A) > Type (B) > Type (C) and that there is a corresponding increase in the duration of the pressure peak.

Table 8 also shows that when the ignition source was remote from the bursting canister and hence ignition of the gas cloud delayed, a lower maximum pressure was attained but the total burning time increased.

Since previous work at FRS had shown that the bursting characteristics of the vent cover used in these experiments are reproducible for explosions initiated in quiescent gas–air mixtures, the observed trends must reflect the turbulent state of the dispersed gas at the moment of ignition. That is, immediate ignition of a highly turbulent mixture by an adjacent ignition source leads to

TABLE 8

Summary of explosion pressure resulting from the ignition of small amounts of LPG ($K=8$)

Explosion type	P_{max} kPa (psi)	P_{vent} kPa (psi)	Duration of pressure peak (ms)	Product group	Ignition location
Type (A)	20–43 (2.9–6.1)	12–14 (1.7–2.0)	70–200	1,3	Adjacent
Type (B)	11–19 (1.6–2.75)	10.5–12 (1.5–1.75)	150–300	1,3	Adjacent
Type (C)	7–10.5 (1–1.5)	7–10.5 (1–1.5)	> 500	1,2,3	Remote
Type (D)	< 3.5 (< 0.5)	–	–	1,2,3	Remote

TABLE 9

Summary of explosion pressures resulting from the ignition of small amounts of LPG ($K=4$)

Result	P_{max} kPa (psi)	P_{vent} kPa (psi)	Duration of pressure peak (ms)	Product group	Ignition location
Type (B)	11–16 (1.6–2.3)	7–11.3 (1–1.8)	120–200	1,2,3	Adjacent
Type (C)	3.5–12 (0.5–1.7)	3.5–11 (0.5–1.6)	120–280	1,2,3	Adjacent

higher rates of combustion, higher peak overpressures and shorter overall burning time. The maximum pressure obtained from a canister containing approximately 170 g of butane (i.e. similar size to the largest in the investigated incidents) was 28 kPa (4 psig). Remote ignition tends to a delay ignition allowing the level of turbulence to decay, thus giving rise to lower peak overpressures. Clearly it is not possible to rigourously control these factors in experiments which seek to simulate potential incidents and as a consequence the results mirror the range of explosion behaviour observed in reported incidents.

7.2.2 Experiments with a Relief Vent Coefficient, $K=4$

For vent areas with $K=4$ (equivalent to 25% of the wall area) explosion pressures were lower, as would be expected. Type (A) explosions were not experienced and all events were variations of either Type (B) or Type (C) events. (Remote ignition was not used). Explosions of both types were observed to occur from all poduct groups. The results are summarised in Table 9.

The results show that the ignition of small (<500 g) amounts of LPG can generate explosion pressures in the range 14–42 kPa (2–6 psi) inside a 22.5 m^3 compartment with vents in the range $K=4$ to 8 (typical of many domestic rooms).

8. Conclusions

1. An examination of UK fire statistics 1982–1984 has shown that approximately 100 LPG explosions are reported in domestic buildings in the UK each year. Over half of these involve small containers, where LPG content is below 500 g.
2. Visits to explosion incidents revealed that explosions involving aerosols containing LPG are capable of producing severe injury and a wide range of damage to buildings.

3. Experimental simulations of a particular type of incident (overheated-ruptured container) has shown that the ignition of LPG ejected from small disposable containers (LPG content <500 g) can result in explosion pressures in the range 14-42 kPa 2–6 psi in rooms of typical domestic size. These pressures are capable of causing damage to buildings, as demonstrated by the statistical evidence.

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