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HEALTH & SAFETY LABORATORY

The Behaviour of 'Bernzomatic' MAPP and Propane Cartridges When Exposed to Heat and Flame

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Science Group: **Hazard Reduction**

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EXECUTIVE SUMMARY

A number of concerns were raised by HSE following an application to store large quantities of MAPP gas in 450 g cartridges. The fire risk and mitigation control measures appear based on the assumption that cartridges of MAPP behaved in a similar way to propane and comparable to aerosols. It has been reported that MAPP can spontaneously detonate when heated. HSE therefore commissioned a programme of work, comprising a series of experiments on both single and multiple cartridges of MAPP and propane to establish the hazards.

Objectives

a) Determine if MAPP detonates on heating,

b) Develop an understanding of the failure temperature/pressure of cartridges under uniform and non-uniform heating.

c) Direct comparison of fireball diameters between LPG and MAPP cartridges,

d) Projection distances for ejected cartridges, and

e) Knowledge as to whether spontaneous failure of multiple cartridges is induced under fire engulfment.

Main Findings

Based on the evidence of the tests undertaken, it was concluded that:

a) MAPP gas contained within a ‘Bernzomatic’ cartridge does not detonate upon heating under the conditions of the tests carried out here.

b) When heated uniformly, cartridges vent at 80±2°C.

c) Similar MAPP and propane gas cartridges behave in the same way.

d) Intensely heated cartridges present an explosion hazard by a pressure burst failure.

e) The likelihood of explosion depends upon cartridge orientation.

f) Projection distances for ejected cartridges and fragments were a maximum of 13.9m and 26.4m respectively.

g) No fireballs were seen, but flame heights of 1-2 m are achievable from venting cartridges.

h) There was no evidence of induced or spontaneous failure of multiple cartridges.

Recommendations

There is the potential to extend the scope of this work to include:

- Multiple cartridge tests with increased confinement to ensure cartridges stay in close proximity to each other
- Scale up to several transport packs
- Cartridge systems other than Bernzomatic.
- Aerosols containing flammable propellants.

1 INTRODUCTION

A number of concerns were raised by HIDCI2G following an application for a warehouse occupier to store 48 tonnes of propane, including 9.5 tonnes of methyl acetylene-propadiene-propane mixture (MAPP gas) in 450 g cartridges. The company’s fire risk and mitigation control measures appear based on the assumption that the behaviour of cartridges of these gases is repeatable and comparable to aerosols containing propane. However, it has been reported (see Section 2) that Methyl Acetylene can spontaneously detonate when heated. HSE therefore has an urgent need to address this issue to establish the hazards of MAPP gas in storage.

Large-scale test data on the fire behaviour of such cartridges are not available. Consequently, HIDCI2G requested that HSL undertake a series of experiments on both single and multiple cartridges containing both gases to identify the hazards. The main objectives/deliverables of this work were to:

a) Determine if MAPP detonates on heating.

b) Develop an understanding of the failure temperature/pressure of cartridges under uniform and non-uniform heating.

c) Provide a comparison of fireball diameters with propane and MAPP cartridges.

d) Measure projection distances for ejected cartridges.

e) Determine if spontaneous failure of multiple cartridges can occur under fire engulfment.

f) Take a video record of all tests.

2 BACKGROUND INFORMATION

MAPP gas is a complex mixture, comprising mainly methyl acetylene (35 mol%), propadiene (27 mol%) and propane (18 mol%) with other trace stabilising compounds. Taken individually these first two components are considered flammable and reactive. The most important properties of these constituents are parameterised in Table 1.

Methyl acetylene (also known as propyne) is a flammable, colourless liquefied gas with a boiling point of –23.1°C and a freezing point of -101.5°C. It is self-reactive and can decompose explosively at 4.5 to 5.6 atmospheres pressure. It has the chemical structure $CH_3C{\equiv}CH$ [1].

Propadiene is also flammable with a critical temperature and pressure of 120°C and 54 bar. It is an isomer of propyne but is not acetylenic, containing instead, a carbon atom carrying two double bonds. Like propyne, it decomposes explosively when a hot-spot is created inside it. It has the chemical structure $CH_2{=}C{=}CH_2$ [2].

Table 1: Properties of MAPP gas constituents [3,4].

	Constituent Gas		
Property	Methyl Acetylene	Propadiene	Propane
Molecular weight	40	40	44
Boiling Point (°C)	-23.2	-34.5 to -32.0	-40
Melting Point (°C)	-102.7	-146 to –136	-190
Flammable limits (vol%)	1.7 to 11.7	1.7 – 12.0	2.1 to 9.5
Critical Temperature (°C)	127.8	120	96.8
Critical pressure (kPa)	5349	4417	4255
Vapour pressure (kPa)	517 (at 20°C)	873 (at 21.1°C)	853 (at 21.1°C)
Specific gravity (water = 1)	0.70 (at -50°C)	1.787	0.5853 (at -45°C)
Vapour density (air = 1)	1.4	1.4	1.55

Mixtures of methyl acetylene, propadiene and propane are produced as a C_3 fraction during steam cracking treatments of heavier hydrocarbons at oil refineries. Other trace stabilising compounds are then added to produce the commercially available MAPP.

Unlike acetylene, commercial MAPP is not distributed in pressurised cylinders, dissolved in acetone in a porous mass, but as complex mixtures stored in the liquid state in gas cylinders. Components added to stabilise the propyne-propadiene mixtures are typically C_3 and C_4 alkanes and alkenes. By changing the relative proportions of each component, a wide range of mixtures is produced. The levels of stability of these mixtures vary - a diagram given by Medard [2] and shown in Figure 1 explores this and gives a limit line for stability.

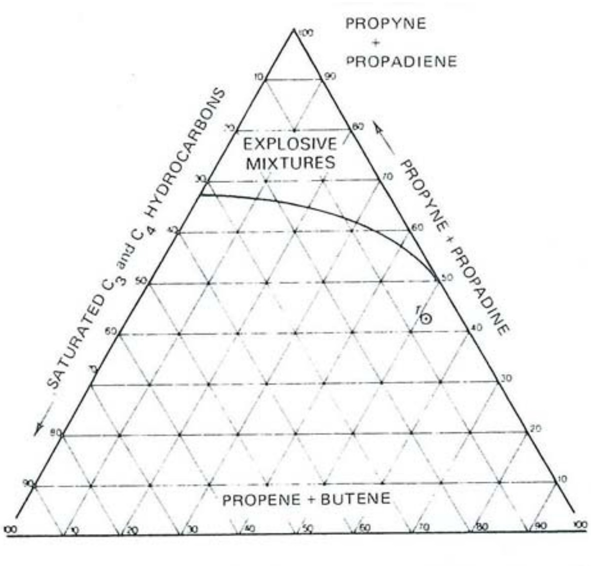

Figure 1: Stability diagram for MAPP, according to Medard.

An example MAPP gas composition given by Stull [5], is shown in Table 2, and includes some thermodynamic data. One of the principle uses for MAPP gas is for blowtorches or for welding, when used in conjunction with oxygen, as a safer alternative to acetylene. The flame temperature data highlight this, as MAPP provides a (lower) flame temperature close to that of acetylene, yet is significantly hotter than that of propane.

Table 2: Decomposition of MAPP gas.

Mole%	Gas	Heat decomp. $J.g^{-1}$	Flame Temp. K	Peak pressure $kPa.m^{-1}$
35.4	Methyl acetylene	-4628	1816	1236
27.4	Propadiene	-4791	1864	1266
0.7	1,3 – butadiene	-2213	1086	1043
1.5	Cyclopropane	-1958	936	831
3.3	Propylene	-1628	866	689
1.9	Iso-butane	-1331	800	760
18.0	Propane	-795	628	456
11.8	Iso-butane	-762	623	567
100	MAPP	-2259	1034	932
100	Ethylene	-2259	1005	1074

Evidence for the detonation of methyl acetylene is given by Bretherick [6] who states that the liquid material in cylinders is not shock sensitive, but a wall temperature of 95°C accompanied by pressures of about 3.5 bar, will cause a detonation to propagate from a hot-spot. Induced decomposition of the endothermic hydrocarbon leads to flame propagation in the absence of air above minimum pressures of 3.4 and 2.1 bar at 20 and 120°C, respectively.

Both Stull and Bretherick present the opinion that although pure methyl acetylene is highly endothermic (ΔH_f = +185.4 $kJ.mol^{-1}$) the diluted MAPP gas can be handled safely by treating it in the same way as ethylene.

Previous work has been undertaken at HSL on cartridges of MAPP gas. In 1984, flame impingement tests were conducted on several gas brazing and welding kits [7]. Of relevance here, one of the kits, under the 'Bernzomatic' trade name, comprised steel cylinders of oxygen and fuel. The cylinders were fitted with a pressure relief device and contained either 400g of propane or 450g of MAPP gas. Photographs in the report show that these cylinders are very similar to the cartridges tested in this work (see Section 3.2 for a description).

In these tests the flame from a torch (powered by MAPP/oxygen) impinged on the steel cylinder under test, held lightly upright. Tests were performed on single full MAPP cylinders with flame impingement below liquid level and on single almost empty cylinders, so that impingement was above liquid level.

A range of effects was observed including gas escaping from the pressure relief device and small jets of flame/gas released from the sidewall at the point of impingement. During testing, the cylinders bulged 4-16mm at the point of observed impingement. No cylinders were seen to fail.

3 EXPERIMENTAL

3.1 TEST PROGRAM

All tests involved heating either 400 g propane cartridges or 450 g MAPP cartridges with a propane flame until they burst. Tests performed were:

a) Non-uniform heating of single cylinders in a protective bunker with a diffuse flame, to establish if MAPP could be made to detonate on heating.

b) Uniform heating of single cylinders in a water bath to measure cylinder failure temperatures.

c) Repeat of a) using a pre-mixed flame from several burners to give more intense heating.

d) Heating single cylinders in the open air to study the projection distance of cylinders and fragments and fireball diameter/lift-off.

e) Heating multiple cylinders: 1 box (12 cartridges).

Multiple cylinder tests were intended to provide information on fireball diameter; projection distances and whether failure of one cylinder induced failure in neighbouring cylinders. All tests were repeated for both gas types to allow a qualitative comparison. Tests were recorded to videotape for subsequent review.

3.2 TEST CARTRIDGES

Cartridges for test were sourced from two suppliers. Two boxes of each gas were supplied by the company concerned, whilst a further two boxes of each were obtained from an independent supplier. Each box contained 12 cartridges of gas. Cartridges from both sources carried the 'Bernzomatic' trade name/branding. Cartridges of both gases appeared identical in construction but were readily identifiable/separable by their colour: yellow for MAPP and blue for propane. The cartridges were of pressed steel construction, in two parts with a central circumferential crimp or weld, and complied with the U.S. DOT 39 standard for non-refillable gas cylinders. The upper section of the cartridge contained the main filling or 'end use' valve and a pressure relief valve (PRV). A white plastic cap covered the main valve. Some measurements of the cylinders are given in Table 3 and example photographs of the cartridges are shown in Figure 2. Cartridges were labelled in compliance with DOT-39 with the following information:

- Bernzomatic Propane
  PW 16 PH 25 bar 0.4 kg 1.0 L .7 mm
  EN12205 0035/2005/11
  UN1978 Propane –20°C + 50 °C
  DOT-39 NRC228/286 M1003
  USA Chiltern SN W11E22E

- Bernzomatic MAPP
  PW 13 PH 22 bar 0.45 kg 1.0 L .7 mm
  EN12205 0035/2005/11
  UN1060 Methyl acetylene and propadiene mixture, stabilised –20°C + 50 °C
  DOT-39 NRC188/235 M1003-E6686
  USA Chiltern SN W11E55E

Where: PW is the normal service pressure, PH is pressure at which the PRV operates, 0.4/0.45 kg is the nominal weight of the contents and L is the wall thickness.

EN provides cylinder type/batch/manufacture date information.

UN is the United Nations designation for the article.

DOT-39 NRC gives the normal working pressure and test pressure (in psi). M is the manufacturers registration number.

The final line gives additional manufacturer information.

Table 3: Measurements of test cartridges.

Measurement	MAPP	Propane
Height to shoulder	250 mm	
Height to top	275 mm	
Diameter	75 mm	
Gross weight	900 g	850 g
Mass of gas	450 g	400 g

Figure 2: Photographs of the test cartridges.

3.3 TEST SERIES A, NON-UNIFORM HEATING, DIFFUSE FLAME

In this test series, single cartridges were placed horizontally on a stand, unclamped, and heated by the impingement of a diffuse flame from the open end of a propane hose. Figure 3 shows a schematic diagram of the test arrangement while Figure 4 shows a photograph of the apparatus. Tests were conducted in an enclosed bunker and the gas flow to the heating flame controlled remotely via a solenoid valve, with a small tray of solvent providing the ignition source (for convenience, this was later changed to a gas pilot flame). Cartridges containing both gas types were tested.

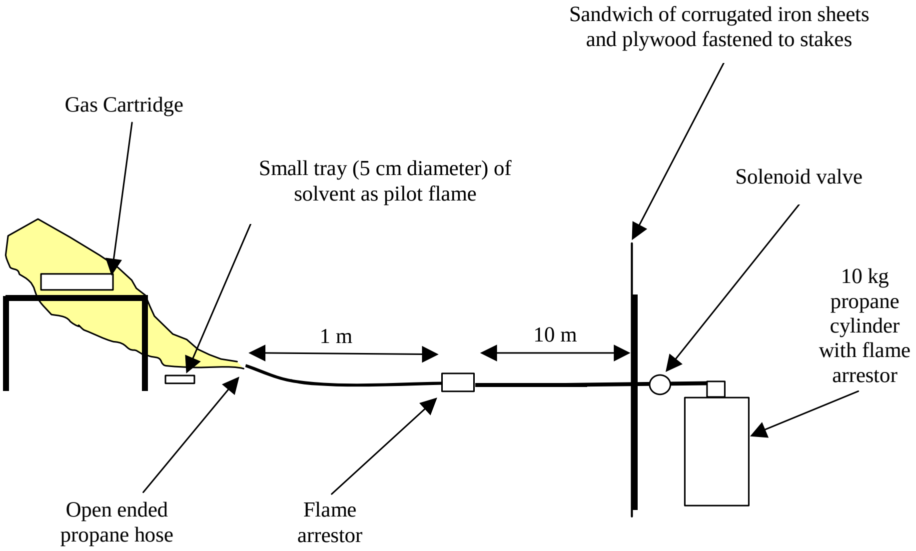

Figure 3: Schematic diagram of test apparatus for non-uniform heating - Test Series A.

Figure 4: Photographs of the set-up for Test Series A.

3.4 TEST SERIES B, UNIFORM HEATING IN A WATERBATH

In this test series, cartridges were heated using a water bath. The water bath comprised a steel tank with dimensions 425mm width x 740mm length x 295mm height, fitted with four electric heating elements with a power rating of 2.2 kW. The bath was filled with water to a depth of 200mm (approximately 60 litres).

Test cartridges were submerged under the water and held in a horizontal position by steel wire wrapped loosely around a retort stand. The water and cartridge temperatures were monitored using 1.5 mm diameter, stainless steel sheathed type K thermocouples. The latter was fixed to the cartridge body, positioned against the central seam, using steel wire. Temperature data were recorded to computer via a Microlink data logging system at one second intervals.

3.5 TEST SERIES C, NON-UNIFORM INTENSE HEATING, PRE-MIXED FLAME

The test apparatus used was as in Test Series A. However, for these tests, a twin burner arrangement was connected to the previously open-ended hose. This allowed for pre-mixing of the propane fuel with air producing a significantly hotter, bluer and more intense flame.

The burners were simply placed on the floor underneath the metal stand, approximately symmetric either side of the test cartridge and directed upwards, to impinge on to the central seam of the cartridge. Again, cartridges containing both gases were tested.

3.6 TEST SERIES D, SINGLE CYLINDERS IN THE OPEN

The burner system and stand used for Test Series B were modified to incorporate three burners instead of two, with the aim of giving a greater coverage of flame around the circumference of the test cartridges. Test cartridges were placed on the stand in either upright or inverted orientations, supported loosely by a retort ring and then heated rapidly by the burners, see Figure 5. In total, 12 cartridges of both gas types were tested with 6 in the upright and 6 in the inverted positions.

Figure 5: Burner assembly for Test Series D.

3.7 TEST SERIES E, MULTIPLE CYLINDERS, POOL FIRE

Complete boxes of cartridges were subjected to a pool fire for a sustained time period and observations recorded.

The test boxes were standard supply/transport cardboard cartons, as received from the supplier, containing 12 cartridges of gas in a 2 x 6, upright arrangement, see Figure 2. These boxes were placed on a stand in the centre of a steel tray with a base 1 m square and a wall height of approximately 300 mm. The tray was partially filled with 50 litres of n-heptane, to a depth of 50 mm and then ignited, remotely, using a hot wire ignition source.

The resulting pool fire lasted for approximately 10-20 minutes.

One box of MAPP cartridges was subjected to the first trial, E1, and one box of propane cartridges was used in the second trial. Both tests were recorded for subsequent review.

4 RESULTS

4.1 TEST SERIES A, NON-UNIFORM HEATING, DIFFUSE FLAME

Two MAPP cartridges and one propane cartridge were tested in this manner. The same behaviour was observed for all three cartridges:

After a short period of time, venting of gas was heard. The heating flame ignited this release and a large jet of flame was observed issuing from the top of the cartridge. Due to the relative orientation of the cartridge and video camera it was not possible to distinguish from which of the cartridge orifices the gas was being released. The venting/jetting continued until all gas in the cartridge had been consumed. No cartridges were seen to fail. It was noted that the flame from MAPP appeared hotter, more intense and yellower in colour compared to that from the propane flame, which was orange in appearance.

Due to a technical fault, no video footage of Test 1 was recorded. Masses of recovered cartridges were recorded. Some results are summarised in Table 4, while Figure 6 shows the recovered cartridges.

Table 4: Results of Test Series A, non-uniform heating, diffuse flame.

Test	Gas	Time to jetting, Duration of jetting	Mass After (g)	Observations
A1	MAPP	N/a	437.0	Cartridge remained intact and complete. Not bulged, contracted or cracked. Entire surface covered in black deposits.
A2	MAPP	2 mins, 3mins	438.7	As A1
A3	Propane	2 mins, 4 mins	436.5	As A1

Figure 6: Photograph of cartridges post Test Series A.

4.2 TEST SERIES B, UNIFORM HEATING IN A WATERBATH

Three tests were performed in total. The first test was discounted because an electrical fault caused a malfunction in three of the heating elements part way through the test, but some useful data were still obtained. In all three tests, gas was observed venting from the PRVs, which formed a fog/mist on the water surface. Venting was observed between 78 to 82°C and continue up to the point the water began to boil. Actual heating rates were calculated from the collected temperature data, see Table 5. The recovered cartridges were intact, but some of the labels were peeled back. Cartridges appeared to be slightly bulged below the central join. Vernier calliper measurements gave the diameter of each cartridge tested as 76 mm below the join and 75 mm above.

Table 5: Results of Test Series C, uniform heating in a waterbath.

Test	Gas type	Temperature for start of venting (°C)	Overall heating rate ($K.min^{-1}$)
B1	MAPP	79-81	1.3
B2	MAPP	82	1.8
B3	Propane	78-80	1.6

Figure 7: Photographs of cartridges post Test Series B.

4.3 TEST SERIES C, NON-UNIFORM INTENSE HEATING, PRE-MIXED FLAME

A total of five cartridges were tested, three MAPP and two propane. The observations recorded are given in Table 6. In summary, cartridges behaved in a similar manner to those in the previous Test Series A, with jetting from the top of the cylinder. In this instance, it was possible to identify from where the gas was venting and that the PRV had failed.

In these trials one cartridge failed catastrophically, with an audible bang, bursting into several large pieces. Three pieces were retrieved, one comprising the top section of the cartridge with the valves. Photographs of the test cartridges are shown in Figure 8.

Table 6: Results of Test Series C, non-uniform intense heating, premixed flame.

Test	Gas	Observations	Time to Venting (s)	Time to Explosion (s)
C1	MAPP	Gas released from cartridge PRV after a short period of heating. Visible as ignited jet. Subsequently, with further heating the cartridge failed.	28	56
C2	Propane	Gas released from cartridge PRV after a short period of heating. Visible as ignited jet.	35	N/a
C3	MAPP	As C2.	39	N/a
C4	Propane	As C2.	29	N/a
C5	MAPP	As C2.	34	N/a

Figure 8: Photographs of cartridges post test series C.

4.4 TEST SERIES D, SINGLE CYLINDERS IN THE OPEN

Following on from Test Series C, a further 24 cartridges were tested by exposure to an intense flame. The effect of cartridge orientation and retaining the white plastic cap or otherwise was examined. Initially, all cartridges behaved in a similar manner. As in previous tests, after a short period of heating, gas was released from the test cartridge PRV. This was visible as an ignited jet. Subsequently, with further heating, some cartridges were seen to fail with an audible bang and ejection of fragments, while other cartridges were either ejected from the test burner assembly or continued venting until the gas was exhausted. Details are given in Table 7, including the time to start of venting (or failure/explosion) and cartridge masses before and after testing. Additional data for tests where cartridges either exploded or were ejected are given in Table 8; this includes fragment projection distances.

Table 7: Results of Test Series D, intense heating of single cylinders in the open.

Test	Gas	Orientation	Cap	Observations	Time to venting (s)	Time to explosion or ejection (s)	Mass before (g)	Mass after (g)
D1	MAPP	Upright	Off	Venting	N/a	-	909.3	439.9
D2	MAPP	Upright	Off	Venting	N/a	-	900.7	439.2
D3	MAPP	Upright	Off	Venting	21	-	901.6	438.6
D4	MAPP	Upright	On	Venting	21	-	890.3	437.8
D5	MAPP	Upright	On	Venting	19	-	912.6	437.5
D6	MAPP	Upright	On	Venting	25	-	919.8	439.9
D7	MAPP	Inverted	Off	Vent then explosion	29	98	914.8	-
D8	MAPP	Inverted	Off	Venting	28	-	902.5	436.8
D9	MAPP	Inverted	Off	Vent then ejection	18	40	901.0	442.4
D10	MAPP	Inverted	On	Vent then ejection	21	33	912.8	441.9
D11	MAPP	Inverted	On	Venting	19	-	885.6	440.3
D12	MAPP	Inverted	On	Vent then explosion	20	57	906.2	-
D13	Propane	Inverted	Off	Venting	24	-	881.2	455.3
D14	Propane	Inverted	Off	Venting then explosion	22	54	849.8	-
D15	Propane	Inverted	Off	Venting	21	-	845.1	434.2
D16	Propane	Inverted	On	Venting then ejection	16	31	867.7	457.3
D17	Propane	Inverted	On	Venting then explosion	20	70	868.0	-
D18	Propane	Inverted	On	Venting	21	-	860.5	436.5
D19	Propane	Upright	Off	Venting	13	-	878.0	451.4
D20	Propane	Upright	Off	Venting	17	-	877.2	451.8
D21	Propane	Upright	Off	Venting	16	-	869.1	451.4
D22	Propane	Upright	On	Venting	15	-	863.6	447.4
D23	Propane	Upright	On	Venting	12	-	863.2	446.6
D24	Propane	Upright	On	Venting	16	-	871.3	440.7

Table 8: Additional data for failed or ejected cartridges from Test Series D.

Test	Effect	Fragment mass (g)	Distance (m)	Sound Level (dBa, LcpKmax)
D7	Exploded, into 3 pieces	382.9	5.2	155.9
		17.7	3.8	
		7.7	1.7	
D9	Ejected		7.5	
D10	Ejected		3.8	
D12	Exploded, into 3 pieces	344.0	1.0	144.7
		47.6	26.4	
		48.1	19.7	
D14	Exploded, 2 pieces recovered, valve assembly missing	222.3	13.0	153.4
		74.6	2.5	
D16	Ejected		13.9	
D17	Exploded, into 1 piece	398.0	1.0	153.4

Figure 9: Photographs of failed cartridges from Test Series D.

4.5 TEST SERIES E, MULTIPLE CYLINDERS, POOL FIRE

A timeline of observed events is given for the MAPP cartridge trial in Table 9 and for the propane cartridge in Table 10, with photographs of the retrieved cartridges in Figure 10 and Figure 11, respectively.

In the MAPP trial, a total of three cartridges failed explosively with one cartridge ejected from the fire. Retrieved cartridges were weighed and all those intact were found to be empty/spent. One cylinder and one large fragment were retrieved from outside the tray at distances of 3.7m and 2.4m respectively.

In the propane trial, a total of four cartridges failed explosively. No cartridges were ejected from the fire.

The average heptane fuel consumption rate was calculated as 3.5 ± 0.2 mm.min^{-1}.

Table 9: Timeline of events for Test E1, MAPP pool fire.

Time (Min:Second)	Observations
00:00	Fire started.
00:00 – 00:37	Cardboard box is consumed by fire and contents fall into metal tray.
00:55	First venting of gas heard.
01:00 onwards	Venting witnessed from cartridges as a jet of flame varying in height from 1 to 2 m.
01:33	Audible report from cartridge failure.
01:34	Audible report from cartridge failure.
08:45 – 09:02	More jetting increasing in intensity, culminating in explosive failure of a cartridge. At the same time a single cartridge or large fragment is ejected from the fire.
11:53	More jetting, decreasing in intensity
13:10	Pool fire extinguished

Table 10: Timeline of events for Test E2, propane pool fire.

Time (Min:Second)	Observations
00:00	Fire started.
00:30 – 0:39	Cardboard box is consumed by fire and contents fall into metal tray.
00:58	First jetting heard and seen.
01:43	Audible report from cartridge failure.
04:01	Audible report from cartridge failure.
11:39	Audible report from cartridge failure.
12:37	Audible report from cartridge failure.
15:00	Pool fire extinguished.

Figure 10: Photograph of retrieved cartridges from Test E1.

Figure 11: Photograph of retrieved cartridges from Test E2.

5 DISCUSSION

Test Series A and B provided an initial opportunity to assess the hazards posed by these cylinders when heated or exposed to flame. All cylinders behaved in a similar manner; i.e. venting after a short heating period. All cartridges remained intact, no detonation of contents was observed and it was considered viable to proceed with the subsequent intense heating test series. In early tests (Series A and B) the only observed difference between propane and MAPP was the colour of the jetting flame: orange for propane and (more) yellow for MAPP.

It was not possible to see the origin of venting in Test Series A and B, but in Test Series C it was evident that venting was occurring from the pressure relief valve, indicating either a PRV failure or deliberate operation/release due to elevated internal pressure. The first apparent difference in the behaviour of MAPP and propane was observed in this test series with one of the three MAPP cylinders tested failing (exploding), while neither of the two propane cartridges failed. From a review of the video footage it was noted that the failed cartridge had a lower PRV than all the other cartridges, possibly below the liquid level in the cartridge. This may have caused a cartridge failure due to a ‘liquid locked’ PRV or a PRV unable to control the rate of internal pressure rise due to passing liquid rather than gas. With the cartridges positioned horizontally, the PRV from the failed cartridge was at ‘2 o’clock’ compared to ‘12-1 o’clock’ for the other cartridges. In view of this and to give a wider understanding, Test Series D was conducted with more cartridges, orientated vertically, both upright and inverted.

The results from Test Series D confirmed a dependence of cartridge orientation on probability of cartridge failure but cartridges of propane and MAPP behaved in a similar manner. In these trials, two cartridges of each gas failed when in an inverted position, a failure rate of 33%, yet no cartridges failed when in an upright position.

Besides the failed cartridges, a number of cartridges were ejected from the test apparatus – two MAPP and one propane. These cartridges were self-propelled by venting gas and travelled distances of up to 13.9m. A good example of this is Test D16 where video footage shows the venting cartridge being propelled randomly around the test area, before leaving the view.

Failed cartridges comprised a single large section with two or three ejected fragments. Generally, the large section comprised both the base and top shoulder linked by the main body that was burst or split, typically of mass 200 to 400g. The ejected fragments typically weighed around 50g (measured range 7.7 to 74.6g) and were retrieved at distances up to 26.4m. The edges of the retrieved fragments were smooth indicating a pressure burst rather than a detonation. If the contents had detonated then it would be expected that many small fragments would be found with torn or jagged edges.

No fireballs were observed during testing. However, flame heights from venting cartridges were estimated at between 1 and 2 m in length.

Following on from Test Series D, the multiple cylinder pool fire trials (Series E) provided an opportunity to examine the behaviour of cartridges in a more realistic fire scenario[1]. As in Test Series D and previous tests, cartridges were observed to vent and several were seen to fail. Three MAPP and four propane cartridges failed, a failure probability of 25% and 33% respectively. Cartridges and fragments were again ejected and were retrieved at distances up to 3.7m from the fire. There was no mass explosion, and no evidence of induced or spontaneous cartridge failure, with cartridges venting and/or failing linearly in sequence, although in the E1

[1] While Test Series E gives a reasonable simulation of an engulfing fire, the intense heating from Series D can be likened to the scenario where the flame from a jetting cartridges impinges on to another neighbouring cartridge.

MAPP test there were two failure events in close succession (1s apart). In these tests, the cardboard box burned away early on in the test and cartridges fell away from each other into the fire pool. It is likely therefore that the cartridges would not be in close enough proximity to each other for an induced failure to occur.

6 CONCLUSIONS

Based on the evidence of the tests undertaken, it was concluded that:

a) MAPP gas contained within a 'Bernzomatic' cartridge does not detonate on heating, under the conditions of tests performed here.

b) When heated uniformly, cartridges vent at 80±2°C.

c) Similar MAPP and propane gas cartridges behave in the same way.

d) Intensely heated cartridges present an explosion hazard by a pressure burst failure.

e) The likelihood of explosion depends upon cartridge orientation.

f) Projection distances for ejected cartridges and fragments were a maximum of 13.9m and 26.4m respectively.

g) No fireballs were witnessed, but flame heights of 1-2 m are achievable from venting cartridges.

h) There was no evidence of induced or spontaneous failure of multiple cartridges.

7 FURTHER WORK

There is the potential to extend the scope of the tests carried out here:

- Multiple cartridge tests with increased confinement to ensure cartridges stay in close proximity to each other.
- Scale up to several transport packs.
- Cartridge systems other than Bernzomatic, including aerosols containing flammable propellants.

Further work could seek to expand upon the multiple cartridge tests performed here. Video footage showed the carton containing the cartridges disintegrating and the cartridges falling away from each other into the fire. Additional tests could be designed to prevent this happening, holding cartridges with increased confinement in close proximity to each other. Such a test would be better able to determine if a failed cartridge can induce failure in neighbouring cartridges. One method of increasing confinement would be to scale-up to include several transport packs, perhaps even to a pallet-sized scale.

This work has focused solely on the 'Bernzomatic' cartridge system. It could be extended to other similar systems, perhaps containing other gases, either fuel or oxygen. For example, aerosols are similar in design, incorporating a fuel gas (propane) used as a propellant confined in a thin walled steel canister. A comparative study between these and the Bernzomatic cartridges would confirm the validity of assuming these behave similarly for risk assessment purposes.

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