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Assessment of the safety features of adapted plastic fuel container spouts

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Research Report

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Assessment of the safety features of adapted plastic fuel container spouts

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Four commercially available fuel container anti-spill spout adapter devices were tested for their ability to prevent spillage by overfilling and if the fuel container was knocked onto its side. The devices were also tested for their ability to resist flashback and prevent internal explosions in petrol containers.

The key findings were:

- Only one of the four devices prevented spillage from over-filling and knocking over; this device has a normally closed push action valve. A study in the US has, however, observed instances of this design of valve failing by sticking in the open position.

- One of the devices prevented spillage from over-filling but created spillage when it was removed from the fuel can.

- Two of the devices did not prevent spillage from over-filling in the test.

- The three devices tested provided flashback resistance under the conditions tested. The fourth device, the push valve variant, was not tested for flashback resistance as the valve needs to be physically held open to allow pouring.

- The tests undertaken at HSL and the previous studies examined demonstrate that the devices do not eliminate all the risks involved in using petrol; care is still needed during use to avoid spillages and accidents.

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KEY MESSAGES

Four commercially available fuel container anti-spill spout adapter devices were tested for their ability to prevent spillage by overfilling and if the fuel container was knocked onto its side. The devices were also tested for their ability to resist flashback and prevent internal explosions in petrol containers. A video demonstration was carried out to highlight the volatility of petrol and the flammability of its vapour.

The key findings were:

- Only one of the four devices prevented spillage from over-filling and knocking over; this device has a normally closed push action valve. A study in the US has, however, observed instances of this design of valve failing by sticking in the open position.

- One of the devices prevented spillage from over-filling but created spillage when it was removed from the fuel can.

- Two of the devices did not prevent spillage from over-filling in the test.

- Three devices tested provided flashback resistance under the conditions tested. The fourth device, the push valve variant, was not tested for flashback resistance as the valve needs to be physically held open to allow pouring.

EXECUTIVE SUMMARY

Objective

In undertaking the consolidation of the existing petroleum legislation, including the Petroleum-Spirit (Plastic Containers) Regulations 1982, the Health and Safety Executive is considering including guidance on the use of fuel containers with spouts or spout adapters that prevent flashback. There are several types of adapted anti-spill spout devices on the market; HSE wishes to understand how these spouts may benefit user safety during use and in the event of petrol related accidents and any limitation of this type of device.

The purpose of the work was to:

- Test if the devices prevented spillage of petrol both during the filling of fuel tanks and if the fuel container was knocked over.
- Test the devices' resistance to flashback and their ability to prevent explosion within fuel containers.
- Provide discussion material of some of the mechanisms involved in petrol related accidents.
- Provide video demonstrations of the danger of misusing petrol to accelerate fires.

Main Findings

- Only one of the four devices prevented spillage from over-filling and knocking over; this device has a normally closed push action valve. A study in the US has, however, observed instances of this design of valve failing by sticking in the open position.
- One of the devices prevented spillage from over-filling but created spillage when it was removed from the fuel can.
- Two of the devices did not prevent spillage from over-filling in the test.
- Three devices tested provided flashback resistance under the conditions tested. The fourth device, the push valve variant, was not tested for flashback resistance as the valve needs to be physically held open to allow pouring.

Conclusion

These tests undertaken at HSL and the previous studies examined demonstrate that the devices do not eliminate all the risks involved in using petrol; care is still needed to avoid spillage and accidents

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1. INTRODUCTION

In undertaking the consolidation of the existing petroleum legislation, including the Petroleum-Spirit (Plastic Containers) Regulations 1982, the Health and Safety Executive is considering including guidance on the use of fuel containers with spouts or spout adapters that prevent flashback.

There are several types of adapted anti-spill spouts on the market as well as an adapter that is intended to convert a standard spout into an anti-spill spout. HSE wishes to know if the devices prevent spillage and offer resistance to flashbacks

HSE is intending to raise public awareness both of the risks associated with using petrol and the dangers of misusing it. Video demonstrations of the dangers of misusing petrol were also produced to aid in this awareness raising.

1.1 PETROL

Petrol, also known as petroleum and gasoline, is a multi-component, highly volatile alkane with a typical flash point, the lowest temperature at which it produces a flammable vapour, of -43^{o}C, and an auto-ignition point, the temperature at which the vapours will spontaneously ignite under normal conditions, of 280^{o}C. It is the vapour of petrol that is flammable when mixed with air. The proportion of petrol vapour to air required for it to be flammable is 1.4% - 7.6% volume for volume. This range is known as the 'explosive' or 'flammable' range; if the mixture is below this it is too lean to be flammable and if it is above this range it is too rich. In the process of burning a pool of petrol it is the vapour evaporating from the surface of liquid and mixing with the air that burns, not the liquid itself. If petrol vapour is allowed to build in the air to within the flammable range then an explosive atmosphere will be produced and a flash fire or explosion will occur if ignited. The explosion can range from a faint whooshing sound and fireball in open air to a blast with overpressures capable of damaging buildings in confined or congested spaces.

Petrol is a multi-component liquid and it is the more volatile components that evaporate first. Okamoto et al [1] discovered that if evaporation is allowed then the chemical composition of the petrol changes as components of greatest volatility are lost from the liquid. The remaining liquid is no longer petrol and, depending on how much evaporation has occurred, its properties, such as its flash point, will more closely resemble other less volatile hydrocarbons. For instance, if a sample of petrol is reduced to around 30% of its initial mass then its flash point will be similar to heptane at above 20^{o}C. This effect of petrol evaporating to a point where its characteristics change is often referred to as weathering.

1.2 ACCIDENTS INVOLVING PETROL

Using the author's experience of forensic fire investigation, as well as information supplied by HSE [2], many of the accidents involving petrol are due to its volatile nature; often when petrol is used as an accelerant to start fires or promote existing fires.

When petrol is poured or spilt, a flammable vapour and air mixture is produced that can accumulate and disperse away from the liquid. If this mixture contacts an ignition source it will ignite and the flame will flash back towards the petrol spill. An example of accidents occurring by this mechanism is where petrol has been decanted near a naked flame and the vapours have been ignited by the flame causing a fire.

1.3 EXPLOSIONS WITHIN PETROL CONTAINERS

The volatile nature of petrol means that when it is stored in a sealed container the vapour evaporating off the petrol into the air space of the container produces an atmosphere that is above the flammable limit and too rich to burn. In this circumstance if the lid to the container is removed and a flame is applied to the opening, the vapour at the mouth will burn as it mixes with air and the flame will continue to burn until there is not enough petrol vapour remaining to sustain it. In the cases of less volatile flammable liquids, the slower evaporation of the liquid may result in an atmosphere within the flammable range of that liquid being present inside the container. In this circumstance the application of the flame to the opening of the container would ignite the vapour inside it, resulting in an explosion within the container.

There have been several experimental studies into explosions of petrol within commercial fuel containers by the Bureau of Alcohol Firearms and Tobacco (ATF) [3], Hasselbring [4] and Stevick et al [5]. In these studies petrol was poured from containers onto naked flames in an attempt to observe the vapours flashing back and exploding within the containers. These studies were based in the United States (US) and used containers 7.85 litres and 18.93 litres in capacity, larger than the 5 litre containers common in the United Kingdom (UK). Hasselbring and Stevick et al both observed instances of flashback where the quantity of petrol in the container, whilst still being very small, equates to an atmosphere above the flammable limit and therefore theoretically too rich to explode. The reason for this could be due to some air being drawn into the container during pouring, either up the spout or via the vents in the containers used by Hasselbring. Another reason could be due to the common commercial practice of the oxygenation of petrol in the US; the presence of oxygen within the fuel means that less atmospheric oxygen is required to produce an explosive atmosphere.

All three of the studies carried out tests using evaporated or weathered petrol and found that much larger quantities of such liquids could result in flashback and explosion when poured onto a flame. In these instances, the explosions forced liquid out of the opening in a jet reminiscent of a flamethrower. The reason for this is that the evaporated petrol is less volatile than fresh petrol: the quantity of vapour produced by the liquid in the fuel container does not exceed the flammable limit, in some circumstances, such as cold weather.

Hasselbring and Stevick et al recreated their tests with flashback arresters; i.e. a gauze or mesh that restricts flame passage back into the container. A flashback arrester used at the mouth of the container prevented flashback and internal explosion.

2. METHODOLOGY

To understand any benefits to user safety that adapted spouts may offer over standard fuel container spouts, a series of tests was carried out. In order to provide discussion material on the mechanisms of accidents and to provide video footage showing the dangers of petrol, a demonstration was also designed.

2.1 TEST SUBJECT SELECTION

HSE requested that several commercially available adapted spouts and a spout adapter be subjected to comparison of their safety features with standard spouts. These were selected based on the different appearance and features of the devices. Samples of the devices were purchased with the exception of one, which is no longer in production.

Standard plastic 5 litre fuel containers (Figure 1) were purchased for the purpose of testing the devices that are designed to be used with these and as the baseline comparator.

Unleaded petrol was purchased from a local service station and stored in sealed 5 litre fuel containers for tests involving fresh petrol. As a safer alternative to evaporating petrol on site, and to allow for more predictable reactions, it was decided to use a hydrocarbon with a flash point similar to the ambient air temperature. At the point of testing, toluene had the closest flash point to the air temperature; therefore laboratory grade stocked toluene was used.

Tap water was used where possible as a low cost, safer alternative to petrol for tests that involved spillage without ignition.

2.2 SPOUT DESCRIPTIONS

Each of the adapted spouts and the spout adapter are very different in appearance, but have the common feature of a breather tube. The devices are referred to as Device A, B, C and D.

2.2.1 Standard Spout

The standard spout is the one that came with the standard green 5 litre fuel containers with a tall and rounded appearance. The spout is rigid plastic with a concertina section in the centre. The open end of the spout is ragged and uneven in diameter on many of the received examples. There is no rubber seal but the section of the spout that fits into the neck of the container is slightly tapered and slightly flexible. When not in use the container is designed to hold the spout between a tether on the lid and a hole on a flat section extending from the handle.

Figure 1 - Standard 5 litre fuel container

2.3 EXPERIMENTAL DESIGN

Two sets of tests were designed, one to compare the anti-spill features of the adapted spouts relative to standard spouts and another to determine if any of the spouts offer protection against flashback.

2.3.1 Anti-spill Testing

For these tests each adapted spout or adapter was attached to the same standard 5 litre fuel container, with the exception of Device A which only fits the container it was supplied with.

To determine how the spouts performed, they were separately tested for flow rate, over-fill prevention and accidental spill prevention (when a container is knocked over). All measurements taken were indicative only.

For the flow rate test, a volumetric flask was used to decant 2 litres of water into the fuel container. The time from commencement to stoppage of the flow of water from the fuel was measured with a stopwatch. The container was checked to determine if more than residual levels of water remained

For the over-filling testing, a volumetric flask was used to decant 2 litres of water into the fuel container. The spout of the container was then placed in the neck of a 1 litre conical flask (used as a substitute fuel tank) and the water poured into the flask until either the flow stopped or the flask over-filled (Figure 2).

For the accidental spillage test, a volumetric flask was used to decant 4 litres of water into the fuel container. With spout attached, the container was knocked onto its side and any spilled liquid was captured in a collection dish over the period of a minute, timed with a stopwatch.

Figure 2 - Over-filling test

2.3.2 Flashback Arresting Test Rig and Preliminary Scoping Tests

A test rig was built that allows a fuel container to be held securely and poured remotely at varying distances from the operator, who stands behind a protective screen (Figure 3). A mineral wool wick soaked in paraffin was placed into a fire tray under the fuel container and ignited. The container was then positioned so that the end of the spout was in contact with the flame as the contents were poured out. The results of the tests were recorded with a camcorder.

Using a standard spout, preliminary scoping tests were undertaken to find the quantity of petrol that resulted in flashback and explosion when poured onto a naked flame. 100 ml was used as a starting point, followed by 50 ml and then 5 ml. In each case no flashback occurred; the petrol poured out of the fuel container burnt uneventfully in the fire tray and the vapours within the container burnt gently at the neck of the spout when the container was returned to its non-pouring orientation. It was then decided to use 2.5 ml and decrease the quantity in 0.5 ml steps; no explosion occurred when 2.5 ml, 2 ml, 1 ml, or 0.5 ml was used. An explosion only occurred when 1.5 ml was used. The explosion produced a blue and yellow flame and was forceful enough to bounce the fuel container on the rig (Figure 4). No flames remained after the explosion and the wick was extinguished and displaced by the force of the explosion. The experiment was repeated with 1.5 ml of petrol and the result was replicated, therefore it was decided to use 1.5 ml of petrol to test the adapted spouts.

In order to determine the best way to replicate the ‘flame thrower effect’ of the ATF tests, using larger quantities of fluids, a scoping test was undertaken. Initially, 100 ml of toluene was placed into a fuel container with a standard spout and, using the rig, poured out onto the alight wick. An explosion occurred that was less forceful than in the tests using 1.5 ml of petrol, and resulted in a yellow flame and liquid being ejected from the spout (Figures 5 and 6). Due to the result, no further quantities were tried and 100 ml of toluene was chosen to test the adapted spouts.

Operator adjustable arm and protective shield. Arm support and fuel container clamp. Fire tray.

Figure 3 - Remote pouring rig

Figure 4 - Explosion with 1.5 ml petrol

Figure 5 - Start of explosion with 100 ml toluene

Figure 6 - Explosion of 100 ml of toluene as burning liquid is ejected from spout.

2.4 DEMONSTRATION DESIGN

A bund was constructed out of bricks, sand and stone chippings beneath the pouring point of the flashback test rig. The petrol container support arm was raised so that the fuel container was 1 m above the surface of the bund. A pilot flame consisting of a paraffin soaked wick was placed 1.5 m from the edge of the bund, around 1.7 m from the point at which the petrol was poured. Measurements of any draughts at the level of the bund were taken with a Kestrel 2000 anemometer and then 2 litres of petrol were poured from the fuel container onto the bund. The time taken for the vapours to be ignited by the pilot flame was recorded with a stopwatch. The demonstration was videoed from the front, side and above. The process was then repeated at two different air speeds, 0.69 m/s and 1 m/s, although the result was videoed from the front only.

3. RESULTS

3.1 STANDARD SPOUT

The test results for the standard spout are shown in Table 1.

Table 1 – Standard Spout Test results

Test	Result
Flow rate	2 litres emptied in 19 seconds
Over-filling	Flow slowed slightly on contact with water but still over-filled, flow continued on withdrawal of the spout from the flask
Knocking over	1 litre of water spilt in 1 minute
1.5ml petrol flashback	Explosion occurred
100ml toluene flashback	Explosion occurred

3.2 DEVICE A

The test results for Device A are shown in Table 2. User interaction is required to initiate flow of liquid from the device; therefore it was decided for safety reasons not to subject the device to flashback testing.

Table 2 Device A test results

Test	Result
Flow rate	2 litres emptied in 35 seconds
Over-filling	Flow stopped on contact with water, remained stopped on withdrawal of the spout from the flask, but continued if valve is held open
Knocking over	No spillage in 1 minute as valve is closed
1.5ml petrol flashback	Not tested
100ml toluene flashback	Not tested

3.3 DEVICE B

The test results for Device B are shown in Table 3.

Table 3 – Device B test results

Test	**Result**
Flow rate	2 litres emptied in 1 minute 11 seconds
Over-filling	Flow slowed significantly on contact with water but continued in slow pulses and the flask still over-filled. Flow continued on withdrawal of the spout from the flask
Knocking over	10 ml of water spilt in 1 minute
1.5ml petrol flashback	No explosion occurred
100ml toluene flashback	No explosion occurred

3.4 DEVICE C

The test results for Device C are shown in Table 4.

Table 4 – Device C test results

Test	**Result**
Flow rate	1.905 litres emptied in 35 second (see comment below)
Over-filling	Flow stopped on contact with water. Flow remained stopped on withdrawal of the spout from the flask
Knocking over	1 litre of water spilt in 1 minute
1.5ml petrol flashback	No explosion occurred
100ml toluene flashback	No explosion occurred

During the pouring tests it was noted that it was not possible to empty the container fully with the spout in place and some water remained in the spout and spilt onto the hands when the spout was removed. It was also noted that when the flow stoppage was activated by water contacting the breather tube opening, it was very difficult to reinstate flow. This is presumably because water has entered the tube but the tube's position on top of the spout and the upward bend of the tube within the container prevent the water draining freely out of the tube when it is withdrawn from the tank.

3.5 DEVICE D

The test results for Device D are shown in Table 5.

Table 5 – Test results for Device D

Test	**Result**
Flow rate	2 litres emptied in 31 seconds
Over-filling	Flow continued at varying reduced rates on contact with the water and the flask over-filled. Flow continued on withdrawal of the spout from the flask
Knocking over	0.75 litre of water spilt in 1 minute
1.5ml petrol flashback	No explosion occurred
100ml toluene flashback	No explosion occurred

3.6 DEMONSTRATION

The demonstrations were carried out in the HSL Burn Hall, a building designed for small-scale fires. On the day of the demonstrations the external wind speed and direction were not consistent throughout the day; therefore the resultant draughts inside the building were controlled with the use of large boards. The results are shown in Table 6 and Figures 7 to 10.

Table 6 Demonstration results

Internal Air Speed (m/s)	**Time to Ignition (seconds)**
0	20
0.69	12
1	6

4. CONCLUSIONS

Device A prevented spillage from overfilling and when the container with it fitted is knocked on its side. The push action valve on this device is the reason for this, although Stevick et al [5] observed instances of similarly designed spouts, not the specific one tested, jamming in the open position.

Device B does not stop the flow completely during filling when the liquid level reaches the end of the spout; the flow continues in a slow pulse. The spout only allowed 10ml of water to be spilt in a minute when the fuel container with it fitted was knocked over on its side.

Device C does stop the flow completely during filling as soon as liquid contacts the end of the spout. The spout allows a free flow of liquid when the fuel container with it fitted was knocked over on its side. During testing it was noted that resuming flow to fill another tank is difficult. Shaking the fuel container and spout was effective at restarting the flow, as was removing and reattaching the spout. Water was retained in the spout and spilt on to the hands whenever the spout was removed after use to pour water. A further issue is the fact that the spout does not allow the fuel container to be completely emptied.

Device D does not stop the flow completely during filling when the liquid level reaches the end of the spout. The speed at which the flow continues seems to be variable and ranges from a slow trickle to a reduced free flow. The adapter allows a free flow of liquid when the fuel container with it fitted was knocked over on its side.

It proved very difficult to produce a flashback that led to an explosion in a petrol container. The quantities of petrol that can be added to a container before the mixture becomes too rich are very small. The precise quantity depends on temperature and the loss of the more volatile components during handling. A quantity of 1.5 ml was effective in these tests; this indicates that there is negligible risk of an internal explosion during normal fill levels. Once a container has been filled it is generally not vulnerable to an internal explosion unless it has been completely emptied of liquid and partially drained of vapours.

The other cause of explosions featured in the US studies was evaporated or weathered petrol. In those studies the petrol was weathered rapidly in open containers or trays. Without conducting long duration experiments it is difficult to say how long it would take for petrol to weather to the same extent in sealed 5 litre fuel containers. It is possible that this could occur in a few months under the correct conditions. To provide a safer and more predictable result, 100 ml of toluene was used in the flashback testing as an alternative to evaporated petrol.

Device A spout was not flashback tested due to safety concerns related to the way the push valve works; for the container to be used to pour fuel outside of a fuel tank the valve has to be physically held open.

Devices A, B and C resisted flashback in the two conditions tested: 1.5 ml of fresh petrol and 100 ml of toluene poured onto a naked flame. The spouts prevented explosions in the tests; however, it should be borne in mind that petrol can be poured from a container without the spout attached.

Petrol is an inappropriate fuel to use as an accelerant due to its volatility and the explosive nature of the vapour. The demonstration of pouring petrol near a naked flame (Figures 7 to 10) highlights this danger; when there was very little airflow it took just 20 seconds for flammable vapours to reach the flame that was 1.5 metres away. When the demonstration was repeated in a 1 metre per second airflow it took just 6 seconds for the vapours to ignite. The increased airflow also increased the speed at which the flame travelled back to the pouring area, even though it was travelling against the airflow. These demonstrations took place when the air temperature was 4^{o}C; had the air temperature been higher the rate of evaporation would have increased and the timings would have changed.

4.1 OVERALL CONCLUSIONS

The overall conclusions are:

- Only one of the four devices prevented spillage from over-filling and knocking over; this device has a normally closed push action valve. A study in the US has, however, observed instances of this design of valve failing by sticking in the open position.

- One of the devices prevented spillage from over-filling but created spillage when it was removed from the fuel can.

- Two of the devices did not prevent spillage from over-filling in the test.

- Three devices tested provided flashback resistance under the conditions tested. The fourth device, the push valve variant, was not tested for flashback resistance as the valve needs to be physically held open to allow pouring.

These tests undertaken at HSL and the previous studies examined demonstrate that the devices do not eliminate all the risks involved in using petrol; care is still needed during use to avoid spillage and accidents.

Figure 7 – Demonstration of pouring petrol near a naked flame, note the flame is straight as there is no noticeable draught

Figure 8 - Vapours have ignited

Figure 9 - Flames travel across the vapour towards the source of pouring

Figure 10 - After 21 seconds from commencement of pouring, the petrol is now alight

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