CONTROLLING THE FIRE RISKS FROM COMPOSITE IBCS

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INTRODUCTION

The use of plastic and composite intermediate bulk containers (IBCs) for the storage of liquids has increased rapidly in recent years. They can have a number of advantages over traditional steel drums, in particular; resistance to corrosion, efficient space utilisation in storage and ease of reuse or recycling.

There have been a number of serious recent fires in the UK that started or spread as the direct result of the use plastic IBCs for combustible liquids. These incidents prompted an HSE research project to provide data to allow more reliable risk assessments for premises using IBCs for liquid storage (Reference). The main findings were that plastic IBCs are relatively easily ignited (e.g. by a match) and that very high rates of liquid loss then occur, so that IBCs may lose their contents in a few tens of seconds. This latter fact is of particular concern in storage areas where there are large stocks of liquids in sensitive areas with limited bunding capacity.

This paper reports results from the second phase of the HSE research project. The focus for most of this additional work has been to explore the potential for improvements in fire performance through developments in IBC design. Work has been undertaken in the following areas:

i) Reduced scale experiments to determine the behaviour of high density polythene when one side is in contact with various types of liquid and the other side is exposed to a closely controlled fire.
ii) Full scale tests on IBCs containing high flash point liquids (up to 196°C).
iii) Full scale experiments to determine the potential for internal explosions in the ullage to accelerate the rate of liquid loss in the event of fire.
iv) Full scale experiments on stacks of IBC to determine the effect of mechanical deformation on the rate of liquid loss.
v) Full scale tests to investigate the ignition resistance of IBCs with a range of IBC pallet designs.

REDUCED SCALE TESTS

The vast majority of plastic IBCs are made from high-density polythene (HDPE). This material has limited compatibility with organic solvents even at ambient temperatures. Observations made in the first phase of the HSE project suggested that there were very significant differences in the responses to fire of IBCs containing water, water miscible liquids such as alcohol and hydrocarbons. The conditions of fire exposure in large scale tests are relatively difficult to control and it would be prohibitively expensive to attempt to test a large number of different liquids at full scale. For this reason a reduced scale test was developed.

The system used is illustrated in Figure 1. Panels (400 mm × 400 mm) were cut from the sides of IBC HDPE receptacles. The top surface of each of the panels was exposed to various liquids at a moderate pressure (500 mmH_2O) which is characteristic of the hydrostatic pressure in IBCs. The lower surface was exposed to a well controlled propane flame. Note this type of test should be undertaken with caution if volatile liquid fuels are used.

Results are summarised in Table 1. Photographs of the remains of tests on water and diesel (flashpoint 72°C) are shown in Figure 2. Generally the time to failure decreased as the proportion of the molecule with an aliphatic or aromatic hydrocarbon character

Table 1. Summary of results from small scale tests

Liquid	Time to first failure (min:sec)	Mechanism of failure
Diesel (four tests)	1:12, 1:17, 1:18, 1:25	Large tear
Cooking oil	1:13	Large tear
Xylene	1:37	Large tear
Kerosene	1:48	Large tear
Cyclohexane	1:56	Large tear
Ethylene glycol phenyl ether	2:02	Large tear
2Ethyl-hexanol	2:14	Large tear
Cyclohexanone	2:18	Large tear
Isopropyl alcohol	2:55	Pitting
Trimethyl pentane	3:10	Large tear
Ethanol	3:35	Pitting
Ethylene glycol	3:39	Large tear
Butyl acetate	3:42	Large tear
Isopropyl acetate	3:53	Large tear
2 butanol	5:43	Pitting
Methanol	10:30*	Pitting
Water (two tests)	11:26, 11:27	Pitting

*It is possible that some leakage from pits occurred sooner than this but the rate of evaporation was too high to allow observable dripping.

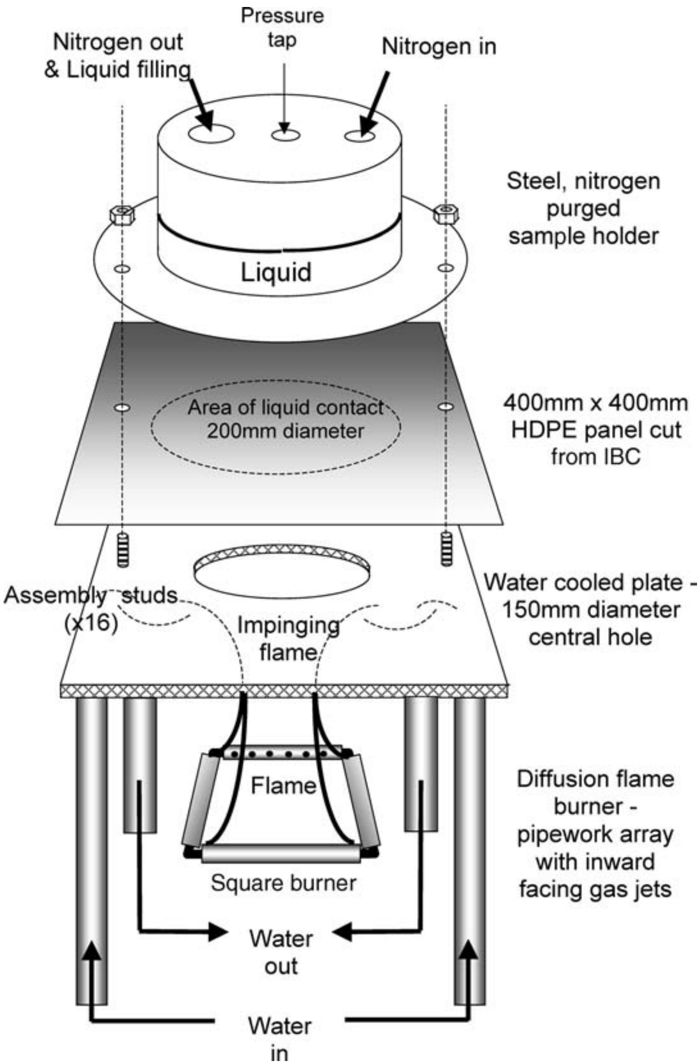

Figure 1. Reduced scale test for liquid/HDPE compatibility

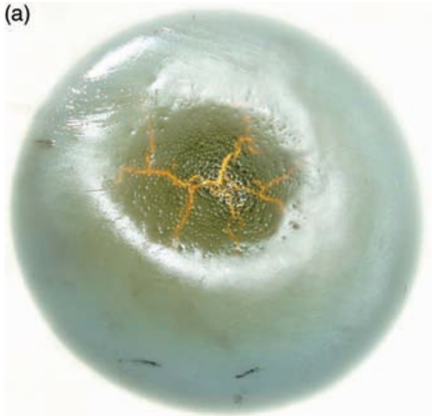

Figure 2. HDPE panel after water test (view from liquid side). The failure mechanism is pitting to produce holes a few hundred micron across. The characteristic leakage rate is of order 1 g/s

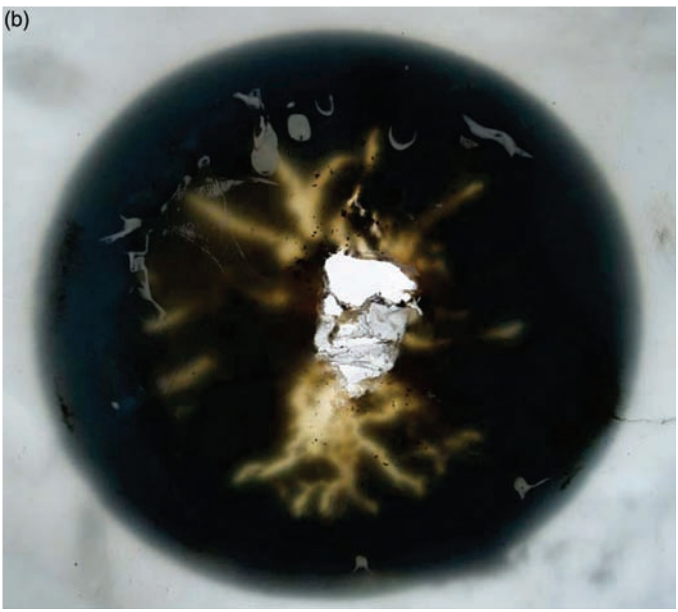

Figure 2. HDPE panel after diesel test (view from flame side). The failure mechanism is a large scale tear several centimetres across. The characteristic leakage rate is of order 100 g/s

increased. High molecular weight hydrocarbons (with the highest viscosities) had the lowest failure times of all.

The mechanism of failure and rate of liquid release also varied widely with the type of liquid. For hydrocarbons such as diesel there was a large scale tearing process that allows leakage at a rate of order 100 g/s. For water and low molecular weight alcohols the failure consists of a series of very small holes that apparently were stabilised by the liquid flow as soon as they opened up. The characteristic flow rate immediately after failure was around 1 g/s.

For practical reasons the panels used in these experiments were cut from a small number of IBCs. The wall thickness varied in the range 2.5 to 4 mm. This variation may explain some of the minor discrepancies in the data – for example the time for failure in the ethanol test was shorter than for IPA.

The results of these tests on the compatibility of HDPE with different liquids under fire conditions are summarised below:

Very good compatibility (extended time to failure, low leakage rates)
Water
Reasonable compatibility
Low molecular weight alcohols and glycols
Poor compatibility
Aliphatic Hydrocarbons e.g cyclohexane, heptanes, octanes
Aromatics e.g xylene
Very poor compatibility (rapid failure, catastrophic yielding of panels)
High viscosity oils e.g. diesel, cooking oil.

This type of test could be useful in developing plastics with improved fire resistance. In this case the wall thickness of test pieces would have to be carefully controlled. Fluorination treatments for the inner surface of IBCs are available to reduce the permeability of the HDPE wall to low molecular weight organic solvents. This type of treatment might be expected to improve the resistance to fire attack by reducing the potential for chemical attack on the inner wall, although cost may preclude this as an option for general risk reduction.

FULL SCALE TESTS ON IBCs CONTAINING HIGH FLASH POINT LIQUIDS

Tests on two industrial lubricants were carried out. These were mineral oil based products with flashpoints of 75°C and 196°C. In all cases ignition of exposed plastic elements around the valve or in the pallet led to complete involvement of the IBC contents.

Two distinct types of fire development were observed. The first type of fire is illustrated by the sequence of photographs in Figure 3. Ignition of plastic components produces a plastic fire that is sufficiently large to ignite the material that leaks out of the IBC. Fire then develops rapidly as the IBC loses its contents in a few tens of seconds.

The second type of fire development occurs if an inner HDPE receptacle fails at an early stage or the plastic fire is too small to trigger immediate ignition of the rapid spill of cold fluid. In this case liquid is lost from the IBC over a period of several minutes. During this time the burning of exposed plastic components continues. When the flow of cold oil

Figure 3. Fire in an IBC containing an industrial lubricant (flashpoint 75°C)
a. Ignition of plastic pallet.
b. The initial leak of lubricant is immediately ignited by plastic fire.
c. Rapid leakage (>10 kg/s) occurs as the fire develops.

slackens the temperature rise produced by the plastic fire increases and eventually the oil is ignited. If unchecked this fire spreads out at an accelerating rate over what might be a very large area affected by the spill. This sequence is illustrated in Figure 4.

Other IBCs affected by the spreading fire will leak very rapidly and it is likely that their contents will become involved almost immediately.

The significance of these findings is that a range of high flashpoint liquids in IBCs are vulnerable to by very small ignition sources and the result of ignition is likely to be total loss. The level of risk can be reduced by limiting the amount of exposed plastic in the valve, pallet, corner protection etc. that is capable of burning for an extended period and igniting the IBC contents.

If stocks of high flashpoint liquids are protected by sprinkler or detection systems the design of the systems should allow for the possibility that a thousand litres of liquid or more may have been spilled and spread over a large area before any significant heat or smoke is released.

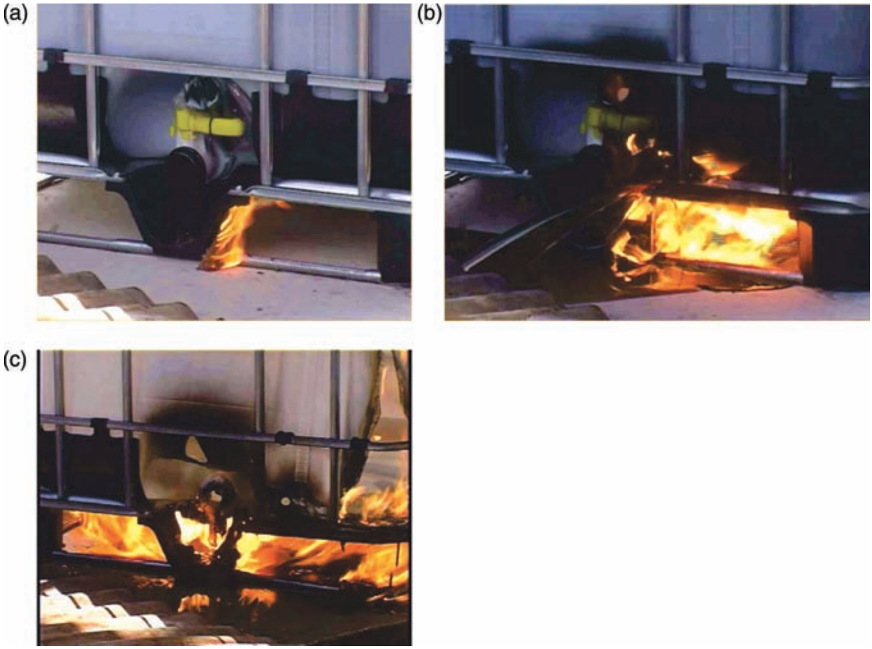

Figure 4. Fire in an IBC containing an industrial lubricant (flashpoint 196°C)
a. Ignition of plastic components in the pallet.
b. The initial leak of lubricant (~1 kg/s) is not immediately ignited by plastic fire and a large spreading pool of unignited oil develops.
c. After around 5 minutes outflow from the IBC starts to slackens and the continuing plastic fire ignites the pool. A very large fire then develops rapidly.

INTERNAL EXPLOSIONS

The Schutz SX-EX IBC has light-weight metal panels that surround the inner plastic receptacle. This design eliminates the possibility of charging of the outer surface by brushed contacts. A series of HSE tests on IPA showed that the metal cladding also reduced the rate of leakage of liquid in the event of fire (Reference).

This improvement in fire performance was observed despite explosions in the ullage of the IBC – which are the norm in IBC fires.

Unfortunately tests using diesel did not give such encouraging results. In all cases an explosion occurred in the ullage after a few minutes of fire exposure. By this stage parts of the metal support cage had been heated to the point where the overpressures generated in the explosion produced large deformations of the cage. Joints between the metal facing panels opened up leading to rapid loss of contents.

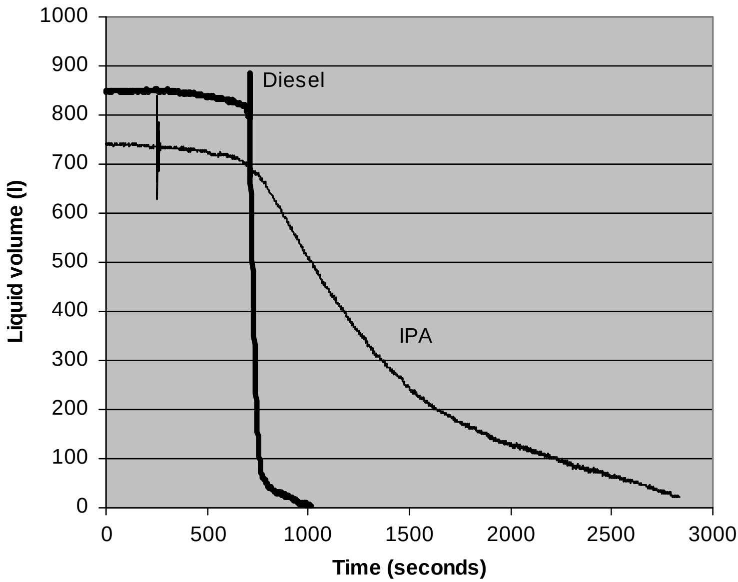

Figure 5. Leakage of metal clad IBCs containing Diesel and IPA. The oscillations in measured volume correspond to explosions in the ullage of the IBCs

The differences in characteristic behaviour in the IPA and diesel tests are illustrated in Figure 5. The explosion in the ullage is registered as a rapid oscillation in load cell output. In the IPA test the small rate of mass loss is unaffected and the IBC subsequently takes at over 1000 seconds to empty. In the diesel test the explosion causes a major breach in the inner receptacle and metal cladding panels and the IBC empties in tens of seconds.

This type of failure could be prevented by removing the metal cladding from the top of the IBC. This top panel is not needed for static protection if the IBC is to be used for a relatively high flashpoint materials such as diesel or if the inner receptacle was made from a conductive plastic. The effectiveness of the metal shielding panels on the sides of the IBC in limiting liquid loss rates would also greatly improved if the cladding was made in a single piece rather than as four separate panels.

An important design criterion for IBCs that will not discharge their contents rapidly is that the improved fire performance should be maintained in the case of internal explosions.

STACK TESTS

IBCs are typically stacked two or three levels high. Any new design that allows crushing of IBCs in the lower levels when weakened by fire attack and or toppling of IBC in the upper levels will be of limited use in reducing the potential for rapid liquid leakage.

Table 2. Conditions in stack tests

Contents of upper IBC	Contents of lower IBC	Approximate size of engulfing fire (MW)
1000 litres water	800 litres cyclohexane	5
970 kg bricks	800 litres water	10
800 litres water	800 litres water	20
850 litres water	800 litres water	40

Four separate tests have been carried out on two-high stacks of Schutz SX-EX (metal clad) IBCs exposed to large engulfing fires. The experimental conditions in these tests are summarised in Table 2. Measurements of steel temperature were made by inserting thermocouples into the interior of the tubes making up the support cage.

In three of the tests both IBCs contained liquids. In these cases total collapse of the lower IBC was not observed. A typical sequence was the following:

- Steel temperatures initially increased rapidly to 800–900°C.
- The strength reduction caused incipient yielding (buckling) of the upper part of the steel cage in the lower IBC.
- This distortion caused spillage from the top of the lower IBC which cooled and strengthened the steelwork with which it came into contact. The yielding was arrested.
- Continued fire exposure caused leakage from the top IBC. In the SX-EX this liquid typically drains out in a distributed way, around the perimeter of the upper pallet,

Figure 6. Damage to a stack of metal clad water filled IBCs during fire engulfment. Separation of metal cladding sheets is visible in lower (closeup) view

and is therefore effective in cooling and strengthening a significant proportion of steelwork in the lower IBC.

- Further yielding is prevented.

An example of the final level of damage is shown in Figure 6.

In one test the liquid load in the top IBC was replaced by an equivalent mass of bricks. In this case the initial buckling was arrested by liquid release from the lower IBC. However, in this case, when the rapid flow from the lower IBC slackened there was no compensating flow from leakage of the top IBC. After roughly 40 seconds yielding resumed and the lower IBC failed completely (Figure 7).

Notwithstanding the resistance to complete collapse, most of the liquid was lost from both IBCs during a 15 minute period of fire engulfment – even when the liquid in both IBCs was water. More rapid leakage might be expected if the IBCs had contained more aggressive liquids such as oils. Whilst the use of SX-EX IBC represents a significant improvement over unclad IBCs, very high overall leakage rates are still possible.

An important design criterion for IBCs that will not discharge their contents rapidly in fires is that the improved fire resistance should be maintained in the upper and lower levels of stacks.

IGNITION RESISTANCE OF IBC WITH DIFFERENT PALLET DESIGNS

A number of full-scale tests have been carried out with different plastic, metal and composite pallets to investigate the ignition resistance to small fires under the pallet. The ignition sources used in the tests were small pieces of mineral wool soaked in a combustible liquids. The flame height of the ignition sources in the open was in the range 100–200 mm. Examples are shown in Figures 8 and 9. The following results emerged:

1. Small fires near the edge of the pallet that impinged on an exposed inner receptacle caused failure of the receptacle wall in a few minutes if the IBC contained an aggressive liquid – Figure 8. This type of failure is clearly not strongly dependent on the pallet type.
2. All of the plastic pallets tested were rapidly ignited by small fires.
3. Surprisingly even IBCs which had metal pallets and metal clad sides (such as the Schutz SX-EX) proved vulnerable to ignition by very small fires beneath the pallet – Figure 9. The metal sheet that supports the base of the IBC in most metal pallets is pressed into folds during manufacture to increase its stiffness – Figure 10. The mechanism of failure during exposure to a small fire under the pallet appears to involve yielding of areas of the base of the IBC inner receptacle above folds in the IBC base. A possible failure mechanism is illustrated in Figure 11.

The relationship between the folding of metal pallets and ignition resistance deserves more systematic investigation. It is possible that changes to the size, shape and location of the folds could significantly improve the level of ignition resistance.

Figure 7. Crushing of lower (water filled) IBC by an upper IBC loaded with bricks (970 kg) during fire engulfment Above – extent of initial (arrested) yielding. Below – extent of damage following final uncontrolled collapse

Figure 8. Small fire at the edge of the pallet of an IBC containing a mineral oil lubricant. Early failure occurs where flames impinge on the inner receptacle

Figure 9. A small fire under of the pallet of a metal clad IBC containing a mineral oil lubricant. Failure of the base of the inner receptacle occurs even though this is protected by the folded metal sheet forming the top of the pallet

Figure 10. The top of a metal pallet – formed into folds to increase stiffness

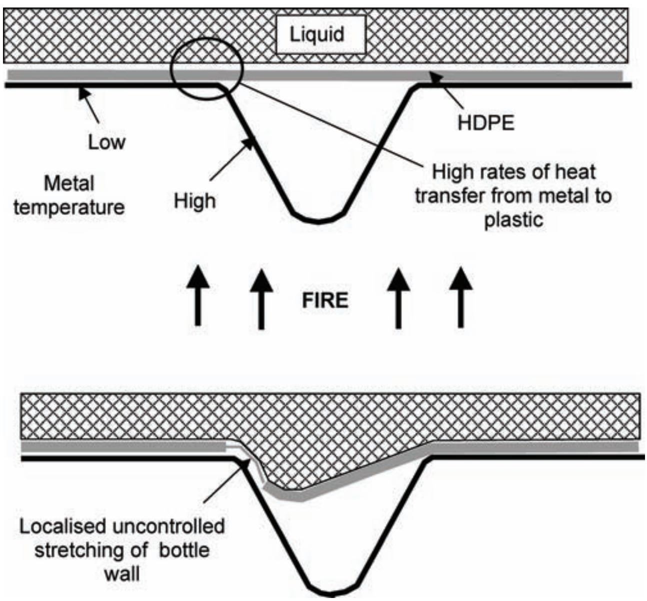

Figure 11. Possible mechanism of failure of HDPE inner receptacle caused by a fire under an IBC with a formed metal pallet

It is possible that drainage holes (that are typically drilled in the lower part of folds) may influence failure in some cases but it was observed that failure of the base of the inner receptacle occurred even if drainage holes were blocked.

CONCLUSIONS

1. A reduced scale method of studying the interaction between plastic panels from IBCs and different liquids under fire conditions has been developed.
2. IBCs containing liquids with a hydrocarbon character e.g. fuel oils, edible oils, lubricants etc. fail very much more quickly in fires than those containing water. The leakage rate on failure is also very much larger.
3. Plastic components of IBCs i.e. valves, corner protection, plastic pallets etc. are easily ignited e.g. by a match. In a programme of more than 20 full scale tests the resulting fire initiated combustion and total loss of contents in all but one case. Even IBCs containing high flashpoint liquids (up to at least FP 200°C) give severe pool fires involving all of the contents.
4. Metal cladding of the sort currently used for static protection of Schutz IBCs can reduce drainage rates. However very rapid leakage of liquid may still occur following explosions in the ullage.
5. Two-high stacks of metal clad plastic IBCs containing water did not collapse during severe fire engulfment tests. This was as a result of the cooling effect of leaks.
6. Unless composite IBC design can be improved to reduce the rate of liquid drainage in fires, the potential consequences of fires will continue to be very serious. Operators of sites with large stocks of IBCs should consider the pattern of drainage in the event of fire. If the amount of liquid is substantial and there are sensitive targets nearby, bunding of storage areas may be required.
7. IBCs and steel drums should be segregated wherever possible. This is to reduce the risk of the rapid onset of pressurised drum failure in a pool fire. The fireball caused by such bursts make fire fighting operations difficult and hazardous. Burning drums can also be projected significant distances and present a risk of spreading the fire.

REFERENCE

Atkinson, G. and Riley, N., 2004, Fire hazards of plastic IBCs containing flammable or combustible liquids, Hazards XVIII Conference.