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Fire performance of composite IBCs

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Fire performance of composite IBCs

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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. Following HSE investigations at the scene of these fires, a research project has been undertaken to provide data to allow more reliable risk assessments for premises using IBCs for liquid storage and to provide a stimulus and direction for change in IBC selection and design.

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EXECUTIVE SUMMARY

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. Following HSE investigations at the scene of these fires, a research project has been undertaken to provide data to allow more reliable risk assessments for premises using IBCs for liquid storage and to provide a stimulus and direction for change in IBC selection and design.

Main findings

Some basic data has been obtained to allow assessment of the rate of liquid drainage during IBC fires. The tests show clearly that **all of the liquid** in a stock of unclad IBCs on level ground is likely to be released in a period of order 5-10 minutes. This is in line with the video records of incidents such as the Distillex fire in North Shields.

Combustible liquids stored in IBCs can produce spreading pool fires in exactly the same way as flammable liquids.

A reduced scale method of studying the interaction between plastic panels from IBCs and different liquids under fire conditions has been developed. This may be of use in developing and testing improved IBC designs and materials.

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.

Plastic components of IBCs i.e. valves, corner protection, plastic pallets etc. are easily ignited e.g. by a match. In a programme of around 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 ^{o}C) give severe pool fires involving all of the contents.

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.

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.

Explosions in the ullage of IBC during the earliest stages of a fire can result in the ejection of finely dispersed burning liquid. Such events would seriously endanger the life of anyone attempting to extinguish the fire.

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.

Sufficient evidence has been gathered in this project to encourage the use of partitions to check the spread of fire through an IBC storage area. Any significant reduction in the rate of fire spread gives fire fighters a better chance control the incident.

Fire modelling has proved useful in exploring the extent to which partitions can prevent fire spread but some more effort is required to develop design guidelines that HSE can recommend with confidence.

If fire spread is to be prevented in the long term without intervention by fire fighters, the spread of pool fires around the seat of the fire must be controlled. This could be done using slopes, kerbs and drains.

Whilst IBCs are very vulnerable to even small flaming ignition sources, the experience gained in this project suggests that they are reasonably resistant to quite high levels of thermal radiation. The guidance given on minimum separation distances to buildings and boundaries given in HSG 51 “The storage of flammable liquids in containers” could be taken over to IBCs – although the guidance currently assumes storage in steel drums.

Recommendations

Risk assessments for IBC storage areas or buildings should be based on the premise that liquid loss will be rapid and complete. Details of what is required in a risk assessment are given in Appendix 1.

The risk assessment should cover the interaction between IBCs and steel drums – see Appendix 1. It is good practice to segregate IBCs and drums to avoid rapid onset of catastrophic failure of drums and associated fireballs and projectiles. For some sites this segregation will be essential.

A risk assessment (Appendix 1) is required for areas or buildings that contain any combustible liquids in IBCs or plastic drums with flashpoints up to at least 200^{o}C.

Manufacturers and reconditioners should provide clear information on the potential behaviour of IBCs in fire when the containers are supplied.

Kerbs and partitions in storage areas may be useful in checking the flow of liquid and spread of fire. For partitions to be effective, the drainage of storage areas must be carefully controlled to limit the extent of pools of burning liquid that may accumulate during a fire.

All processes introducing a risk of ignition e.g. hot work, transfers of volatile solvents etc should be eliminated or tightly controlled in storage areas. Strict control of readily ignitable material e.g. dry vegetation and rubbish in and around IBC storage areas is also required. IBC storage areas should be secure to deter casual vandalism.

Manufacturers should explore the potential for improvements in design. The resistance to ignition by small fires around the valve or under the pallet could be improved. Redesigned metal cladding systems or internal surface treatments could reduce the risk of very rapid liquid loss during a developing fire. In the longer term standard tests to validate these improvements are needed.

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 large and there are sensitive targets nearby, substantial bunding of storage areas may be required.

1 INTRODUCTION

The use of plastic and composite intermediate bulk containers (IBCs) for the storage of liquids has increased rapidly during the last 10 years. They have a number of advantages over traditional steel drums, in particular; resistance to corrosion, efficient space utilisation in storage and ease of emptying when a valve is fitted.

The vast majority of IBCs are made from high-density polythene (HDPE). This material has only limited compatibility with organic solvents. Guidance on suitability of HDPE IBCs for different types of solvent is given in Reference 1. Many of the liquids listed as compatible with HDPE are flammable or combustible: important examples are all the alcohols as well as most acetates and ketones. Notwithstanding the lack of complete compatibility, plastic IBCs are also commonly used in many industries for hydrocarbons for: wastes; fuels such as diesel; solvents such as white spirit; lubricants; edible oils etc.

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 e.g. CSG (Gloucester 30th October 2000), Distillex (North Shields 12th April 2002) and P&R Laboratories (St Helens October 2001). A characteristic of these fires was the rapid release of liquid from IBCs, inadequacy of bunding and damage caused as a result of the unconfined flow of burning liquid.

Following HSE investigations at the scene of these fires, a research project was undertaken to provide data to allow more reliable risk assessments for premises using IBCs for liquid storage and to provide a stimulus and direction for change in IBC selection and design.

HSE also wished to respond to concerns expressed in relation to the vulnerability of such IBCs in road accidents both on-site and on public roads. It is common practice to load IBC's onto heavy goods vehicles such as curtainsiders. Clearly, the rate at which a fire escalates in a road incident has a significant bearing on the outcome. Particularly so, where people are trapped or unable to leave their vehicles and the emergency services are hampered in their efforts to reach the scene by congestion, for example, after a multiple pile-up.

1.1 OBJECTIVES OF RESEARCH

The work has focussed on three areas:

- The ignition resistance of different types of IBC.
- The rate of liquid loss when IBCs become involved in a self-accelerating fire or are engulfed in a pool fire.
- The extent to which partitions can limit fire spread in storage areas

The first issue is clearly relevant to the reduction in the frequency of large fires. The second is relevant to potential mitigation of such fires if they do occur; especially in the design of bunding and drainage systems to prevent escalation of incidents by unconfined flow of burning liquid.

Work on the third issue is reported in Appendix 4.

2 TEST MATERIALS

Very large IBCs in excess of 3000 litres capacity are available but the vast majority in use have a capacity of around 1000 litres. The test programme was restricted to IBCs with a nominal capacity of 1000 litres. The majority of the IBCs tested were manufactured by Schutz who have a high proportion of the sales of new IBCs in the UK. IBCs manufactured by Sotralenz, Mauser and Mamor were also tested and the results showed that problems of low ignition resistance and high rates of liquid loss in fire engulfment are generic problems for composite IBCs. There is no evidence that equivalent products from other manufacturers would behave in a qualitatively different manner.

A variety of liquids were used in the tests including:

Isopropyl alcohol - a highly flammable liquid, flash point 15 ^{o}C, commonly stored in IBCs and involved in several serious accidental fires

Diesel fuel - widely stored in IBCs and commonly regarded as a low fire risk. The measured flashpoint of the diesel fuel used was 72^{o}C.

A typical industrial cutting fluid, supplied in IBCs with flashpoint 75 ^{o}C.

A typical engine lubricant. supplied to distributors in IBCs with flashpoint 196 ^{o}C.

In all of the IBCs tested an external steel cage supported the inner HDPE receptacle. Some tests involved Schutz IBCs with anti-static screens. In these IBCs there was a thin galvanised steel sheet between the cage and the receptacle. This steel sheet is designed to provide electrostatic screening by covering larger areas of exposed plastic. It can also have a significant effect on the rate of liquid loss in the case of fire.

Two other types of anti-static IBC - for use in zoned areas – produced by Mauser were also included in the test programme. The Mauser Repaltainer has a layer of conductive, corrugated plastic around the inner HDPE receptacle. This plays a similar role in preventing surface charging to the metal screening on the Schutz SX-EX. The HDPE receptacle of the Mauser TC1000 EL includes additives that confer sufficient electrical conductivity to prevent accumulation of static.

Photographs of some of the IBCs tested are shown in Figure 1.

Figure 1(a): Schutz SX-EX metal clad IBCs

Figure 1(b): Mamor 1000 litre IBC

3 TEST PROGRAMME

Experimental details for all of the full-scale tests on single IBCs containing IPA, diesel or other liquids are shown in are shown in Tables 1, 2 and 3, covering Tests 1-11; Tests 12-15 and Tests 16-19 respectively.

A further series of eight ignition tests on valves are detailed in Table 4.

3.1 FULL SCALE TESTS ON SINGLE IBCS

A variety of types of full scale tests were carried out on single IBCs.

- Valve ignition tests: Exposed plastic components in the IBC valve were exposed to ignition sources ranging from a match to a 60g wooden crib (Source Number 6 from BS 5852).

- Other ignition tests: Typically a small pieces of mineral wool was wetted with the liquid contained by an IBC. This was placed under the IBC pallet (away from the valve) to investigate the resistance to ignition by small ignited spills and other small ignition sources.

- Fire engulfment test: This test reproduces the kind of fire exposure that would occur if an IBC was exposed to a spreading pool fire – perhaps from another burning IBC nearby.

The arrangement used in the majority of the single IBC tests is shown in Figure 2. A tray (size 1.8 x 2.7m) was positioned under the IBC. In most cases this tray collected liquid draining from the IBC and defined the size of the engulfing fire in the later stages of the test. In some cases (e.g. Test 10) a significant proportion of the diesel was lost in a spigot flow from near the base of the IBC, which took the liquid outside the tray and led to a very large spreading pool fire (Figure 3). In some later tests inclined sheets of profiled steel fringed the tray (Figure 4). These sheets allowed strong projecting flows from IBCs under test to be captured and drained back into the tray.

In tests where rapid loss of liquid led to significant accumulation in the tray, a drain valve was opened to allow flow out of the tray into a sump. This allowed recovery of 60-90% of the contents of the IBC – reducing the cost and environmental impact of the tests without significantly affecting the outcomes.

In most cases load cells in the roof of the experimental enclosure were used to continuously monitor the weight of the IBC.

3.2 VALVE IGNITION TESTS

The experimental arrangement used in the valve ignition tests is also illustrated in Figure 5. In this case the liquid draining from the valves was caught in a tray 500 x 500 mm. The fires were extinguished after complete failure of the valves.

Test No.	Manufacturer model	Anti-static Metal sheet cover	Doghouse protection	Reinforcement type Tubing cage (TC) Wire mesh (WM)	Contents	Fill	Type of test Valve ignition (VI) Fire engulfment (FE)	Tamper seal
1	Schütz MX (reconditioned)	N	N	TC	IPA	Half	VI	N
2	Schütz MX (reconditioned)	N	N	TC	IPA	Full	VI	N
3	Schütz MX	N	N	TC	IPA	Full	FE	Y
4	Schütz SX-EX	Y	N	TC	IPA	Half	FE	Y
5	Schütz SX-EX	Y	Y	TC	IPA	Full	FE	Y
6	Delta	N	N	WM	IPA	Full	VI	Y
7	Schütz SX-EX	Y	N	TC	IPA	Full	VI	Y
8	Schütz MX	N	N	TC	IPA	Full	VI	Y
9	Schütz MX	N	N	TC	Diesel	Full	VI	Y
10	Schütz MX	N	N	TC	Diesel	Full	VI	Y
11	Schütz SX-EX	Y	N	TC	IPA	Full	Doghouse ignition	No valve

Table 1: Experimental conditions in Tests 1 -11

Test No.	*Manufacturer Model*	*Anti-static metal sheet cover*	*Valve + sight hole protection*	*Contents*	*Fill (litres)*	*Ignition source*
12	Schutz SX-EX	Y	N	Diesel	850	BS 5852 Crib 6
13	Schutz SX-EX	Y	N	Diesel	850	Gas match
14	Schutz SX-EX	Y	Y	Diesel	850	Small diesel spill under pallet
15	Schutz SX-EX	Y	Y	Diesel	850	Small diesel spill under pallet

Table 2: Experimental conditions in Tests 12 –15

Test No.	*Manufacturer Model*	*Pallet*	*Contents*	*Flash Point (‘C)*	*Fill (litres)*	*Igntion source*
16	MAUSER Repaltainer	Plastic	Diesel	72	780	Spill under pallet
17	MAUSER TC1000 EL	Metal	Diesel	72	700	Small diesel spill under pallet
18	SOTRALENZ	Plastic	Cascon 52	75	950	Small diesel spill under valve
19	MAMOR	Metal/ Plastic	Castrol GTX	196	800	Small diesel spill under valve

Table 3: Experimental conditions in Tests 16 –19

Test	*Ignition source*	*Valve type*	*Liquid*	*Time to uncontrolled liquid release*
TEST A	Match [1]	HDPE butterfly	IPA to cap	210s
TEST B	Match [1]	HDPE butterfly	IPA to valve	400s
TEST C	Match [1]	HDPE ball valve	IPA to valve	450s
TEST D	Match [1]	HDPE butterfly	Diesel to cap	220s
TEST E	Crumpled sheet of newsprint[2]	HDPE butterfly	IPA to cap	75s
TEST F	Absorbent granules contaminated with kerosene	HDPE butterfly	IPA to cap	100s
TEST G	125g wood crib[3]	Metal ball valve	Diesel to valve (no cap)	No leakage
TEST H	3000 g wood crib	Metal ball valve	Diesel to valve (no cap)	No sustained leakage

1. Gas match from BS5852
2. Tabloid newsprint mass of paper 9 grams
3. Wood crib source 7 from BS5852

Table 4: Summary of valve test parameters and results

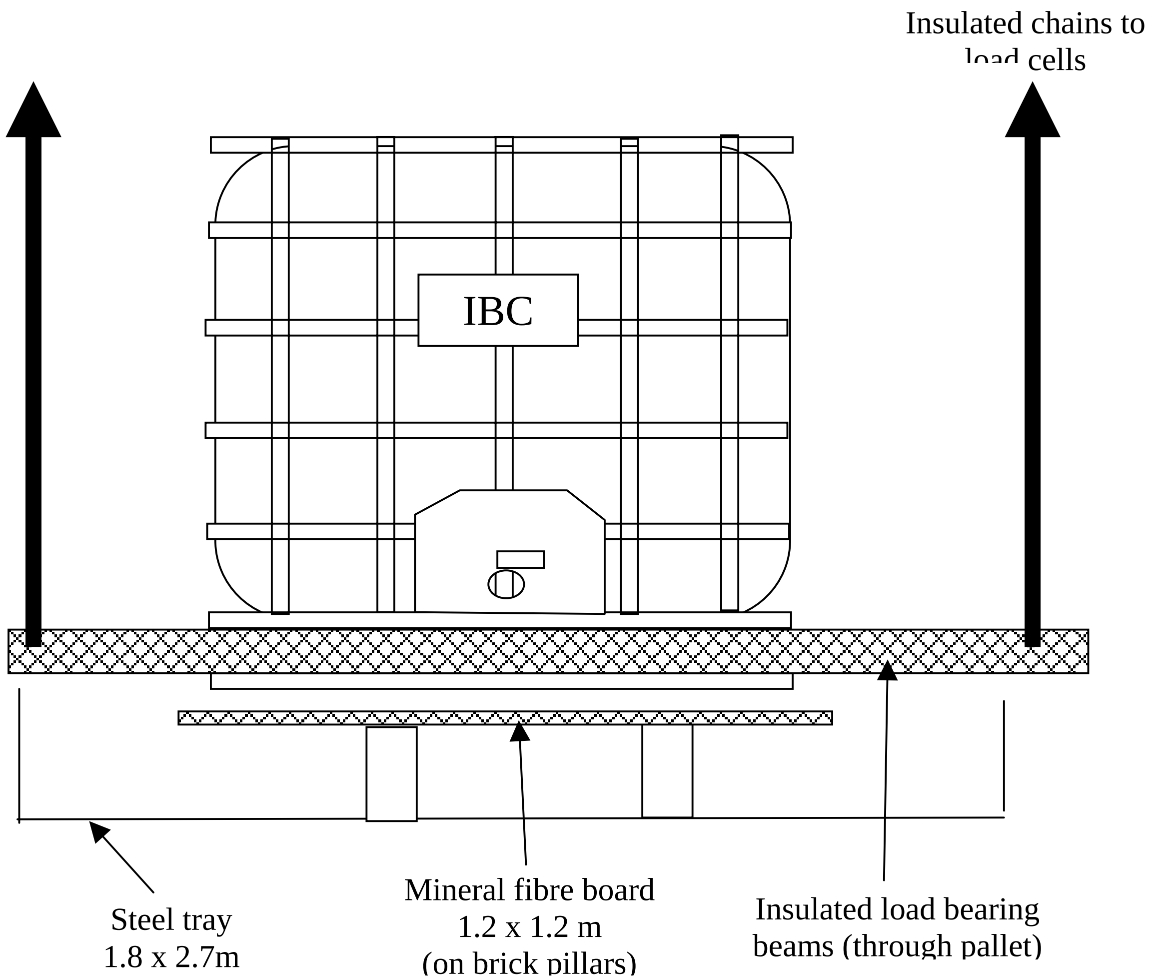

Figure 2: Basic IBC test arrangement

3.3 HIGH-TEMPERATURE HDPE/LIQUID COMPATIBILITY

The system used for reduced scale experiments to investigate the high-temperature compatibility between HDPE and various liquids is illustrated in Figure 6. Panels (400mm x 400mm) 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) that is characteristic of the hydrostatic pressure in IBCs. The lower surface was exposed to a well-controlled propane flame. Note this type of test has to be undertaken with caution if volatile liquid fuels are used.

Figure 3:

Above: Early stages of leakage of diesel fuel from the valve.

Below: Large bore spigot flow of diesel fuel approximately 3 minutes after valve ignition – this was followed by severe and widespread pool fire

Figure 4: Inclined sheets used to capture spigot flow

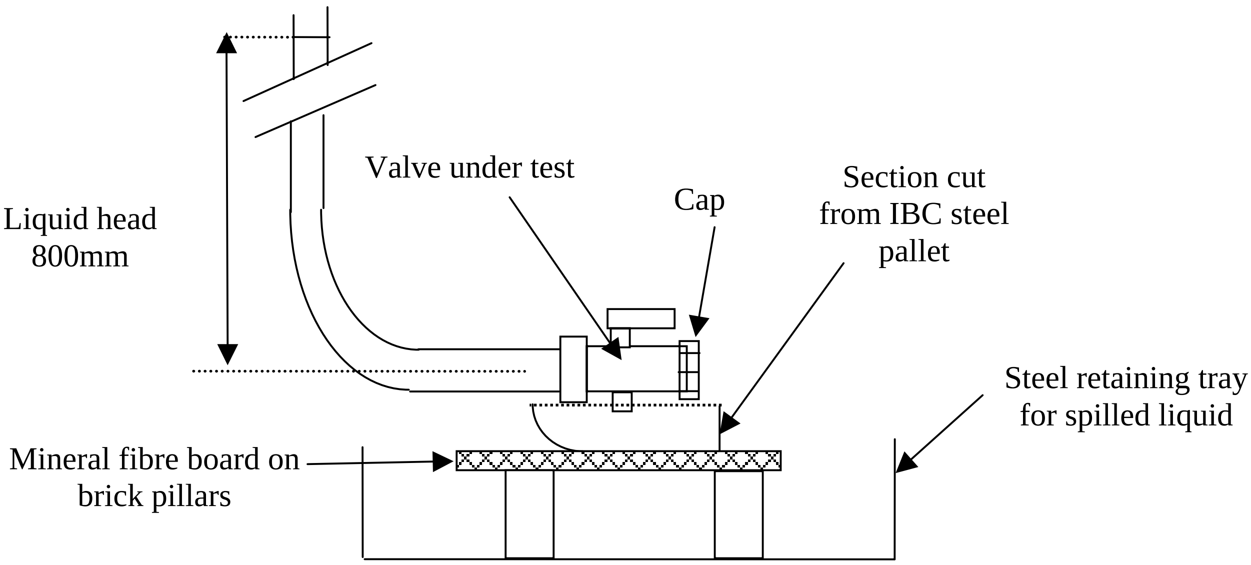

Figure 5: Arrangement for valve tests

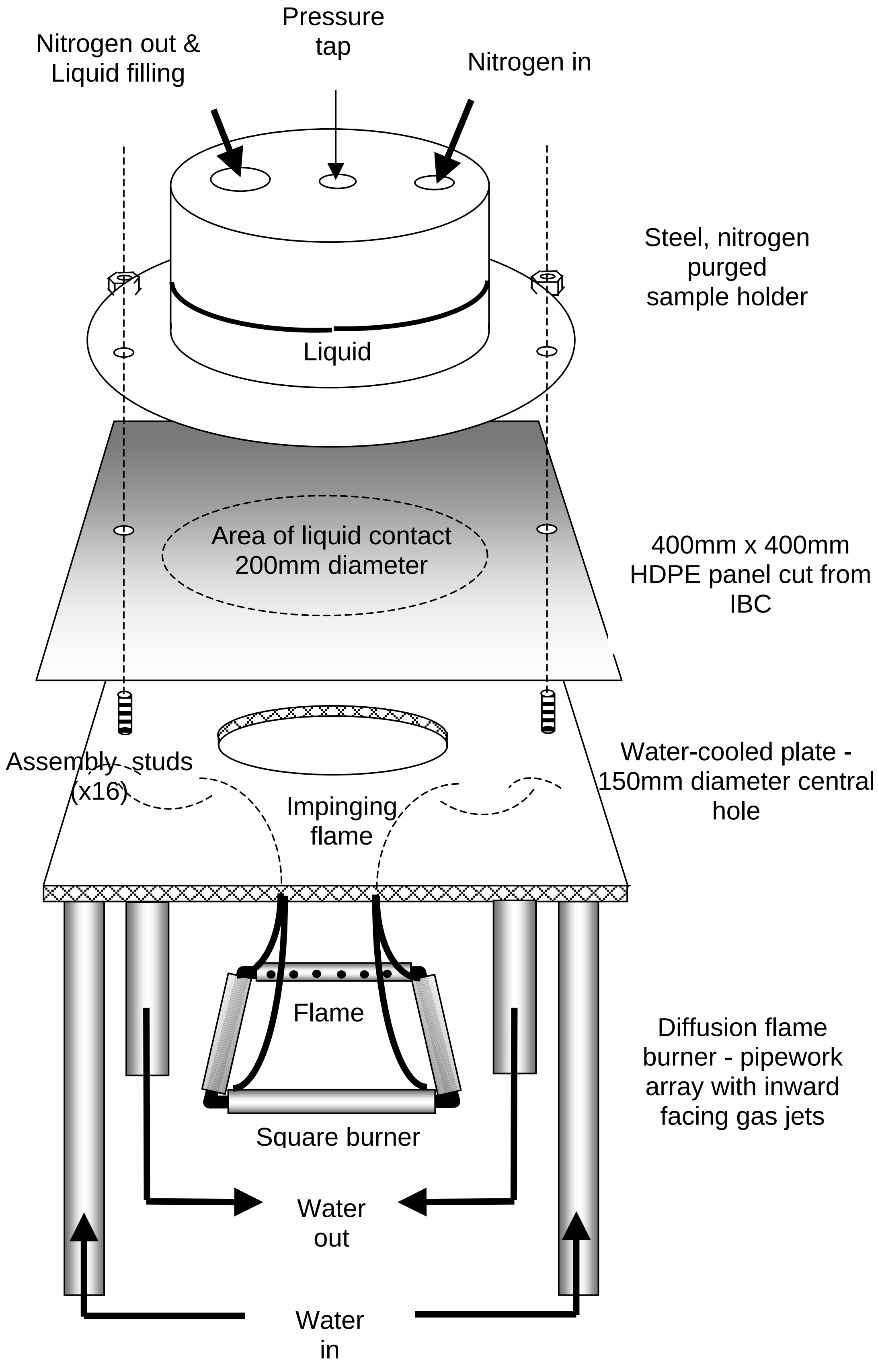

Figure 6: Reduced scale liquid/HDPE compatibility apparatus

3.4 STACK TESTS

Four tests on two-high stacks of Schutz SX-EX IBCs were carried out. The experimental conditions in these tests are summarised in Figure 7.

Measurements of steel temperature were made by inserting stainless steel sheathed 1.5mm o.d K-type thermocouples into the interior of the tubes making up the support cage. The locations of these measurements of temperature are shown in Figure 8.

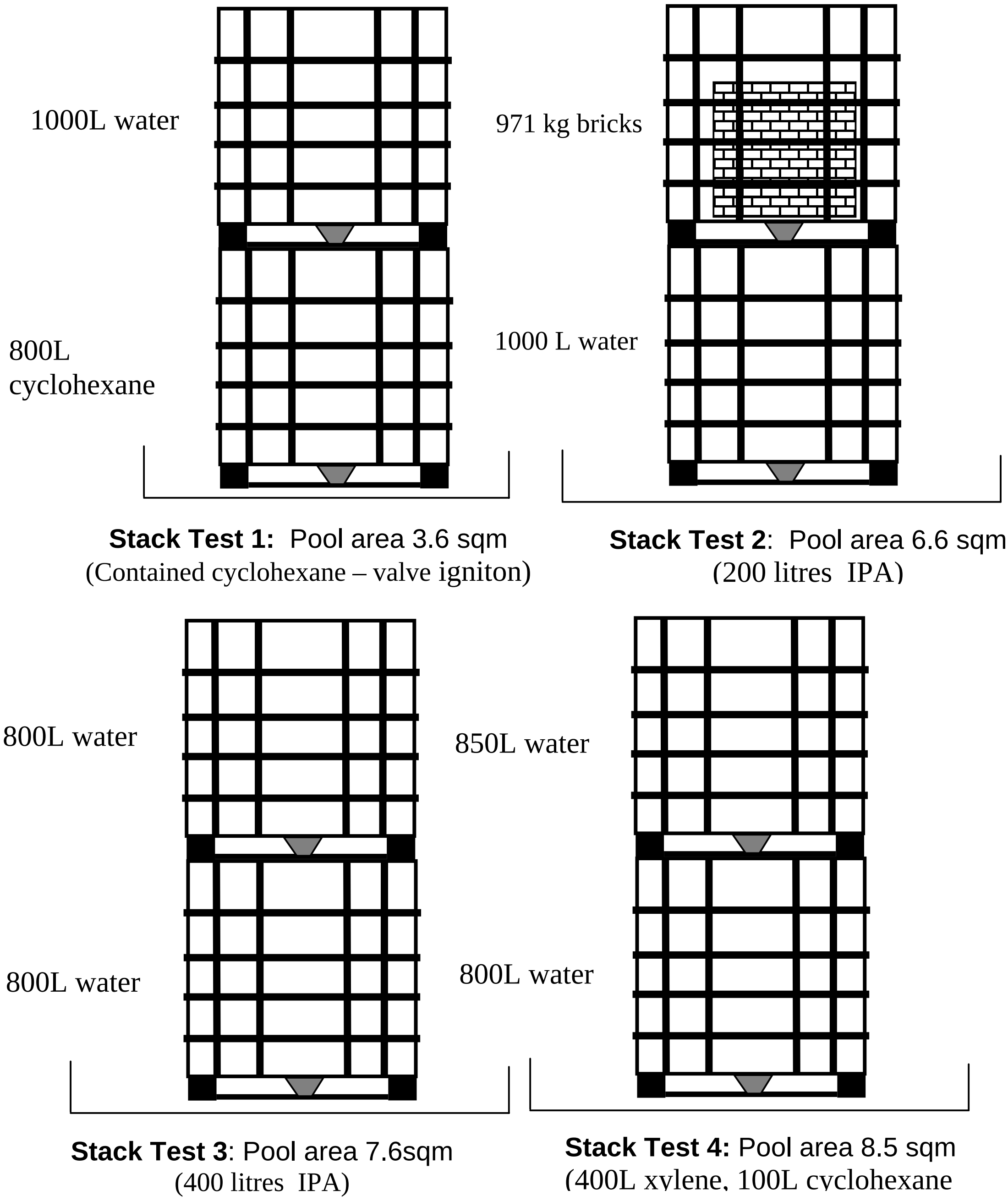

Figure 7: Summary of experimental conditions in stack tests

Figure 8: Locations of thermocouples recording steel tube temperature

Note: thermocouples 10 to 19 continue the sequence around the perimeter of the IBC.

4 RESULTS

Notes on the outcomes of all of the single IBC tests are shown in Tables 5, 6 and 7, covering Tests 1-11; Tests 12-15 and Tests 16-19 respectively.

The key quantitative results from the full-scale test are the rates of liquid loss. These results are summarised in Tables 5 to 7. Some typical measurements of the rate of liquid drainage are shown in detail in Figure 9.

All of the mass loss measurements not shown in the text are included as Appendix 1.

Fire tests on water filled IBCs reported by Scheffery [Reference 2] suggest that massive releases of liquid are a rare occurrence with most breaches producing small liquid release rates. The results of the current work using solvents suggest that (for the majority of IBCs currently in use in the U.K.) catastrophic loss of liquid contents is almost inevitable, if the inner plastic receptacle is reasonably full and not shielded.

Video recordings from different angles were made of all of the tests. Full records of all the tests are available as a set of 5 DVDs. Those interested in specific tests should contact the author. It is intended that HSE will produce a short summary video, including records of ignition and full-scale tests as well as footage from incidents, to improve awareness in industry and amongst regulators about the potential risks associated with storage of flammable and combustible liquids in IBCs.

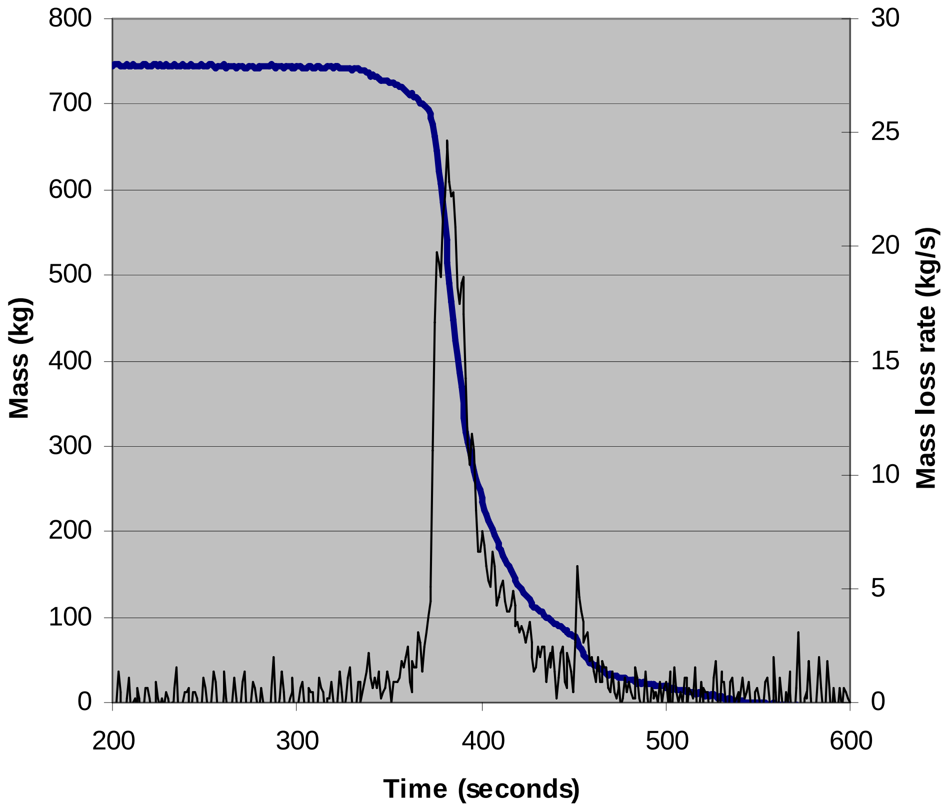

Figure 9: Typical mass loss measurements

Test No.	*Manufacturer model*	*Anti-static Metal sheet cover*	*Contents*	*Fill*	*Leakage rate (g/s)*	*Potential Fire Size (MW)*
1	Schütz MX (reconditioned)	N	IPA	Half	700	21
2	Schütz MX (reconditioned)	N	IPA	Full	3,400	102
3	Schütz MX	N	IPA	Full	17,000	510
4	Schütz SX-EX	Y	IPA	Half	650	19.5
5	Schütz SX-EX	Y	IPA	Full	650	19.5
6	Delta	N	IPA	Full	1,200	36
7	Schütz SX-EX	Y	IPA	Full	180	5.4
8	Schütz MX	N	IPA	Full	3,000	87
9	Schütz MX	N	Diesel	Full	9,000	360
10	Schütz MX	N	Diesel	Full	25,000	1000
11	Schütz SX-EX	Y	IPA	Full	500	14.5

Table 5: Summary of results in Tests 1 -11

Test No.	***Manufacturer Model (fill)***	***Anti-static metal sheet cover***	***Valve + sight hole protection***	***Failure mechanism***	***Leakage rate (g/s)***	***Potential fire size (MW per pallet)***
12	Schutz SX-EX (850l diesel)	Y	N	Around valve No sustained fire	low	-
13	Schutz SX-EX (850l diesel)	Y	N	Breaches around sight holes and valve	5,000	200
14	Schutz SX-EX (850l diesel)	Y	Y	Ullage explosion	5,000	200
15	Schutz SX-EX (850l diesel)	Y	Y	Ullage explosion	20,000	800

Table 6: Summary of results in Tests 12 –15

Test No.	***Manufacturer Model fill***	***Pallet***	**Initial failure mechanism**	**Leakage rate (g/s)**	**Potential Fire Size (per IBC) (MW)**
16	MAUSER Repaltainer Diesel (780l)	Plastic	Major breach caused by pallet fire	12,000	480
17	MAUSER TC1000 EL Diesel (700l)	Metal	Leakage via drainage channels	14,000	560
18	SOTRALENZ Cascon 52 (950l)	Plastic	Pallet fire then valve leakage	Approx 15,000	Approx 600
19	MAMOR Castrol GTX (800l)	Metal/ Plastic	Fire developed after IBC emptied	Slow	High for any additional IBCs involved

Table 7: Summary of results in Tests 16-19

5 DISCUSSION

5.1 UNSHIELDED IBCS CONTAINING FLAMMABLE LIQUID

Rapid rates of loss of flammable liquid (isopropanol) were observed from plastic IBCs without any metal shielding.

- Self-accelerating leaks at the valve led to leakage rates of 3-4 kg/s
- Potential heat release per IBC 90 –120 MW
- Potential size of spreading pool 45-60 m^2

Predictably IBCs exposed to a rapidly growing pool fire failed more rapidly and in some cases leaked more quickly

- Maximum rate of leakage 17 kg/s
- Potential heat release per IBC 500 MW.
- Potential size of spreading pool 250 m^2

These results give an indication of the leakage rates to be expected from the first ignited IBC and those that become involved later in a spreading fire.

In all but one of the tests involving IPA there were vapour explosions causing significant overpressure when the IBC was first breached above the liquid level. In one case a sizable fireball was produced (Figure 10). This was caused by liquid being driven out of a breach in the receptacle just above the liquid line. Anyone standing in front of the IBC, perhaps attempting to fight the fire, would have been sprayed with burning liquid and would probably have been fatally burned unless wearing special clothing. Caution should be exercised in attempting to extinguish IBC fires.

5.2 UNSHIELDED IBCS CONTAINING COMBUSTIBLE LIQUID

Tests on diesel (measured flashpoint 72^{o}C) showed that IBCs containing combustible liquids are also vulnerable to very small ignition sources.

Self-accelerating leaks at the valve led to leakage rates of up to 25 kg/s (see Figure 3). This corresponds to a potential heat release per IBC of 1000 MW.

Catastrophic collapse of large areas of the tank wall was observed. This provided the first clear indication that there was a chemical interaction between diesel and hot plastic. A sludge like material formed by the combination of hot diesel and HDPE was recovered after the tests.

Fire engulfment tests have not been carried out but it is certain that even higher rates of leakage will be observed for IBCs engulfed by a spreading pool fire.

Figure 10: Consequences of ignition of IPA vapour in the ullage of a part-full IBC

5.3 METAL SHIELDED IBCS CONTAINING FLAMMABLE LIQUID (IPA)

Lower rates of leakage were observed from Schutz IBCs containing IPA with an anti-static metal cover. Even in fire engulfment tests IBCs only leaked at a rate of around 0.5 to 0.7 kg/s. This corresponds to a potential heat release per IBC of around 20 MW. Such a fire would only spread to form a pool of order $10m^2$. Whilst this could cause the failure other IBCs the rate of fire spread would be much less than for unshielded IBCs.

Use of these metal-shielded IBCs would be a significant risk reduction measure for IPA storage. The rate of fire spread and the final rate of burning and more importantly the outflow of flammable liquid would be reduced by at least an order of magnitude.

Work detailed below showed that the type of metal shielded IBCs currently available from Schutz do not give such promising results for most other liquids. Light alcohols: methanol, ethanol, and IPA are special because HDPE is highly resistant to chemical attack by these fluids even at relatively high temperatures. They are also volatile; the exposed area of plastic around the doghouse (the recess in which the valve is located) is always fuel rich (relatively cool) and the heat flux to the plastic is limited.

In another test (undertaken as part of the investigation into the CSG fire) involving a nominally full, metal-shielded Schutz IBC an internal explosion opened up a large hole in the valve area leading to very rapid loss of the contents of the IBC. In a duplicate test in this programme (Test 7) a vapour explosion did not catastrophically damage the (unsupported) valve area. There are a number of variables that can affect the outcome in these circumstances, for example: vapour concentration at the time of ignition (and the consequent overpressure), degree of preheating of the valve area, ease of venting via distortion of the cladding etc. It is currently not possible to specify the proportion of clad IBCs that will fail catastrophically during fire engulfment.

5.4 METAL SHIELDED IBCS CONTAINING COMBUSTIBLE LIQUIDS (DIESEL)

Four tests were carried out on metal clad IBCs containing diesel fuel to investigate the level of risk reduction that could be achieved by using cladding panels. The outcomes of these tests are summarised in Table 6.

The first test (Test 12) involved ignition of the valve of a metal clad IBC without a valve protection flap. Early and rapid leakage of diesel fuel occurred and this flow extinguished the ignition crib and prevented the development of a plastic fire. All of the diesel subsequently leaked out of the IBC but was there was no large fire. In a programme of approximately 20 full-scale tests this was the only occasion on which an ignition did not trigger complete combustion. A number of factors appear to have contributed to this unusual behaviour:

1. The early and rapid leakage of diesel fuel. There was not time for the establishment of a significant plastic fire.

2. A gap of around 100mm between the IBC and underlying surface – because of the way the IBC was suspended in this case. This reduced heat transfer from the ignition source to the leaking fluid to a low level.

3. A very low ambient temperature of around -7^{o}C.

In the three subsequent tests the gap between the base of the IBC and the underlying surface was removed by using a piece of mineral fibre board supported on plastic foam (Figure 11). This kept the surface pressed lightly against the base of the IBC at the start of the test but did not interfere with later measurements of mass.

Figure 11: False floor on thermoplastic foam supports

The second test on metal clad IBCs containing diesel fuel (Test 13) also used an IBC which had sight holes in the metal cladding to allow monitoring of the liquid level and did not have a valve protection flap. This test was started with a match ignition of the valve cap. In this case a plastic fire in the valve was established, which ignited the diesel fuel as it began to leak. Rapid emptying of the IBC was observed with large leaks from around the valve and the sight holes. Various stages of the fire are illustrated in Figure 12.

This test showed clearly that (in contrast to IBCs containing IPA) all exposed areas of an inner HDPE receptacle containing diesel fuel have to be covered by metal cladding for the rate of leakage to be controlled.

The remaining two tests on metal clad IBCs containing diesel fuel (Tests 14 and 15) used IBCs in which sight holes had been covered up with stainless steel sheet and the valve enclosure was covered by a metal flap. These tests were started with small spill fires under the pallet. In both cases a self-accelerating leak occurred leading to an engulfing diesel fuel fire. In both cases there was an explosion in the ullage that permanently opened up joints between cladding panels and led to very rapid loss of contents.

The rate of liquid loss in Tests 13, 14 and 15 are compared in Figure 13.

Figure 12: Views of Test 13

Above – Early ignited leak from valve

Below – Leakage from sight holes

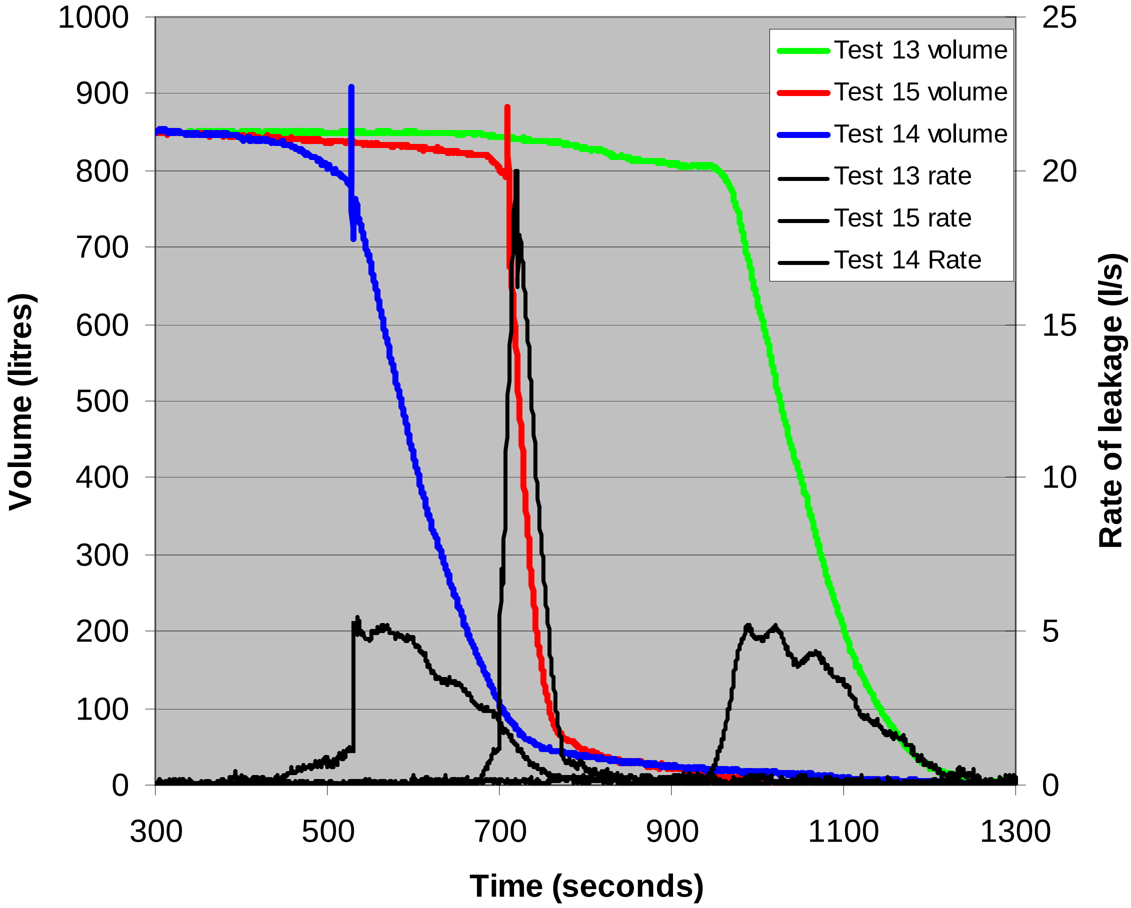

Figure 13: Liquid loss in Tests 13 ,14 and 15

Overall, the level of risk reduction conferred by metal cladding panels on IBCs filled with diesel fuel was disappointingly limited. Further information on the importance of internal explosions and methods of reducing their impact is given in Section 5.8.

5.5 IGNITION TESTS

Ignition sources at the valve

A summary of the time taken for ignition to lead to uncontrolled loss of liquid in various valves is shown in Table 4.

The HDPE cap and valve assembly are made from readily ignitable HDPE. A plastic fire in the cap and/or valve progresses until liquid is released (Figure 14). The plastic fire established on or under the cap or valve is a potent ignition source for liquids leaking from the IBC – even if these have high flash points. It is likely that many combustible liquids with high flashpoints (even those with flashpoints in excess of 100^{o}C) may become fully involved following a valve ignition. These materials would not normally be considered to be readily ignitable or a fire risk in storage and are commonly co-stored with toxic or other types of hazardous materials.

Although the valves can easily be ignited with a match the fire takes several minutes to cause liquid leakage. Larger ignition sources – e.g. a 9 gram crumpled sheet of newsprint - lead to much more rapid leakage (Figure 15). IBCs are potentially vulnerable to grass fires or brands blown from bonfires or fireworks. Any type of process activity that could lead to small, ignited spillages should not be carried out in IBC storage areas.

Two demonstration tests were carried on metal ball valves – without secondary closures. These valves withstood severe and prolonged fire without sustained leakage. The ignition resistance of composite IBCs could be improved by using metal valves. Such valves would have to be electrically bonded via the IBC cage to earth during any solvent transfers through the valve.

Ignition by sources under the IBC pallet

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 liquid. The flame height of the ignition sources in the open was in the range 100-200mm. Examples are shown in Figures 16 and 17. 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 16. This type of failure is clearly not strongly dependent on the pallet type.

2. Small fires rapidly ignited all of the plastic pallets tested.

3. Surprisingly even IBCs that 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 17. 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 18. 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 19.

4. 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.

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. A simple flat lightweight metal sheet inserted between the base of the inner plastic receptacle and the pallet might also substantially improve ignition resistance.

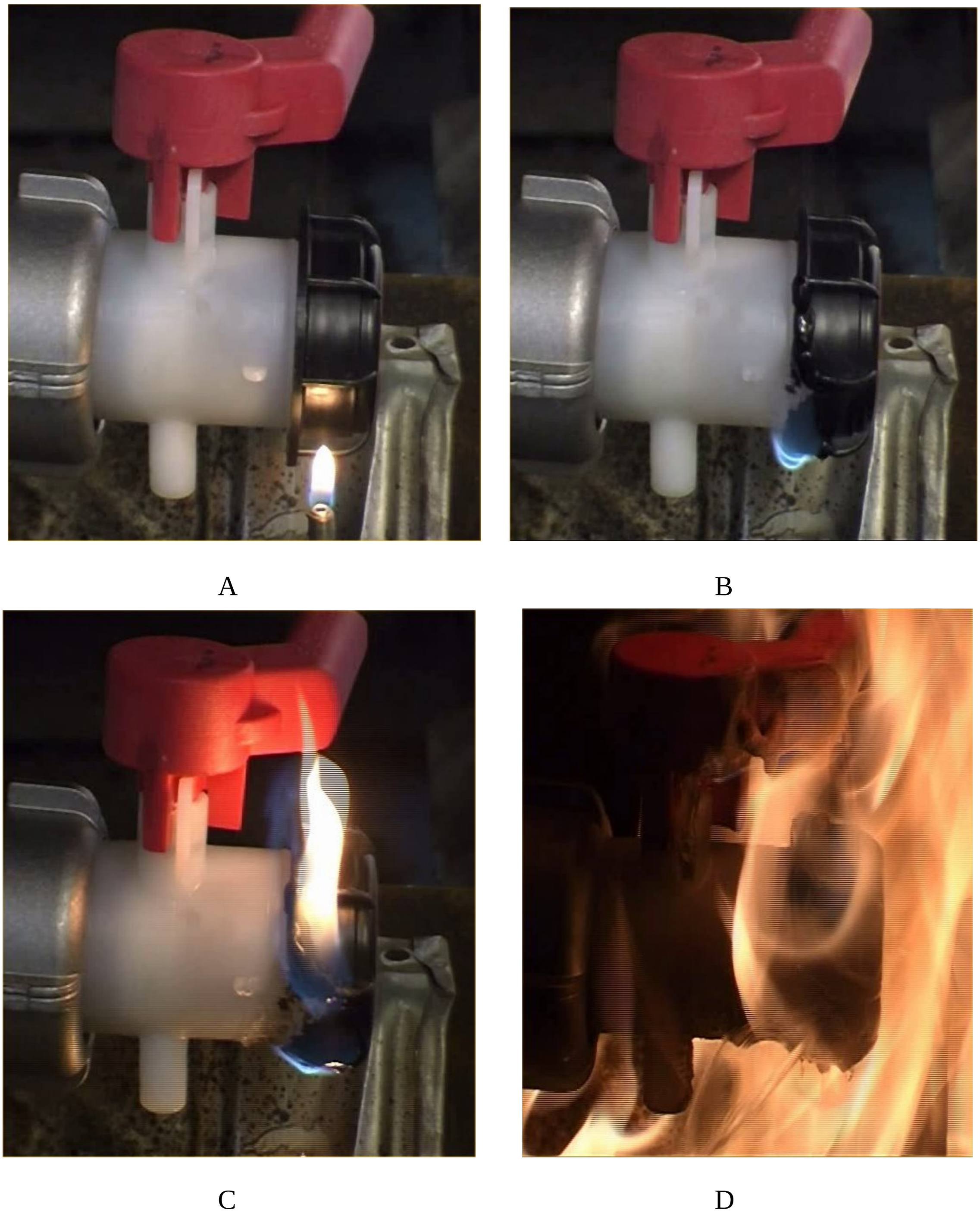

Figure 14: Stages of a valve fire**:**

A – Ignition with a gas match
B – Fire spread on HDPE cap
C – Leakage of IPA vapour
D – Uncontrolled liquid leakage

A

B

C

Figure 15: A crumpled sheet of newsprint causes sustained leakage at the valve in about 1 minute

A – Ignition of paper
B – Flame impingement on the valve
C – Uncontrolled leakage of IPA from valve

Figure 16: 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 17: 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 18: The top of a metal pallet – formed into folds to increase stiffness.

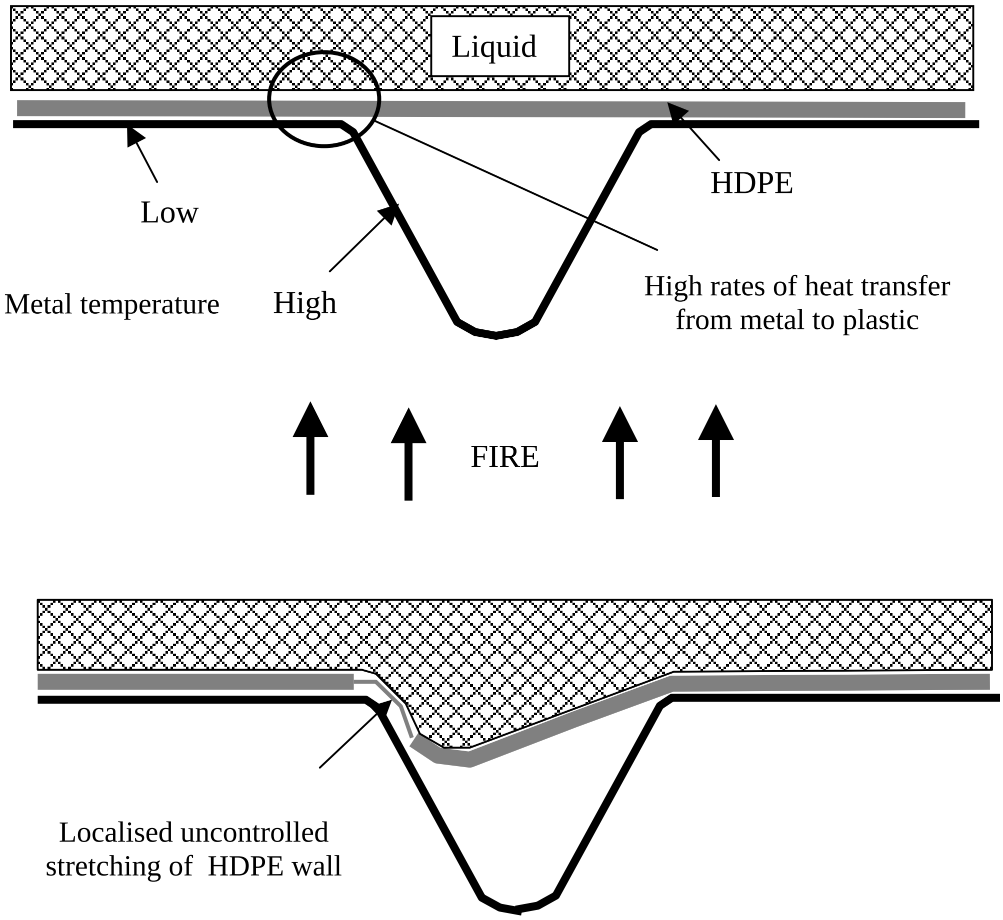

Figure 19: Possible mechanism of failure of HDPE inner receptacle during a fire under an IBC with a formed metal pallet.

5.6 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^{o}C and 196^{o}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 20. 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 empties 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 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 21.

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 many high flashpoint liquids in IBCs are vulnerable to very small ignition sources. 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.

a

b

c

Figure 20: Fire in an IBC containing an industrial lubricant (flashpoint 75^{o}C)

a. Ignition of plastic pallet
b. The initial leak of lubricant is immediately ignited by plastic fire.
c. Rapid leakage (>10kg/s) occurs as the fire develops.


a


b


c

Figure 21: Fire in an IBC containing an industrial lubricant (flashpoint 196^{o}C)

a. Ignition of plastic components in the pallet.
b. The initial leak of lubricant (~1kg/s) is not immediately ignited by plastic fire and a large spreading pool of unignited oil develops.
c. As the outflow from the IBC slackens the continuing plastic fire ignites the pool. A very large fire then develops rapidly.

5.7 CHEMICAL COMPATIBILITY - 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 [Reference 1]. 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 (Figure 6).

Results are summarised in Table 8. Photographs of the remains of tests on water and diesel (flashpoint 72^{o}C) are shown in Figure 22. Generally the time to failure decreased as the proportion of the molecule with an aliphatic or aromatic hydrocarbon character 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 fuel there was a large scale tearing process that allowed leakage at a rate of order 100g/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.

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.

Table 8: Summary of results from small-scale tests

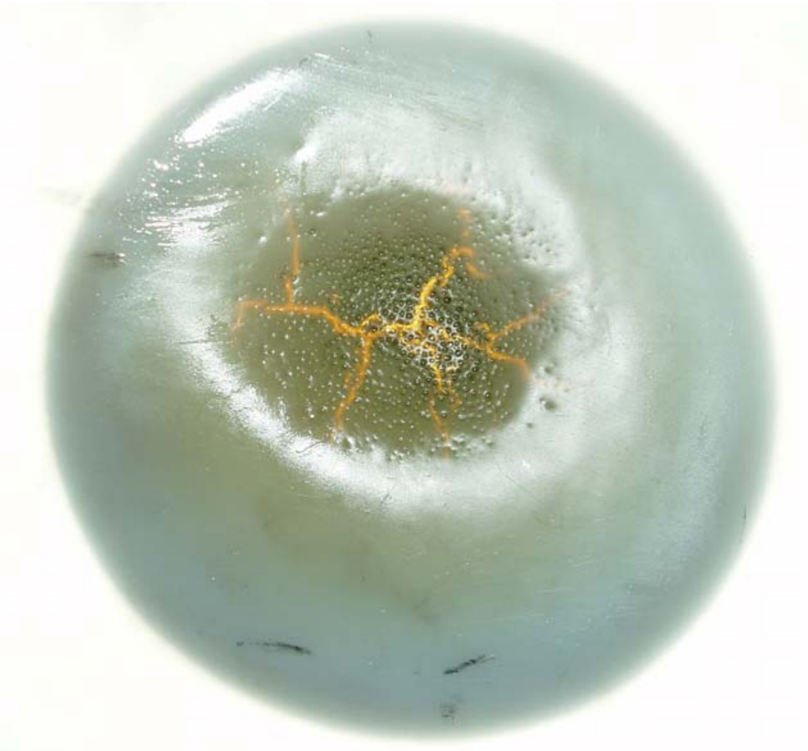

Figure 22a: HDPE panel after water test (view from liquid side).
The failure mechanism is pitting to produce holes a few hundred micron across.
The characteristic leakage rate is of order 1 g/s

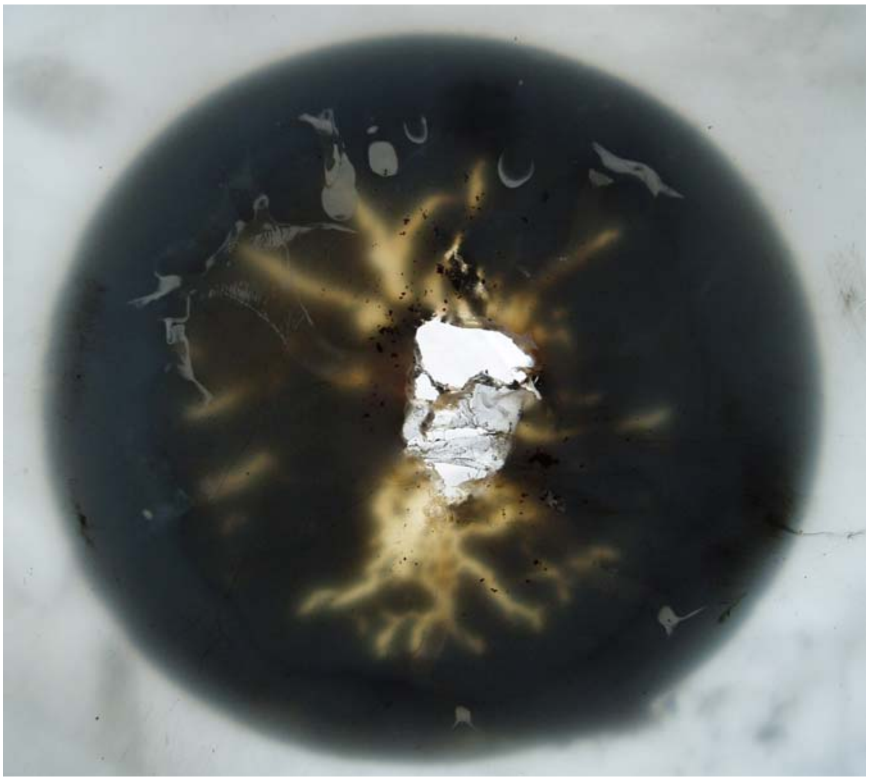

Figure 22b: HDPE panel after diesel fuel test (view from flame side). The failure mechanism is a large scale tear several centimetres across. The characteristic leakage rate is of the order of 100 g/s

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.

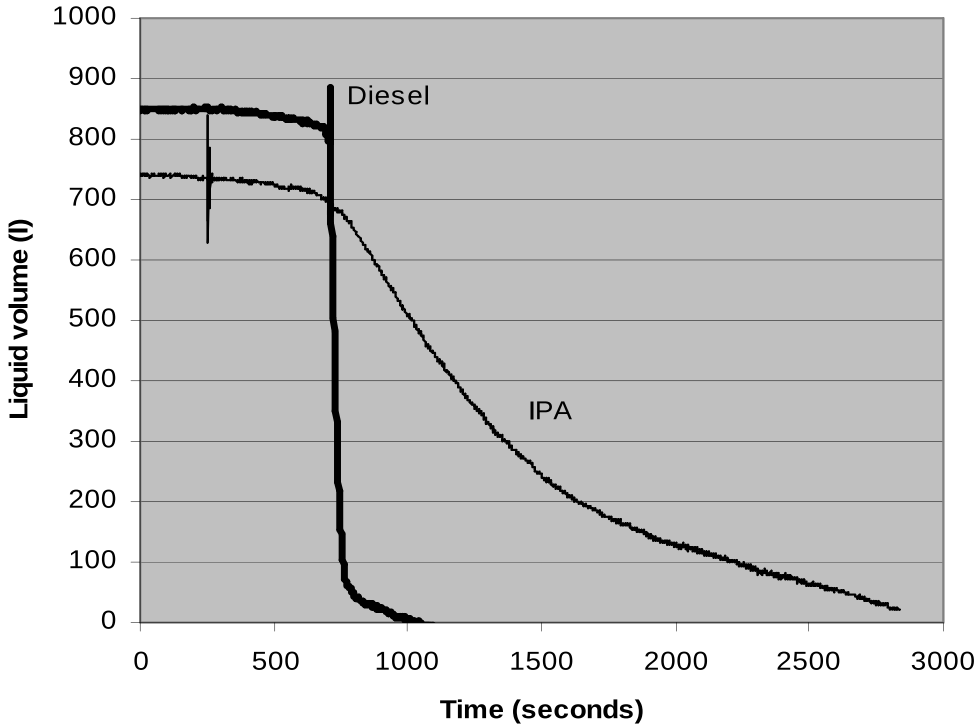

Figure 23: Leakage of metal clad IBCs containing diesel fuel and IPA. The oscillations in measured volume correspond to explosions in the ullage of the IBCs.

5.8 INTERNAL EXPLOSIONS

The Schutz SX-EX IBC has lightweight metal panels that surround the inner plastic receptacle. This design eliminates the possibility of charging of the outer surface by brushed contacts. Tests on IPA showed that the metal cladding also reduced the rate of leakage of liquid in the event of fire. 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 fuel 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.

The differences in characteristic behaviour in the IPA and diesel fuel tests are illustrated in Figure 23. 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 fuel test the explosion causes a major breach in the inner receptacle and metal cladding panels and the IBC empties in tens of seconds.

Removing the metal cladding from the top of the IBC would prevent this type of failure. This top panel is not needed for static protection if the IBC is to be used for a relatively high flashpoint material such as diesel fuel 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 be 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.

5.9 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.

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 Figure 7. Measurements of steel temperature were made (in the third and fourth test) 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^{o}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 that 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, 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 24.

Measurements made of steel temperature during stack tests are included as Appendix 9.2.

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 25).

Figure 24: Damage to a stack of metal clad IBCs during fire engulfment. Separation of metal cladding sheets is visible in lower (closeup) view.

Figure 25: Crushing of lower (water filled) IBC by an upper IBC loaded with bricks (970kg) during fire engulfment
Above – extent of initial (arrested) yielding.
Below - extent of damage following final uncontrolled collapse.

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 performance should be maintained in the upper and lower levels of stacks.

6 CONCLUSIONS

Some basic data has been obtained to allow assessment of the rate of liquid drainage during IBC fires. The tests show clearly that **all of the liquid** in a stock of unclad IBCs on level ground is likely to be released in a period of order 5 minutes.

Combustible liquids stored in IBCs can produce spreading pool fires in exactly the same way as flammable liquids.

A reduced scale method of studying the interaction between plastic panels from IBCs and different liquids under fire conditions has been developed. This may be of use in developing and testing improved IBC designs and materials.

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.

Plastic components of IBCs i.e. valves, corner protection, plastic pallets etc. are easily ignited e.g. by a match. In a programme of around 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^{o}C) give severe pool fires involving all of the contents.

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.

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.

Explosions in the ullage of IBC during the earliest stages of a fire can result in the ejection of finely dispersed burning liquid. Such events would seriously endanger the life of anyone attempting to extinguish the fire.

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.

7 RECOMMENDATIONS

Risk assessments for IBC storage areas or buildings should be based on the premise that liquid loss will be rapid and complete. Details of what is required in a risk assessment are given in Appendix 1.

The risk assessment should cover the interaction between IBCs and steel drums – see Appendix 1. It is good practice to segregate IBCs and drums to avoid rapid onset of catastrophic failure of drums and associated fireballs and projectiles. For some sites this segregation will be essential.

A risk assessment (Appendix 1) is required for areas or buildings that contain any combustible liquids in IBCs or plastic drums with flashpoints up to at least 200^{o}C.

All processes introducing a risk of ignition e.g. hot work, transfers of volatile solvents etc should be eliminated or tightly controlled in storage areas. Strict control of readily ignitable material (e.g. dry vegetation and rubbish) in and around IBC storage areas is also required.

Kerbs and partitions in storage areas may be useful in checking the flow of liquid and the spread of fire.

Manufacturers and reconditioners should provide clear information on the potential behaviour of IBCs in fire when the containers are supplied.

Manufacturers should explore the potential for improvements in design. The resistance to ignition by small fires around the valve or under the pallet could be improved. Redesigned metal cladding systems or internal surface treatments could reduce the risk of very rapid liquid loss during a developing fire. In the longer term standard tests to validate these improvements are needed.

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8 REFERENCES

1. Solvent Industries Association Notice No.51 (2003), Use of IBCs for oxygenated and hydrocarbon solvents.

2. Scheffery J.L. (1997) *Status Report on Fire testing of Liquids stored in Intermediate Bulk Containers.* Proceedings of Fire Suppression and Detection Research and application Symposium

9 APPENDIX 1: RISK ASSESSMENT

9.1 FREQUENCY

The large number of fires in liquid storage areas in the UK in recent years suggests that the frequency of fire starts leading to total loss is of order 10^{-3} per annum. For very well run sites, in low risk areas, the frequency may be closer to 10^{-4} per annum. For other sites, especially in the waste industry, the frequency is undoubtedly higher than 10^{-3} per annum. Some factors that have caused or contributed to fires in the past are listed in 9.5

Generally a fully developed storage fire is a foreseeable event at almost all sites and a hazard assessment is required.

9.2 HAZARD

The assessment is presented as a series of questions with accompanying notes. An example of a completed assessment is also given.

Stage		
1	What is the total liquid inventory (litres)?	This is referred to as V below - Include: All plastic containers i.e 25-205l drums as well as IBCs All liquids (including aqueous solutions as appropriate) Low melting solids (<50°C) as appropriate 25% of all liquids in steel drums
2	What is the total combustible liquid inventory?	Include : All liquids with a flashpoint below 300°C
3	How long will it take (seconds) for all IBCs and plastic containers to lose their contents in a fully developed fire?	This time is referred to as T below: Appropriate assumptions for the time taken for complete loss of all liquid in all containers: • Internal store or no control of liquid flow or partitioning 300 seconds • External store: kerbs and drains designed to control liquid flow 600-900 seconds • External store: kerbs, drains, concrete partitions to at least the height of IBC stacks 900-1800 seconds

4	What is the volume capacity of the bund (litres)?	This value is referred to as C below
5	What is the surface area (m^2) of the pool that will accumulate in the bund before it overflows?	In a flat bund this will equal the total area of the bund.
6	What is the rate of liquid burn-off (litres/s) in the bund?	This is referred to a B below: Assume a rate of burning of 3 litres/m^2/min across the area determined in Stage 5 – this corresponds to a surface regression rate of 3mm/s. Usually the rate of burn-off will be small compared with the rate of liquid leakage from IBCs.
7	What is the rate of release of liquid (litres/s) from the bund when it starts to overflow?	This is the difference between the rate of liquid loss (Stage 3) and the rate of burn-off (Stage 5). Rate of release = $\frac{V}{T} - B$
8	What is the total liquid released from the bund (litres)?	Total release = $V - BT - C$ Unless burn-off is significant this is approximately the difference between the total amount of liquid and the bund capacity.
9	Where does this liquid go?	This is the most important and probably the most difficult part of the assessment. Some subsidiary questions follow.
10	How does the liquid flow compare with the capacity of drains and drain inlets?	Drains may be within the bund or in the path of the liquid after it flows out of the bund. The rate of liquid flow from Stage 7 may be much greater than the flow to drains in heavy rain. See also Stage 21.
11	Where will liquid pool up and what will be the extent of the pools?	The key factors are the location of pools and their surface area. The liquid may pool up by running across the surface or through drains or a mixture of both.
12	What will be the size and shape of flames from pools of liquid in various weather conditions?	Appropriate rules of thumb: Burning rate 3 litres/m^2/min Heat release 30 kJ/g Flame height in metres = $0.18\ Q^{0.4}$ (Q in kW) Flame height independent of wind speed Flame inclination at fairly strong winds 55° to the vertical

		The example assessment (Section 9.4) illustrates use of these rules.
13	How long will the pool fire last?	An approximate estimate can be derived by combining the pool surface area, the burning rate and the total amount of combustible liquid released from the bund – See example. This time is particularly relevant to the question of total firewater use in protecting targets within the site drainage area.
14	What is the effect of pool fires on pressurisable containers?	Consider: Metal drums, cylinders and IBCs Bulk liquid and LPG tanks. Metal drums and IBCs fail catastrophically in a few minutes of fire engulfment. Drums typically produce intensely radiating fireballs with a radius of around 30m. Burning drums can be projected up to around 100m although ranges of a few tens of metres are more common. Metal IBCs could produce much larger fireballs and heavy burning fragments with a larger range. Metal bulk tanks require detailed assessment. Lack of appropriately sized fire engulfment relief for strong tanks is not acceptable. Usually relief vents have to be tens of inches in diameter.
15	Will flow of liquid result in contact between incompatible chemicals e.g. fuels and oxidisers or mixtures that generate toxic gases?	Follow the track that burning liquid would take on the ground. Consider how the locations of different materials might vary in different circumstances e.g. during unloading.
16	Can running or pool fires cause other types of escalation e.g. by affecting reactors, control systems, pipe work etc?	
17	What are the effects of pool fires on occupied buildings on and offsite?	Appropriate assumptions: Radiation as a proportion of total heat release in a large pool fire 15% Point source located at mid-point of flame (see Stage 12) Fairly strong wind towards target (see Stage 12) Maximum heat flux that can be tolerated in escaping from a fire (following CIA guidance on occupied buildings) 6.3 kW/m^2.

		Heat flux likely to spread fire to neighbouring buildings 12 kW/m^2. Use of these rules of thumb is illustrated in the example assessment.
18	How much liquid will enter public drains and what will happen to it?	
19	How much liquid will soak away on and around the site and what will happen to it?	
20	What will the effect of releases on the environment?	
21	How will the Fire Service respond to a fire in the storage area?	The findings of the above risk assessment should be discussed with the local fire service. Information required from the fire service: What is the likely attendance time? How would water be used in the event of developing / well developed / fully developed fires in the IBC storage area? How much water would be used on the fire directly or in cooling targets where firewater will end up adding to the liquid spilling from the bund? A modern appliance can pump of order 200,000 litres /hr Will foam be available and what stage? How (and from where) will the Fire Service protect nearby property in various wind conditions? How could this be affected if drums are exploding regularly on the site? Are there targets on or off-site that cannot be effectively protected in these circumstances?
22	What will be the effect of fire service operations?	The speed of development and intensity of IBC fires means that the Fire Service are very unlikely to be able to control of fire development in the storage area unless it is protected by a well designed system of kerbs, drains and concrete partitions to at least the height of IBC stacks. The role of the fire service will be to prevent fire spreading to nearby plant or property.

9.3 INTERPRETING THE RESULTS OF HAZARD ASSESSMENT

Action is necessary if the hazard assessment indicates that a fire will result in any of the following:

- Catastrophic failure of:

    Strong bulk tanks containing liquids or gases

    Gas cylinders

    Metal IBCs

- Catastrophic failure of steel drums within 50m of housing. This reflects the fact that anyone exposed to radiation from a fireball will be seriously burned if they are closer than about three times the fireball radius to the centre of the fireball.

- Heat fluxes above the CIA limit on all escape routes from any housing.

- Heat fluxes above 12 kW/m2 at any part of nearby housing

- Serious environmental damage

9.4 EXAMPLE ASSESSMENT

This example assessment deals with a waste transfer station. The site includes a storage bund, containing total of 150,000 litre of liquid waste in IBCs and smaller plastic containers. The inventory of this bund comprises:

One third dilute acids

One third waste oils – Flashpoints 70 –200°C

One third highly flammable waste thinners

Risk assessment

Stage		
1	What is the total liquid inventory (litres)?	150,000 litres
2	What is the total combustible inventory (litres)?	100,000 litres
3	How long will it take for all IBCs and plastic containers to lose their contents in a fully developed fire ?	Complete loss of liquid in 300 seconds.
4	What is the volume capacity of the bund?	Bund flat. Area 200m^2. Kerb height 100 mm Bund capacity 20,000 litres

5	What is the surface area of the pool that will accumulate in the bund before it overflows?	200 m^2.
6	What is the rate of liquid burn-off in the bund?	Total burn-off rate 3 x 200 = 600 litres/min = 10 litres/s
7	What is the rate of release of liquid from the bund?	Liquid release rate = $\frac{150000}{300} - 10$ = 500 litres/second The rate of burn off in the bund is small compared with the leak rate
8	What is the total liquid release from the bund?	Total release = 150,000 – 10 x 300 –20,000 = 127,000 litres Assume the 20,000 litres of liquid left in bund is the (heavier) acid. 100,000litres of combustible liquids released
9	Where does this liquid go?	When the effluent interceptor pit backs up, liquid pools at the edge of the lowest part of the site. Bunding at the site boundary can retain 300,000 litres (approx 300 tonnes).
10	How does the liquid flow compare with the capacity of drains and drain inlets?	Not relevant – drains affected do not go off-site directly.
11	Where will liquid pool up and what will be the extent of the pool?	Location SW corner of site Surface area approx 600 m^2
12	What will be the size and shape of flames from pools of liquid in various weather conditions?	Burning rate 3 litres/min, Heat release 30 kJ/g, Density 0.8 kg /l Heat release = 3 x 0.8 x 30,000 x 600 / 60 = 720,000 kW Flame height 0.18 $(720,000)^{0.4}$ = 39 m Flame height independent of windspeed Flame inclination at fairly strong winds 55° to the vertical
13	How long will the pool fire last?	Average depth of combustibles 100,000/600= 0.166 metres Duration 166 mm / 3 mm/min = approx 55 minutes
14	What is the effect of pool fires on pressurisable containers?	Metal drums and IBCs stored in separate area away from liquid flow and radiation. Bulk liquid and site LPG tank are well away (65m) from the liquids storage area and the area likely to be affected by liquid

		flow and pooling. Bulk tanks are in any case all fitted with fire engulfment relieving man lids.
15	Will flow of liquid result in contact between incompatible chemicals e.g. fuels and oxidisers or mixtures that generate toxic gases?	No. Small amounts of oxidisers stored in separate area where no mixing possible.
16	Can running or pool fires cause other types of escalation e.g. by affecting reactors, control systems, pipework etc?	No
17	What are the effects of pool fires on occupied buildings on and offsite?	Nearest housing 75 metres from edge of pool. Nearest houses have doors at 75 and 85 m from edge of pool. Height of housing 6m. Radiation 15% of total heat release = 0.15 x 720 = 108 MW Point source located at mid-point of flame. Height of midpoint = $\frac{39}{2}$ m x sin (90°-55°) = 11m Lateral displacement of midpoint = $\frac{39}{2}$ m x sin 55° = 16m Distance to nearest housing = $\sqrt{(75-16)^2+(11-5)^2}$ = 59 m Heat flux = $\frac{Q_{radiation}}{4\pi r^2} = \frac{108{,}000}{4\pi(59)^2}$ = 2.4 kW/m^2 The heat flux at neighbouring property is well below the heat flux that can be tolerated in escaping from a fire (6.3 kW/m^2) and the heat flux likely to spread fire to neighbouring buildings (12 kW/m^2). .
18	How much liquid will enter public drains and what will happen to it?	Liquid will be retained on site
19	How much liquid will soak away on and around the site and what will happen to it?	Bunding of the site is sufficient to retained spilled liquid. See 21 below.
20	What will the effect of releases on the environment?	Should be minimal liquid release to the environment.

21	How will the Fire Service respond to a fire in the storage area?	Attendance time - Approx 10 minutes Water would be used to protect office block, a solids warehouse, bulk tanks and waste packaging storage areas on-site and off-site commercial units close to northern site boundary. Water will only be used to cool products in the within the storage area if a small fraction of the stock is involved when the Fire Service attend. Use of water to be suspended if the fire continues to spread. It is understood that the site bunding can only take 1- 2 hours of pumping by a single appliance. The main pool fire should be subsiding within about an hour. It is unlikely that foam will be available quickly enough to tackle the pool fire before it becomes fully developed. Locations for the fire service to operate from to apply cooling water to various targets have been identified in a range of wind conditions. Drums will not be fire engulfed so relatively free movement around the area affected by high radiant intensity will be possible.
22	What will be the effect of fire service operations?	The speed of development and intensity of IBC fires means that the Fire Service are very unlikely to be able to control fire development in the storage area. The role of the fire service will be to prevent fire spreading to the offices, warehouse and nearby commercial property.

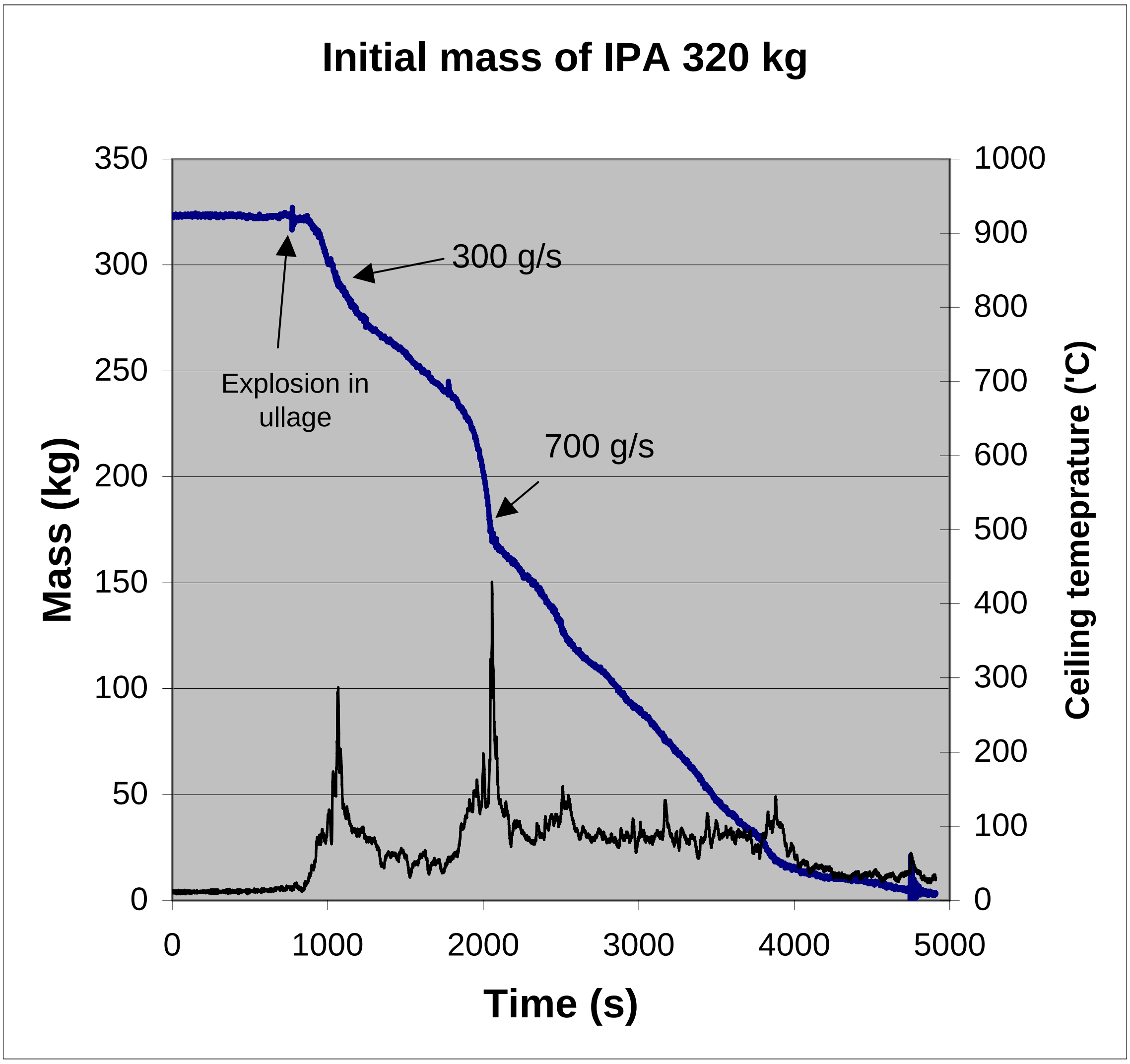
Overall the potential for a fire in the IBC storage area does not present unacceptable risks to nearby populations or the environment.

9.5 FACTORS INCREASING RISK OF FIRES IN IBC STORAGE AREAS

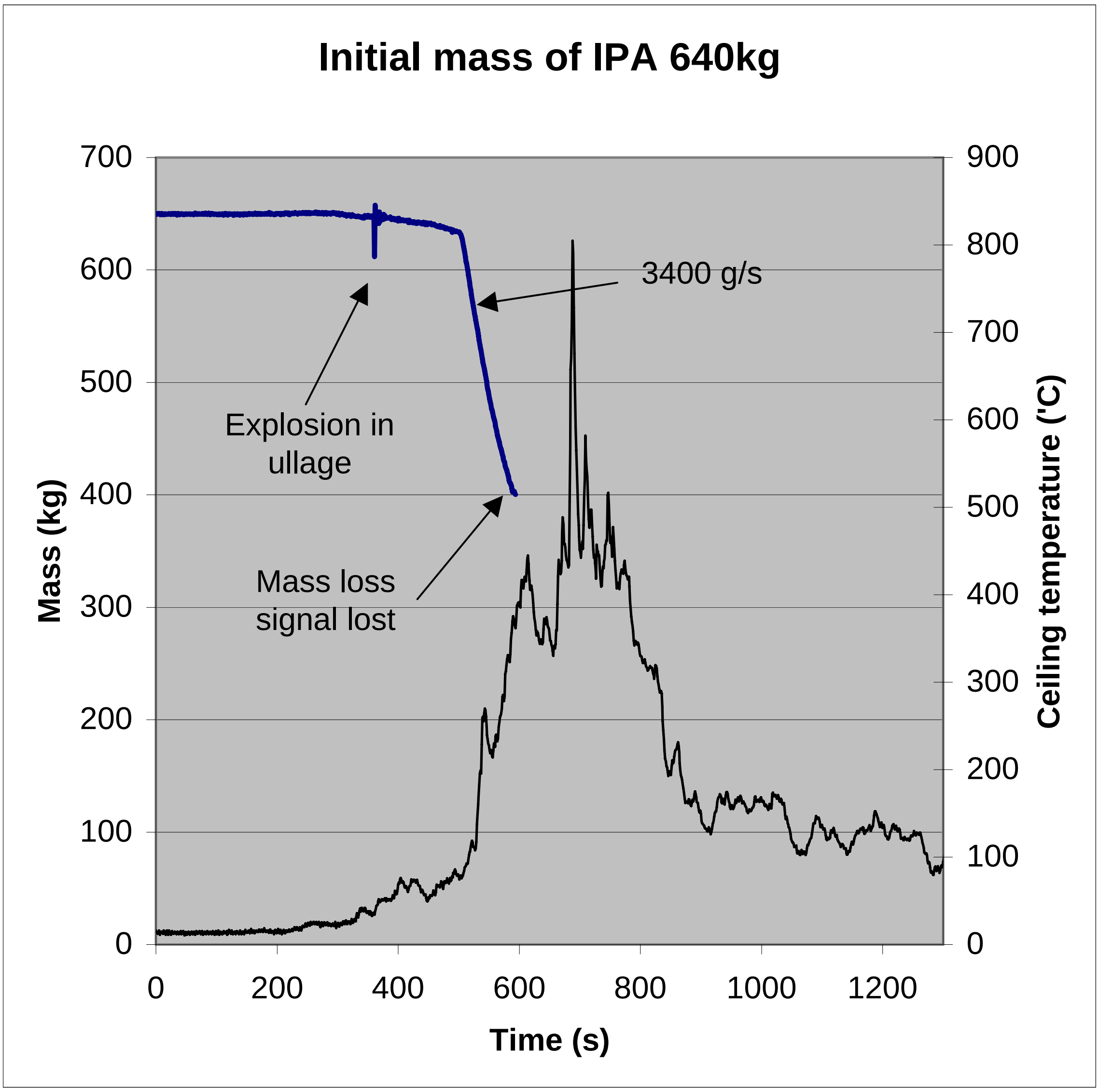
- Incompatible liquids stored in plastic containers e.g. xylene, toluene, heptanes, acetone etc. (See Reference 1)
- Dried vegetation or rubbish in storage areas
- A high risk of arson linked to an urban or semi-urban location and poor security.
- Processes carried out in the storage area: bulking, decanting, container filling, sampling and testing.
- Use of inappropriate plastic containers and IBCs in zoned areas.
- Poor ventilation in enclosed stores.
- Unstable stacking
- Loose packages on pallets
- Overcrowding obscuring stock and preventing early detection of leaks

- Cutting up IBC or other containers for scrap in or near to the storage area.
- Storage areas inadequately separated from site boundaries.
- Lack of control of static and other ignition sources e.g. vehicles, lighting, portable appliances etc.
- Poor segregation of incompatible materials
- Lack of knowledge about or control of materials accepted (especially waste storage).
- Poor awareness of fire risks on the part of management and workforce
- Poor control of smoking
- Poor control of maintenance, especially hot work.
- Overcrowding leading to storage of liquids outside designated areas
- Proximity of IBC storage to other high fuel loads e.g. pallet stacks, empty IBCs, rolls of plastic film etc.
- Proximity of IBCs to poorly controlled storage e.g. waste skips.
- Proximity of IBCs to buildings housing high-risk processes i.e. those involving hot surfaces, naked flames, sparks, flammable gases, volatile solvents, flammable dusts, self-reactive materials etc.

10 APPENDIX 2 - MASS LOSS MEASUREMENTS

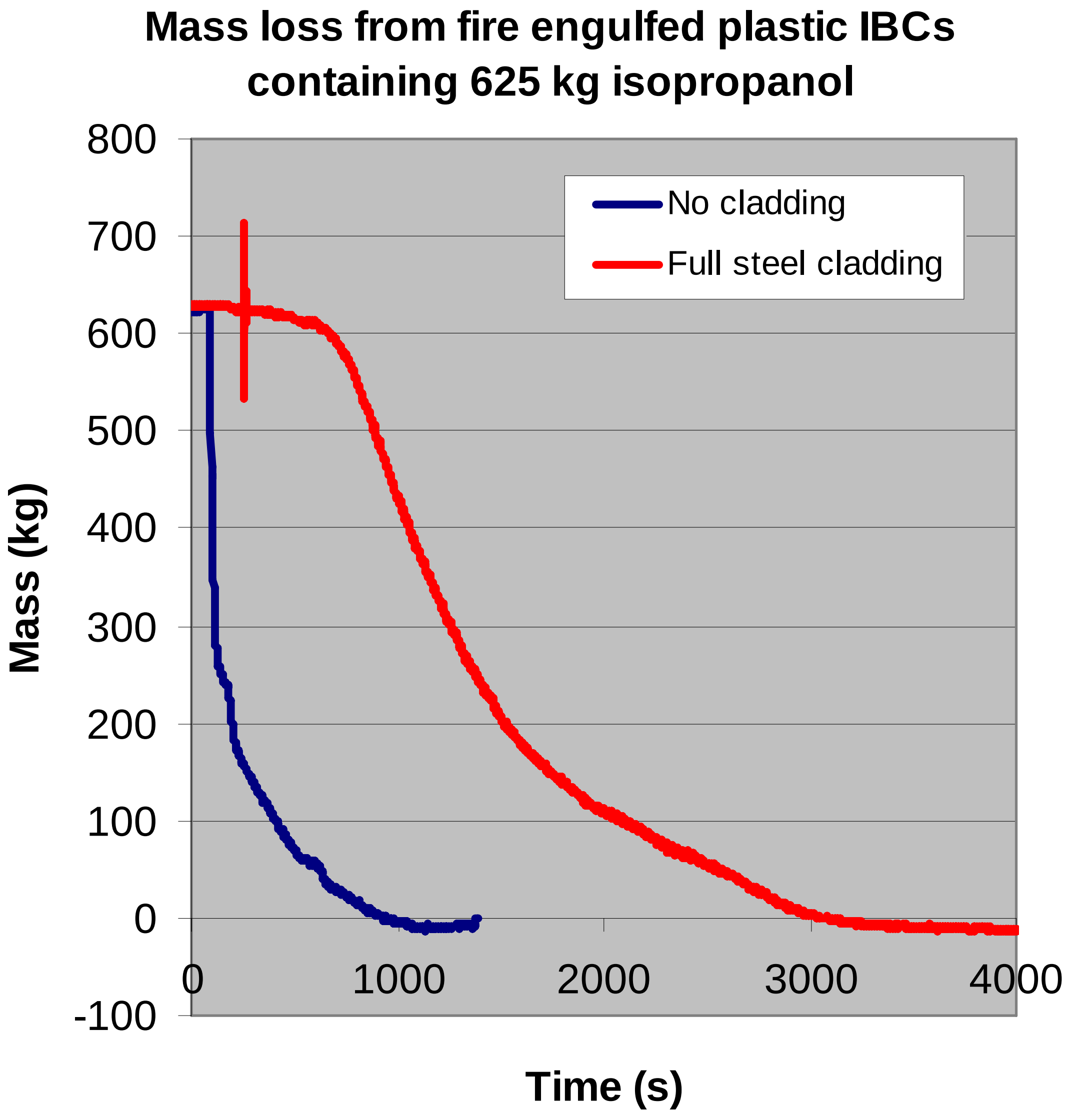


Test 1

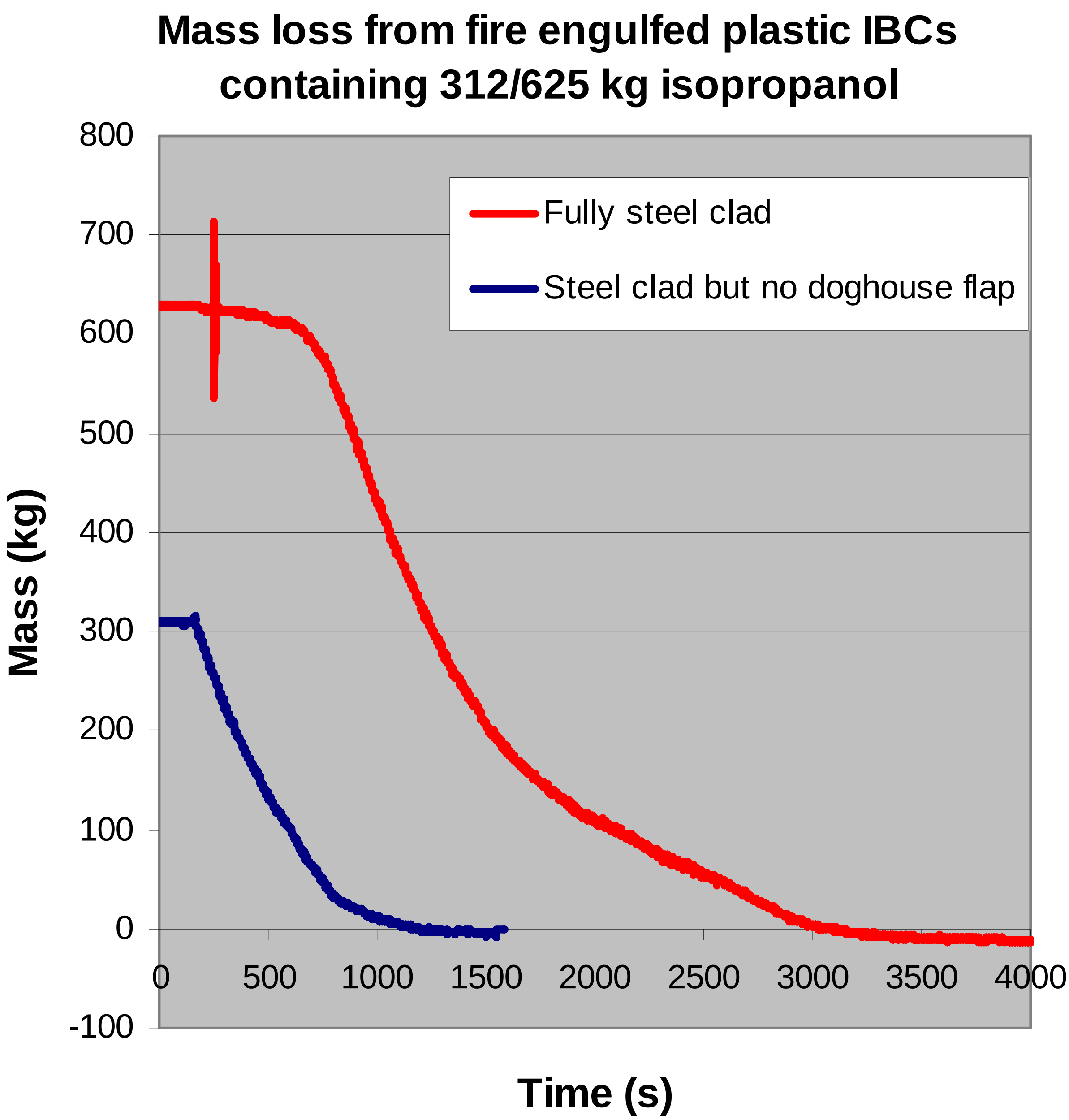


Initial mass of IPA 640kg
Mass (kg)
Ceiling temperature ('C)
Time (s)
3400 g/s
Explosion in ullage
Mass loss signal lost
0
100
200
300
400
500
600
700
800
900
1000
1200

Test 2

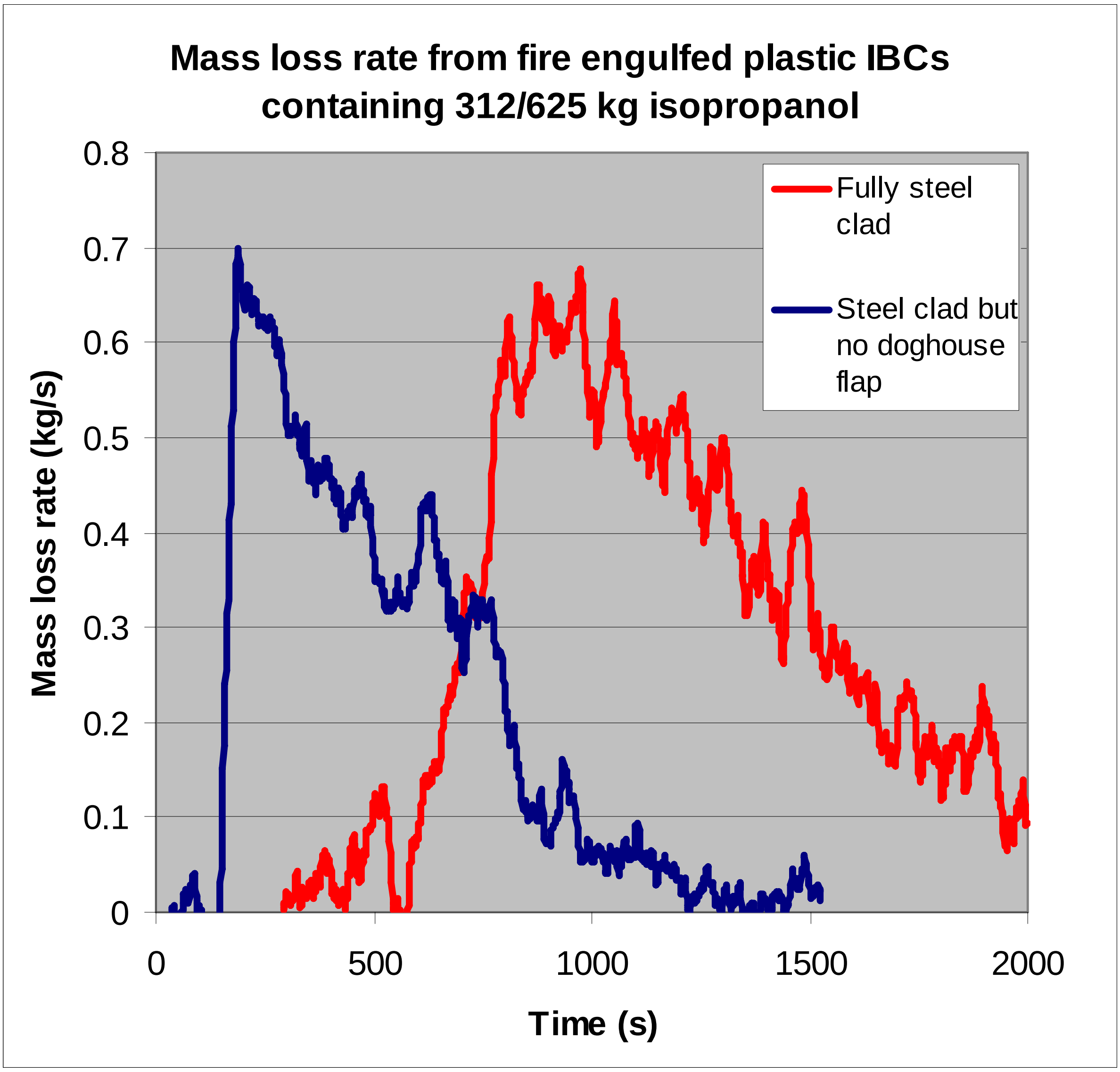

Mass loss from fire engulfed plastic IBCs
containing 625 kg isopropanol
800
700
600
500
400
300
200
100
0
-100
Mass (kg)
0
1000
2000
3000
4000
Time (s)
No cladding
Full steel cladding

Tests 3 and 5



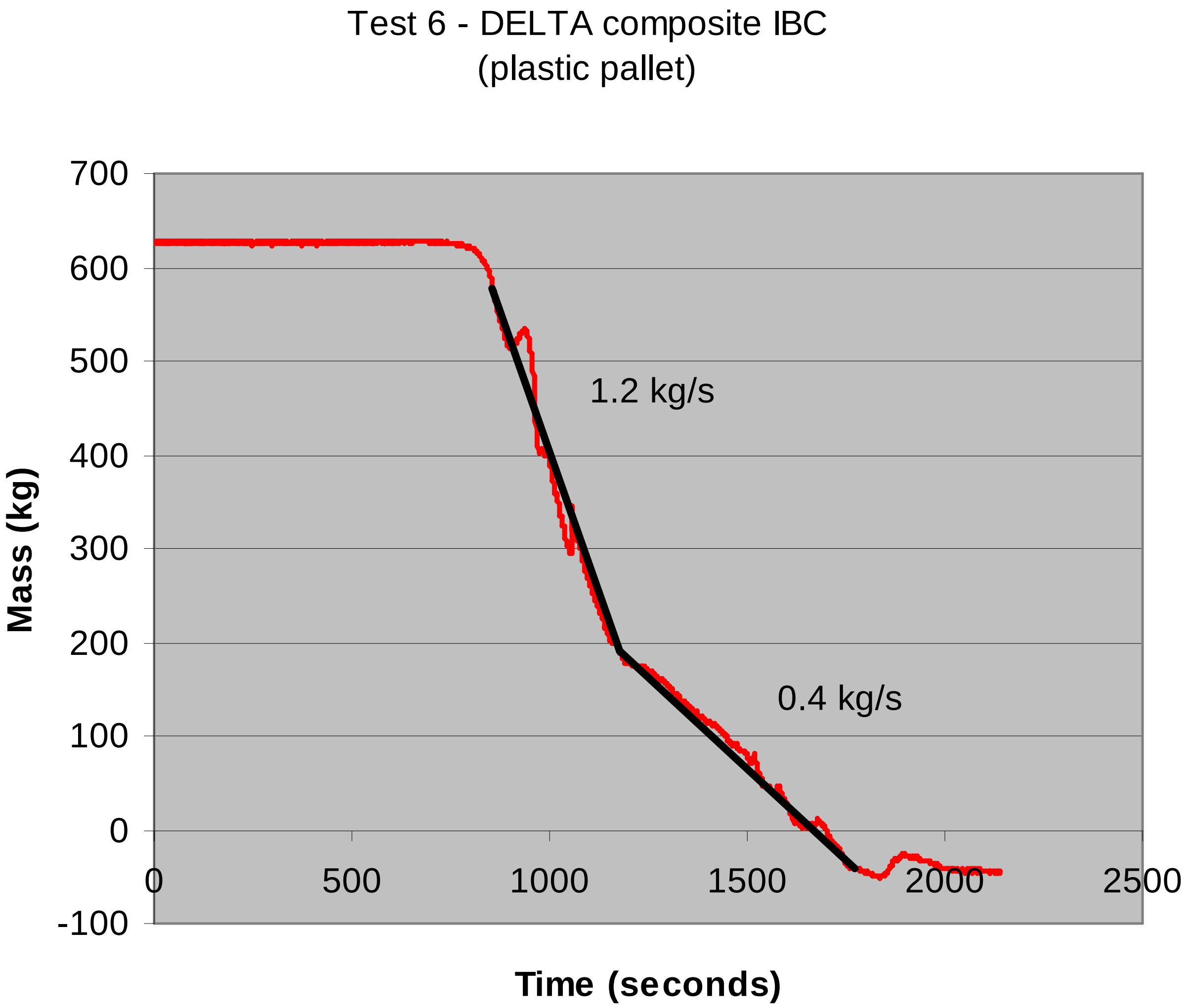
Mass loss from fire engulfed plastic IBCs containing 312/625 kg isopropanol
800
700
600
500
400
300
200
100
0
-100
Mass (kg)
0
500
1000
1500
2000
2500
3000
3500
4000
Time (s)
Fully steel clad
Steel clad but no doghouse flap

Tests 3 and 4

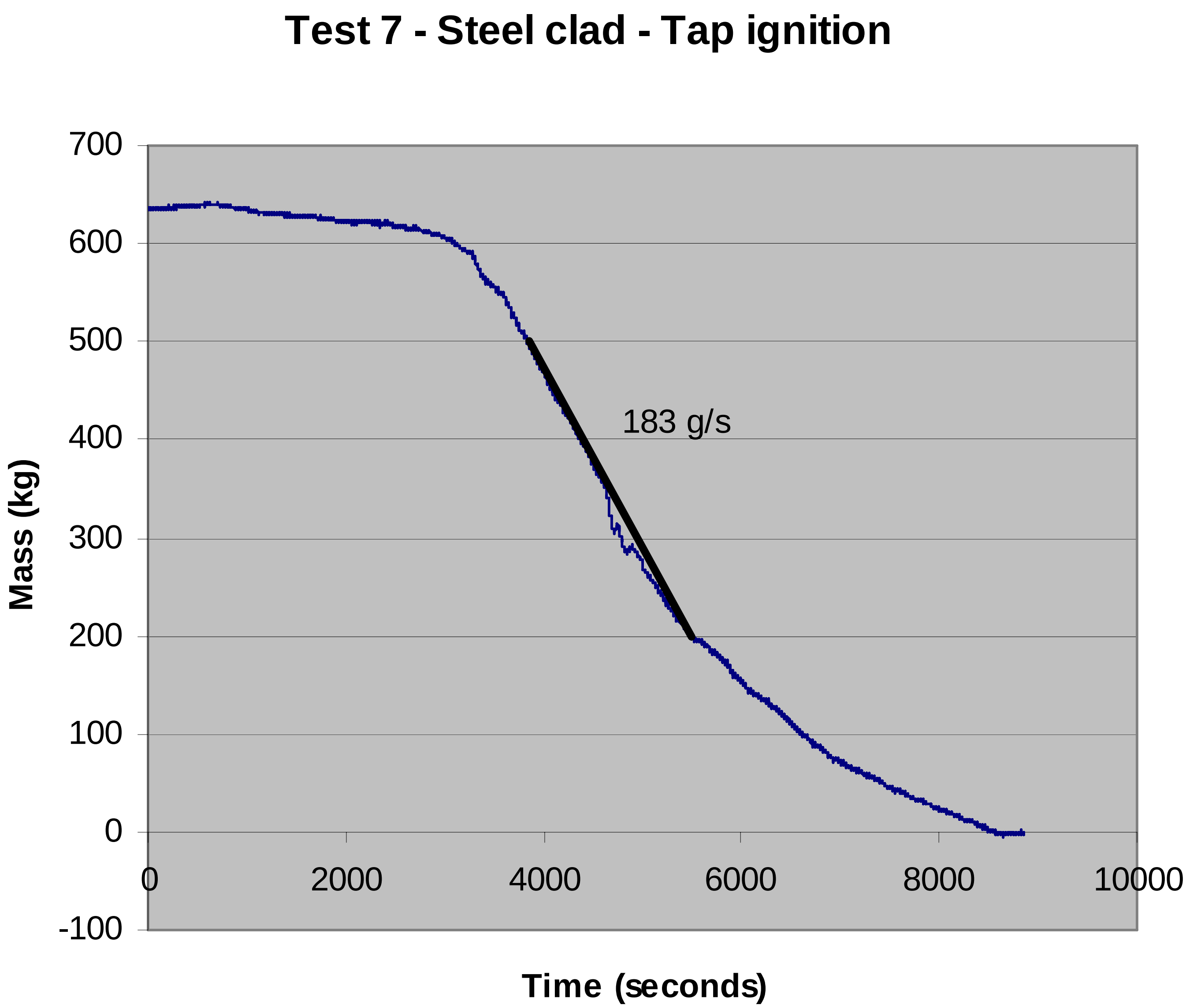


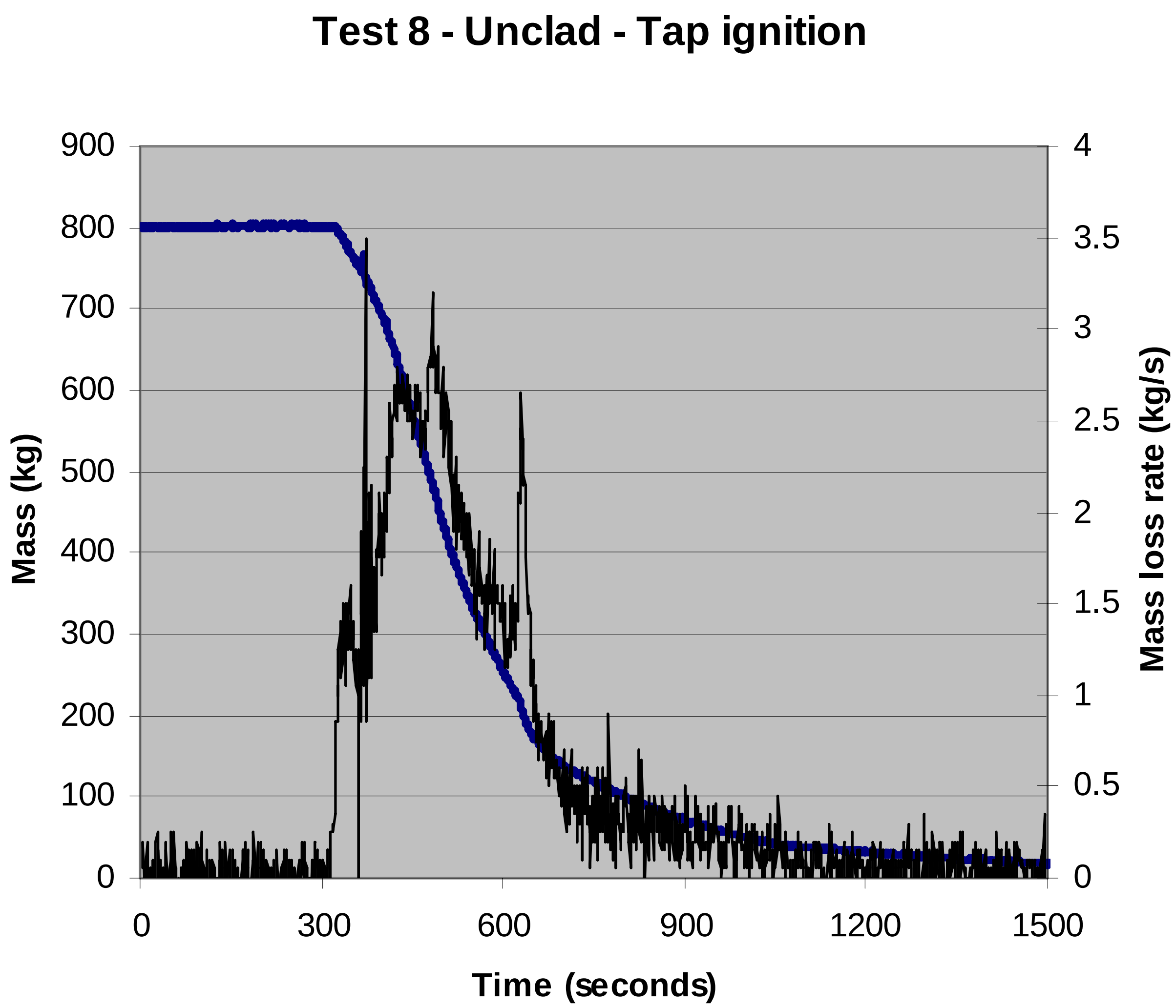
Mass loss rate from fire engulfed plastic IBCs containing 312/625 kg isopropanol
Mass loss rate (kg/s)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
500
1000
1500
2000
Time (s)
Fully steel clad
Steel clad but no doghouse flap

Tests 4 and 5

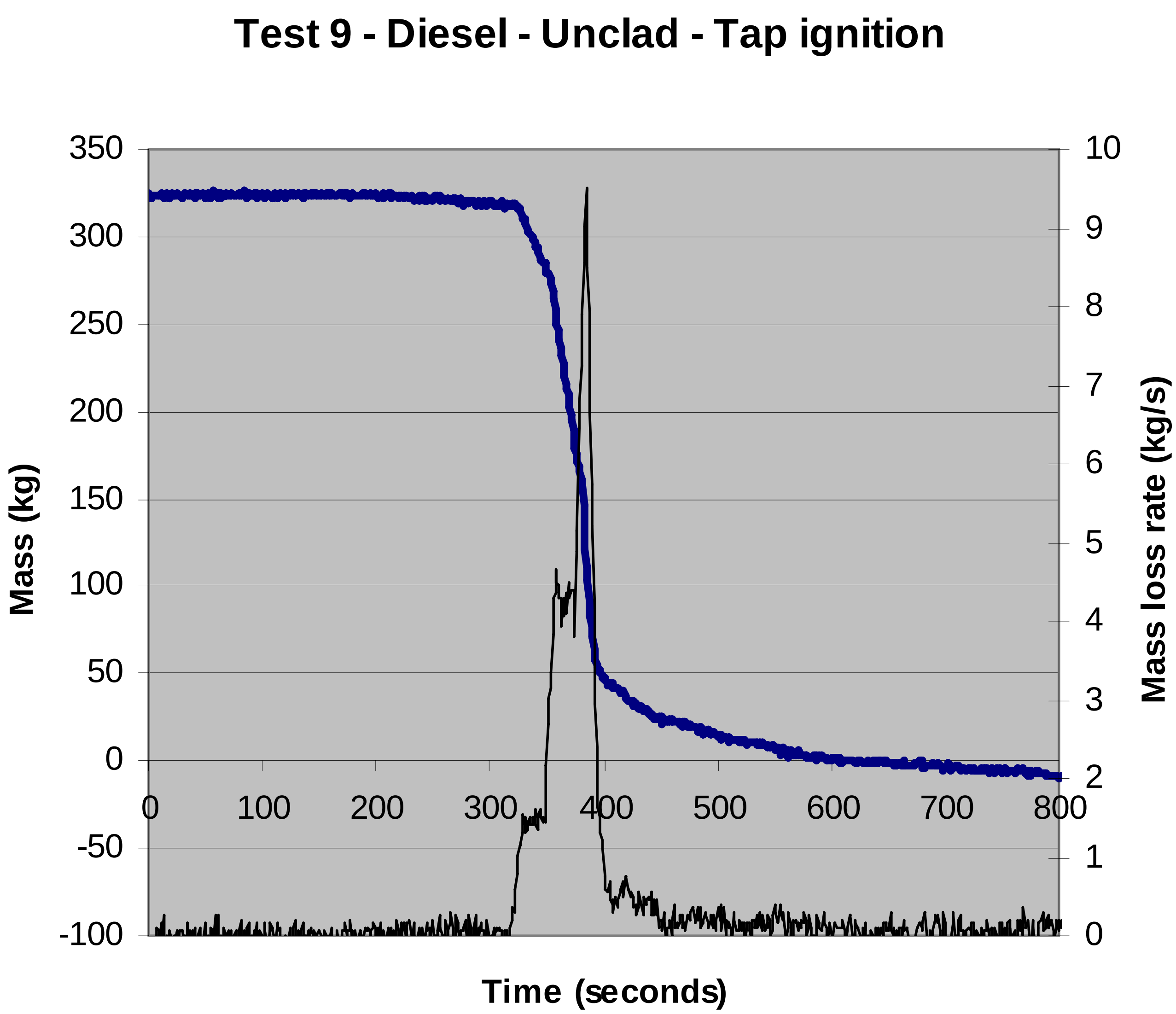


Test 6 - DELTA composite IBC
(plastic pallet)
700
600
500
400
300
200
100
0
-100
0
500
1000
1500
2000
2500
Mass (kg)
Time (seconds)
1.2 kg/s
0.4 kg/s

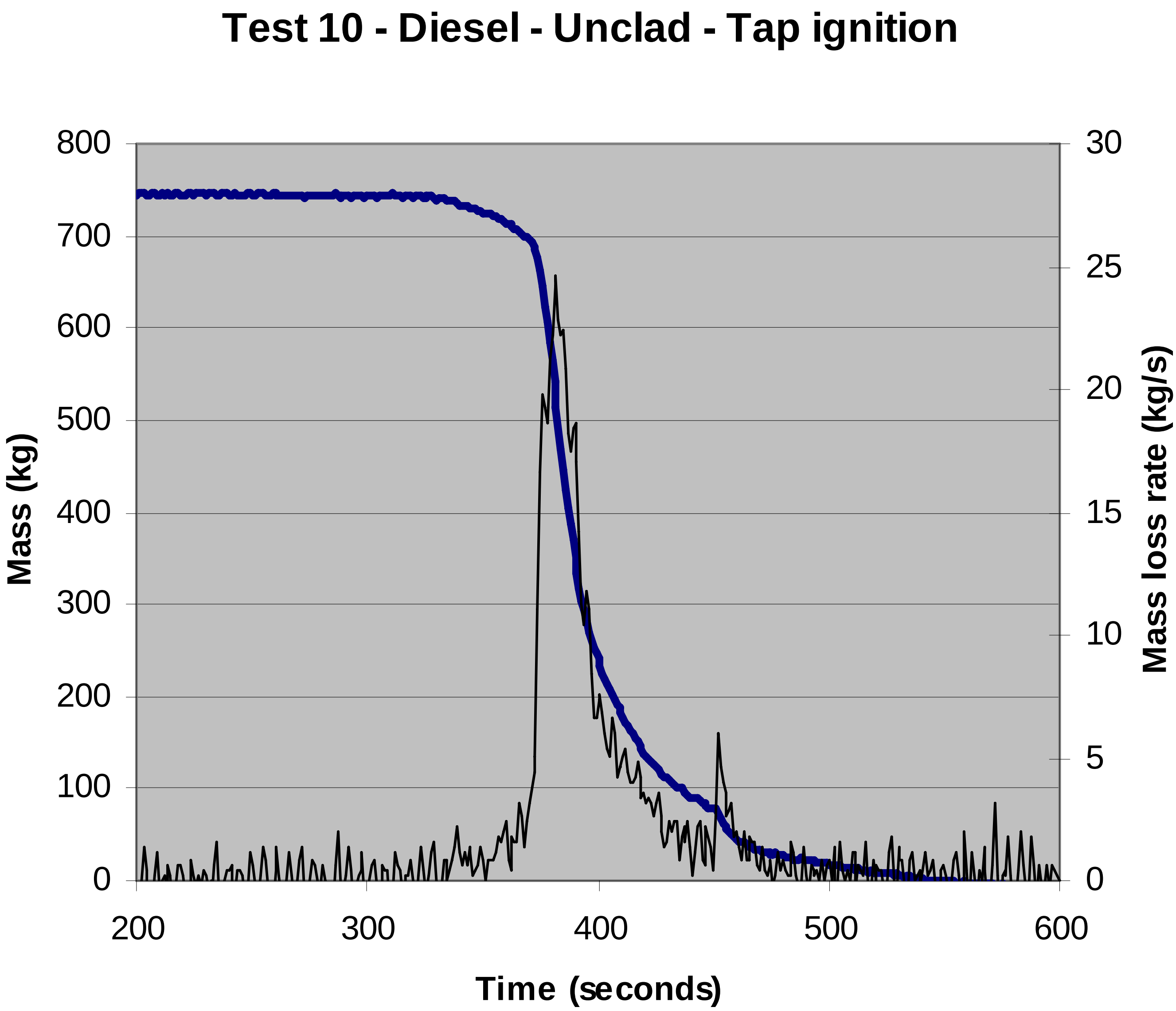

Test 7 - Steel clad - Tap ignition
700
600
500
400
300
200
100
0
-100
Mass (kg)
183 g/s
0
2000
4000
6000
8000
10000
Time (seconds)



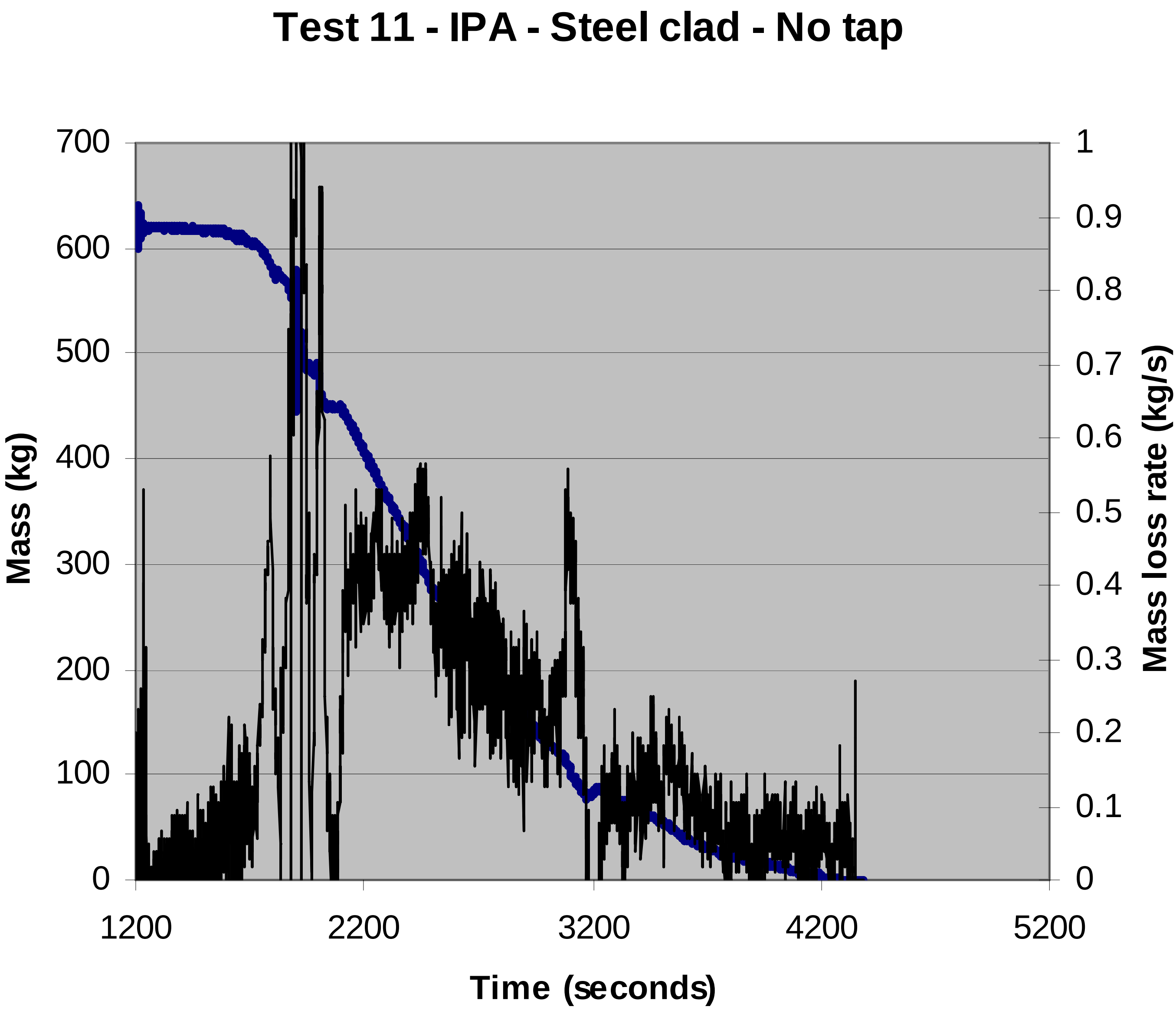
Test 8 - Unclad - Tap ignition
900
800
700
600
500
400
300
200
100
0
Mass (kg)
4
3.5
3
2.5
2
1.5
1
0.5
0
Mass loss rate (kg/s)
0
300
600
900
1200
1500
Time (seconds)



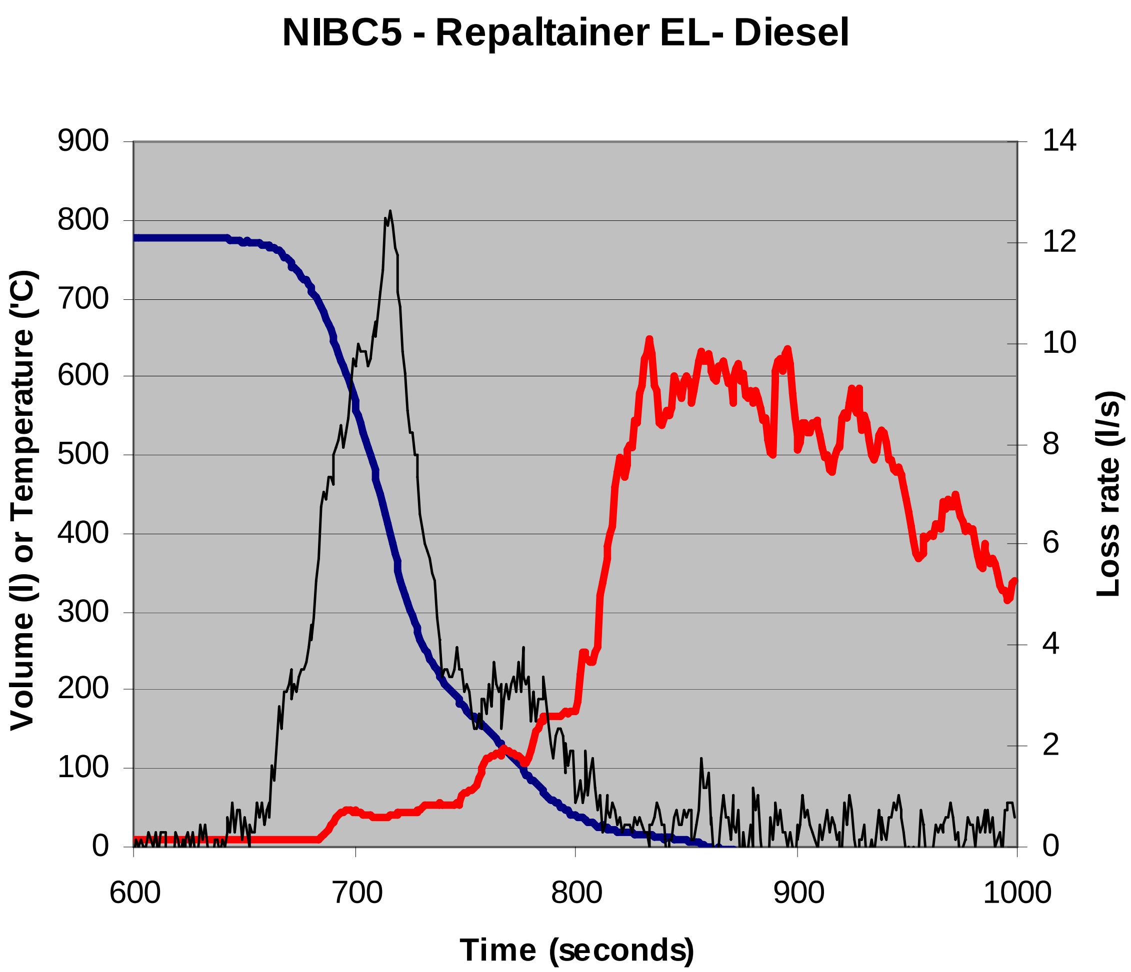
Test 9 - Diesel - Unclad - Tap ignition
Mass (kg)
350
300
250
200
150
100
50
0
-50
-100
0
100
200
300
400
500
600
700
800
10
9
8
7
6
5
4
3
2
1
0
Mass loss rate (kg/s)
Time (seconds)



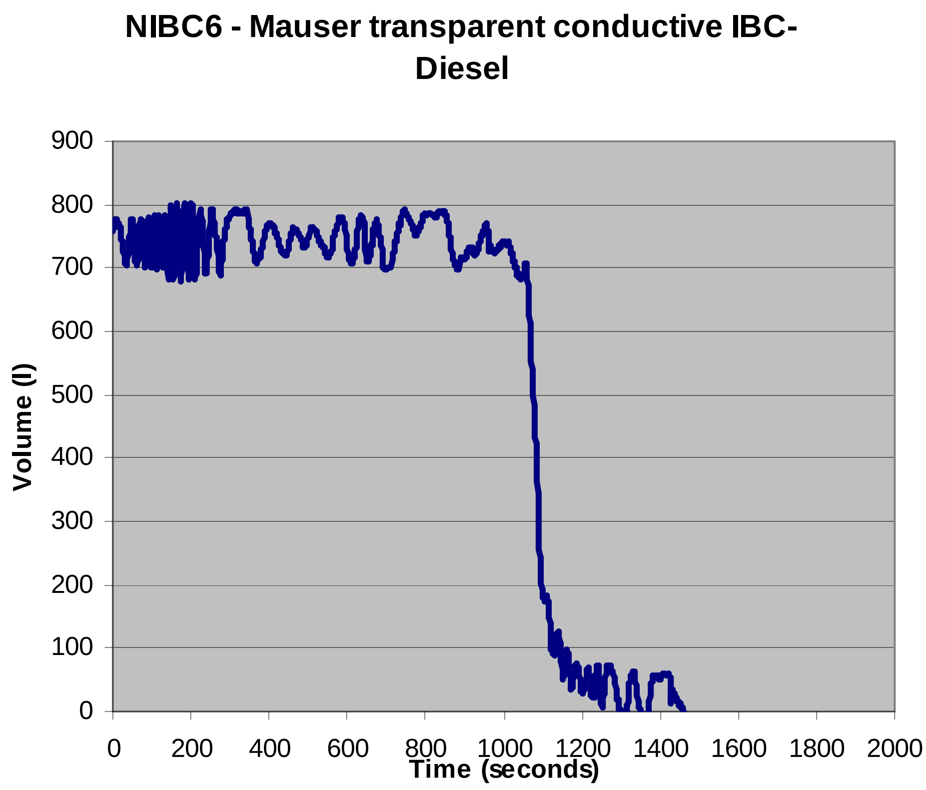
Test 10 - Diesel - Unclad - Tap ignition
800
700
600
500
400
300
200
100
0
Mass (kg)
30
25
20
15
10
5
0
Mass loss rate (kg/s)
200
300
400
500
600
Time (seconds)



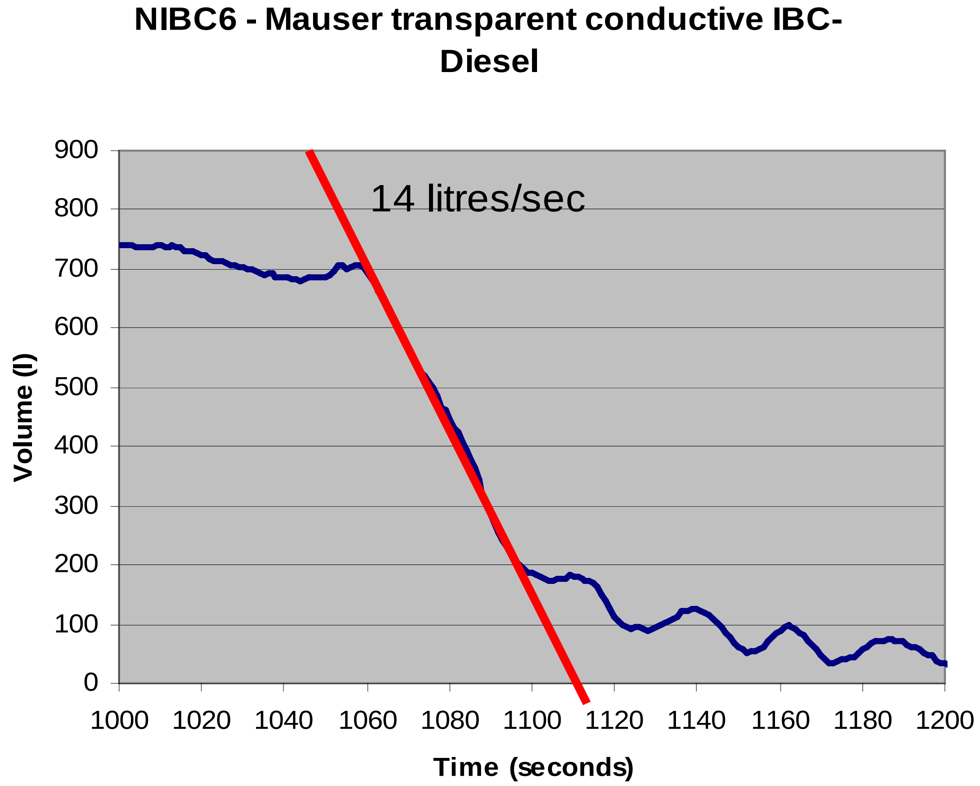
For Tests 12 to 15 see text


NIBC5 - Repaltainer EL- Diesel
900
800
700
600
500
400
300
200
100
0
Volume (l) or Temperature (°C)
14
12
10
8
6
4
2
0
Loss rate (l/s)
600
700
800
900
1000
Time (seconds)

Test 16



NIBC6 - Mauser transparent conductive IBC-Diesel
Volume (l)
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Time (seconds)



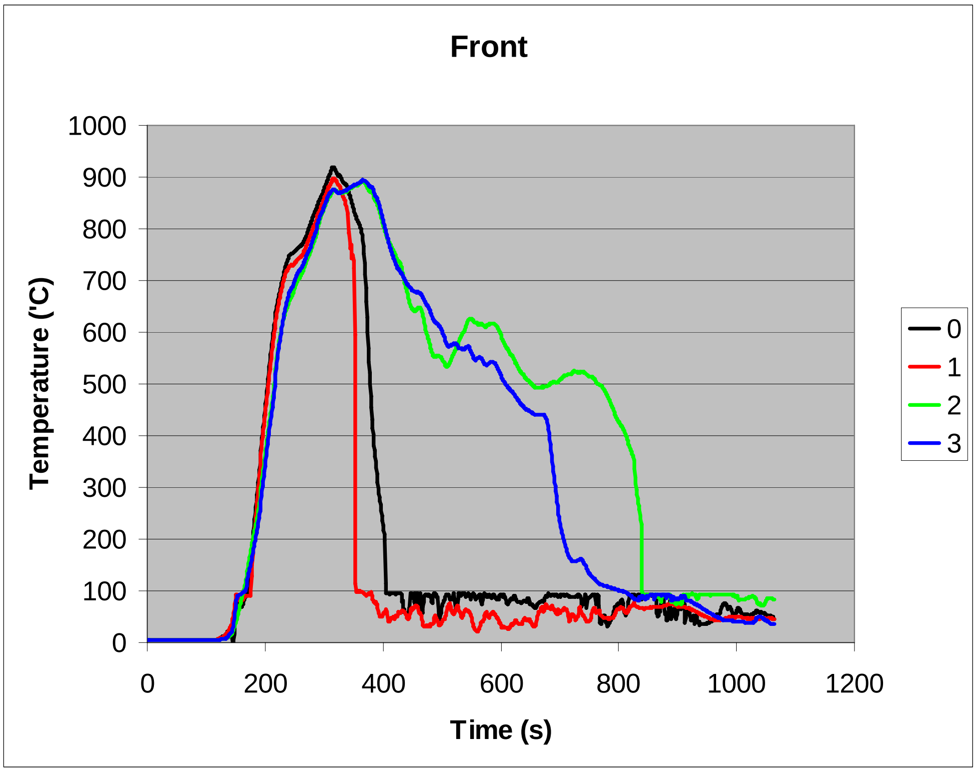
NIBC6 - Mauser transparent conductive IBC-Diesel
14 litres/sec
Volume (l)
900
800
700
600
500
400
300
200
100
0
1000
1020
1040
1060
1080
1100
1120
1140
1160
1180
1200
Time (seconds)

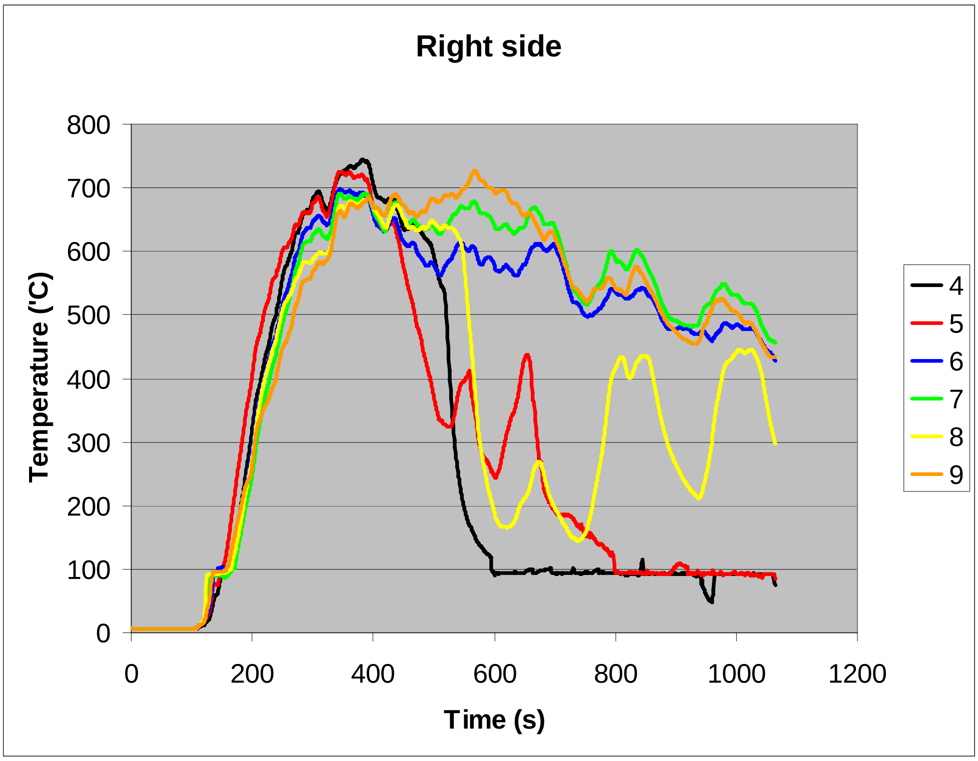
Test 17

11 APPENDIX 3 - TEMPERATURE MEASUREMENTS IN STACK TESTS

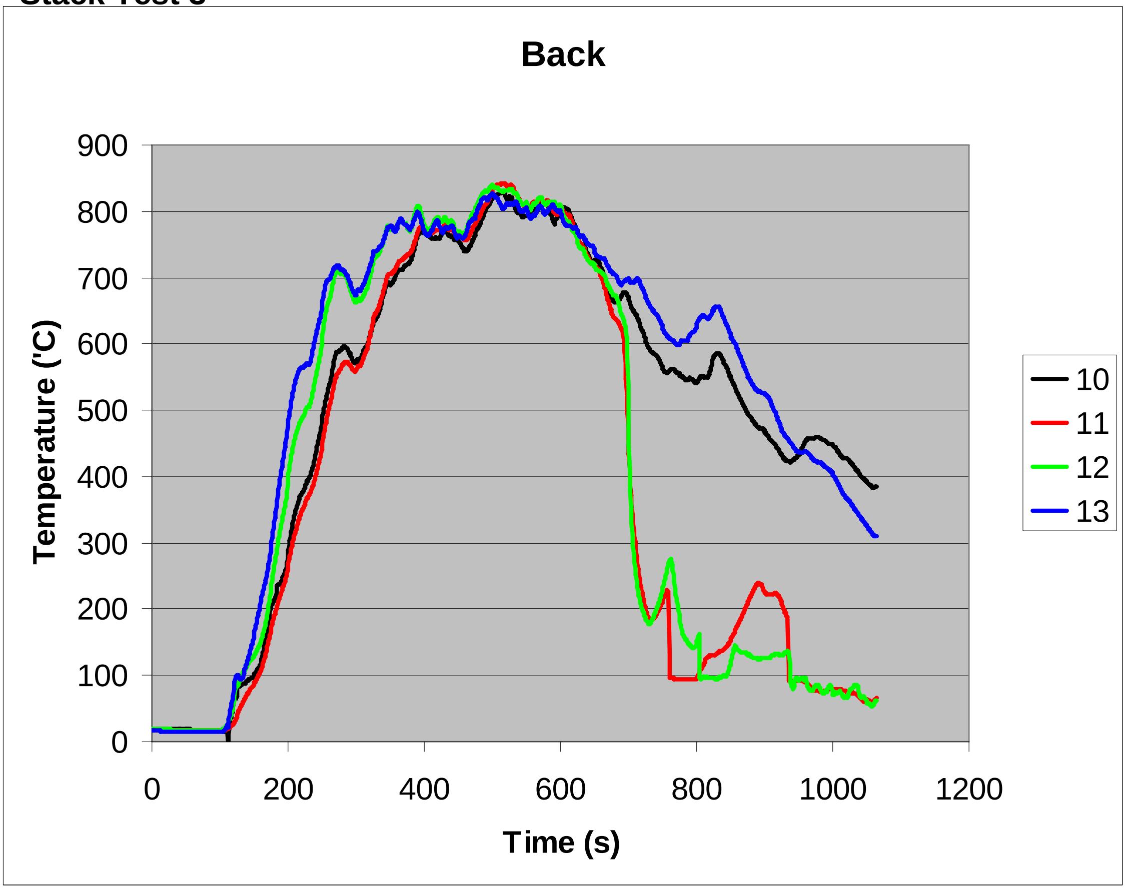
Thermocouple positions are shown in Figure 8

Stack Test 3

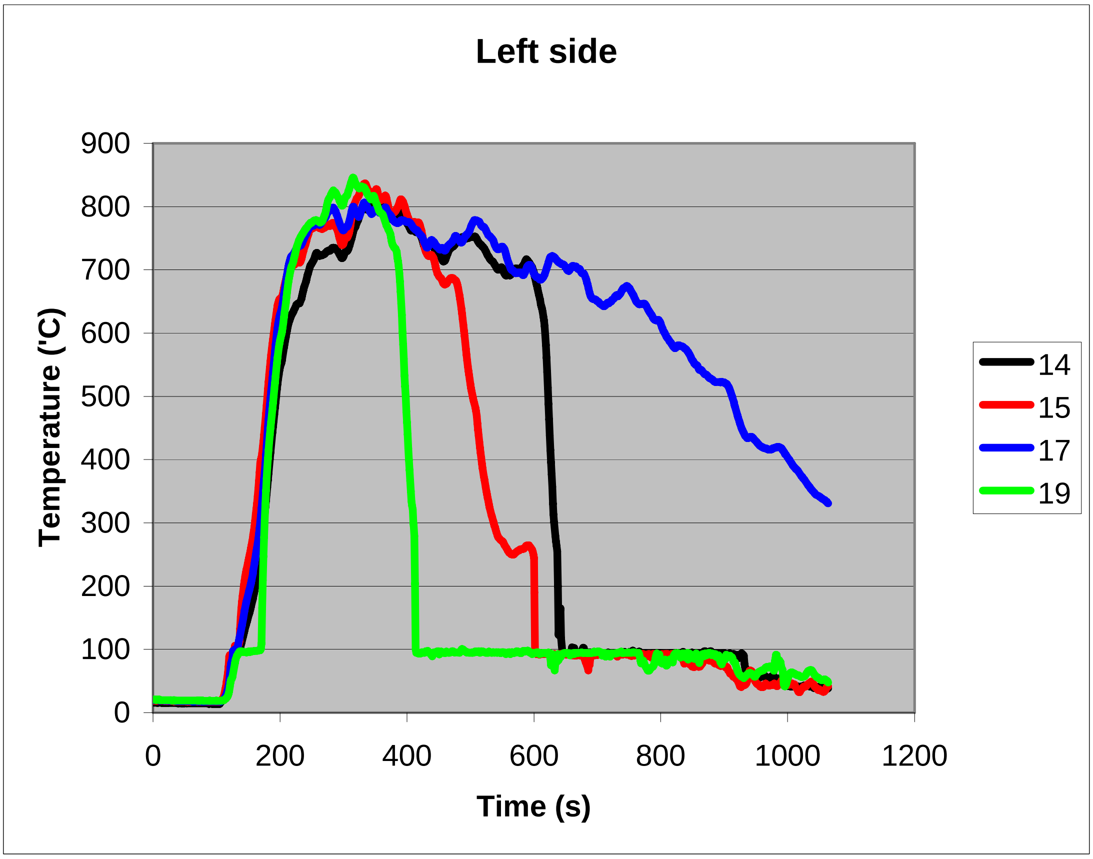




Stack Test 3

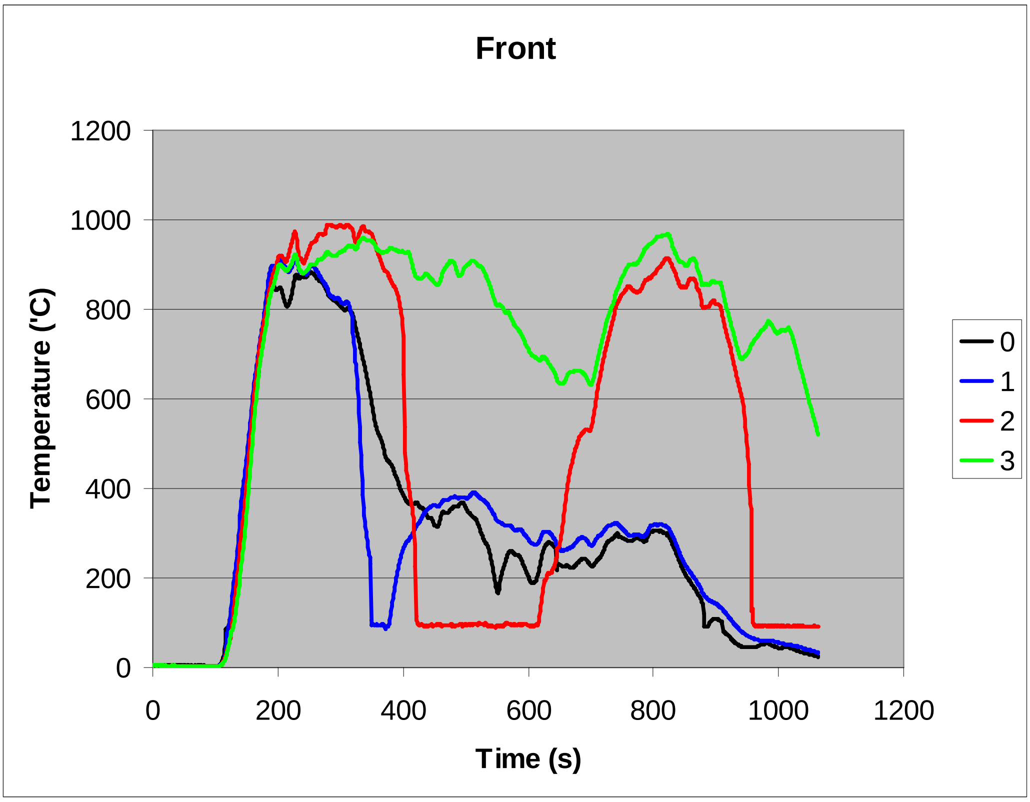


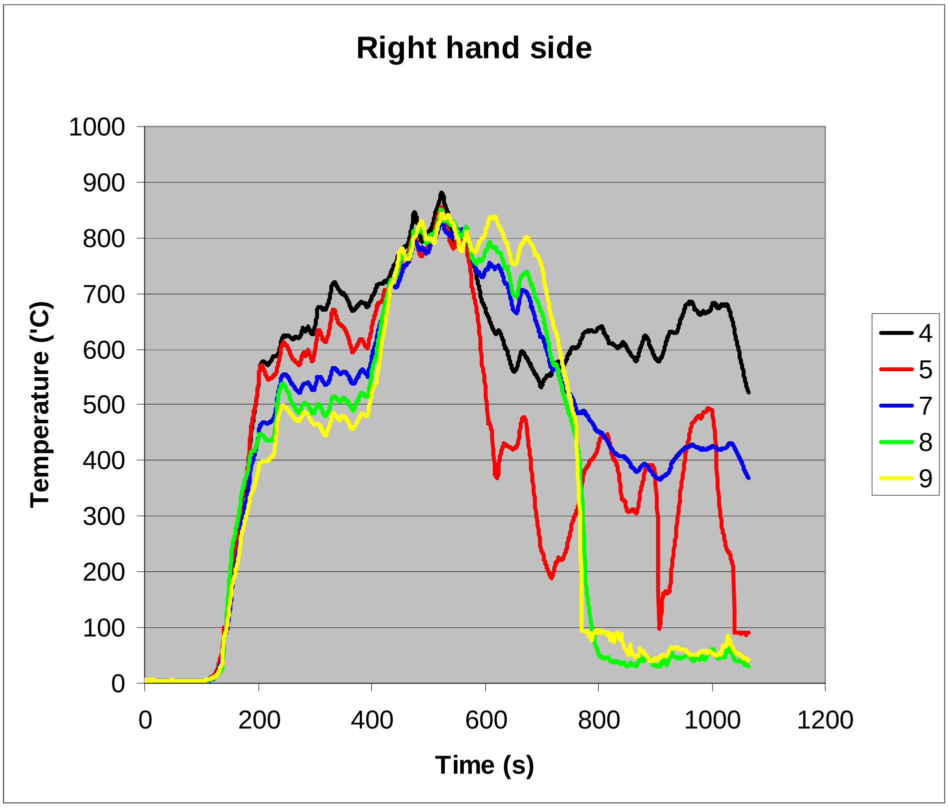
Back
Temperature ('C)
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Time (s)
10
11
12
13



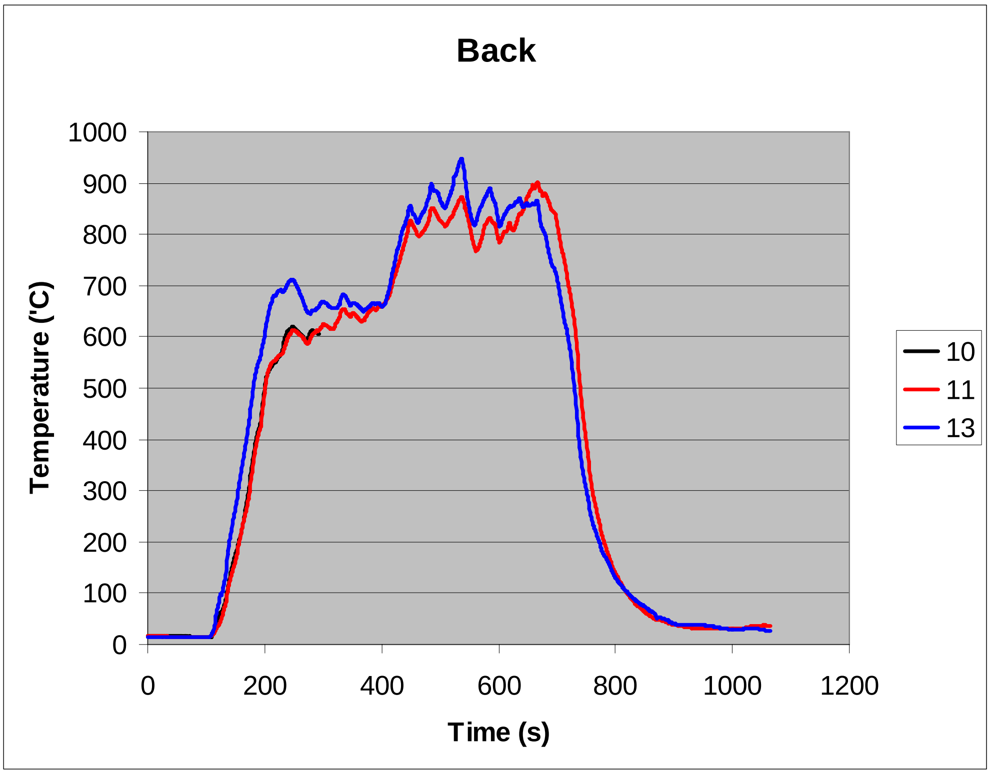
Left side
Temperature ('C)
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Time (s)
14
15
17
19

Stack Test 4

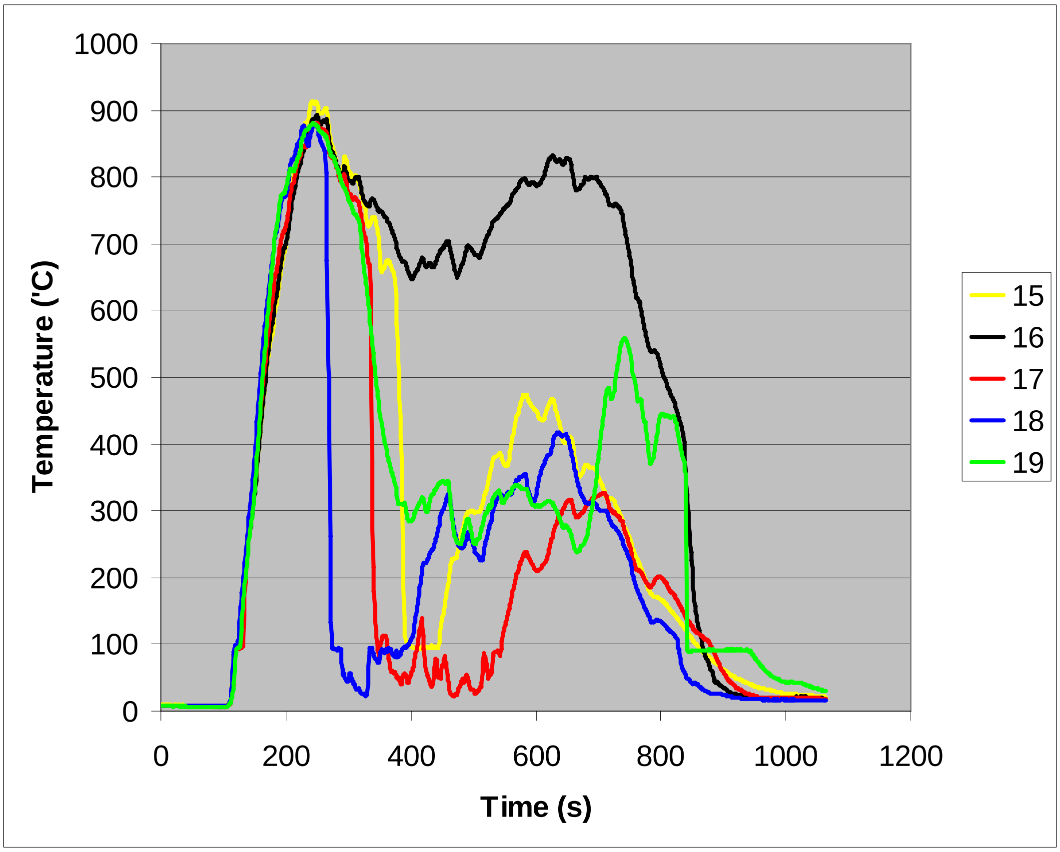

Front
Temperature ('C)
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
Time (s)
0
1
2
3


Right hand side
Temperature ('C)
1000
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Time (s)
4
5
7
8
9

Stack Test 4



Back
Temperature ('C)
1000
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Time (s)
10
11
13



Temperature ('C)
1000
900
800
700
600
500
400
300
200
100
0
0
200
400
600
800
1000
1200
Time (s)
15
16
17
18
19

12 APPENDIX 4 - FIRE PARTITIONING OF IBC STORAGE AREAS

12.1 SUMMARY

Objectives

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. A characteristic of these fires was the rapid release of liquid from IBCs, inadequacy of bunding and damage caused as a result of the unconfined flow of burning liquid.

This research project was undertaken to provide data on the vulnerability of IBCs to strong thermal radiation. This information is of interest for two reasons:

1. In establishing appropriate separation standards between IBC stocks and site boundaries.

2. To allow an informed assessment of the effectiveness of partitions in checking the spread of fire through IBC storage areas.

The work has comprised several large-scale experiments as well as some numerical modelling.

Main Findings

1. Sufficient evidence has been gathered in this project to encourage the use of partitions to check the spread of fire through an IBC storage area. Any significant reduction in the rate of fire spread gives fire fighters a better chance to control the incident.

2. If fire spread is to be prevented in the long term without intervention by fire fighters, the spread of pool fires around the seat of the fire must be controlled. This could be done using slopes, kerbs and drains.

3. This project has provided some useful data on the levels of thermal radiation that IBCs can sustain without suffering ignition.

4. Fire modelling (outside the original scope of the project) has proved useful in exploring the extent to which partitions can prevent fire spread but some more effort is required to develop design guidelines that HSE can recommend with confidence.

5. Whilst IBCs are very vulnerable to even small flaming ignition sources, the experience gained in this project suggests that they are reasonably resistant to quite high levels of thermal radiation. The guidance given on minimum separation distances to buildings and boundaries given in HSG 51 “The storage of flammable liquids in containers” could be taken over to IBCs – although the guidance currently assumes storage in steel drums.

12.2 INTRODUCTION

The use of plastic and composite intermediate bulk containers (IBCs) for the storage of liquids has increased rapidly during the last 10 years. They have a number of advantages over traditional steel drums, in particular; resistance to corrosion, efficient space utilisation in storage and ease of emptying when a valve is fitted.

The vast majority of IBCs are made from high-density polythene (HDPE). This material has only limited compatibility with organic solvents. Notwithstanding the lack of complete compatibility, plastic IBCs are also commonly used in many industries for hydrocarbons for: wastes, fuels such as diesel, solvents such as white spirit; lubricants; edible oils etc.

This research project was undertaken to provide data on the vulnerability of IBCs to strong thermal radiation. This information is of interest for two reasons:

1. In establishing appropriate separation standards between IBC stocks and site boundaries.

2. To allow an informed assessment of the effectiveness of partitions in checking the spread of fire through IBC storage areas.

The work has comprised several large scale experiments as well as some numerical modelling.

12.3 EXPERIMENTAL METHODS

Experimental layout

The experiments were carried out in the Industrial Fires Test Area at HSL. The experimental layout is shown schematically in Figure 1.

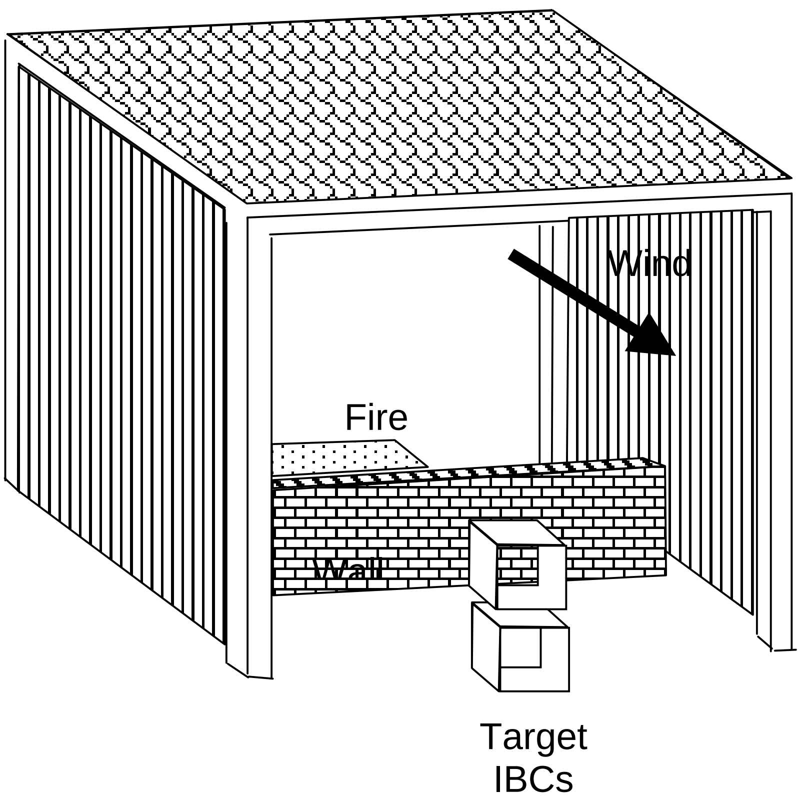


Figure 1a: Schematic showing experimental layout

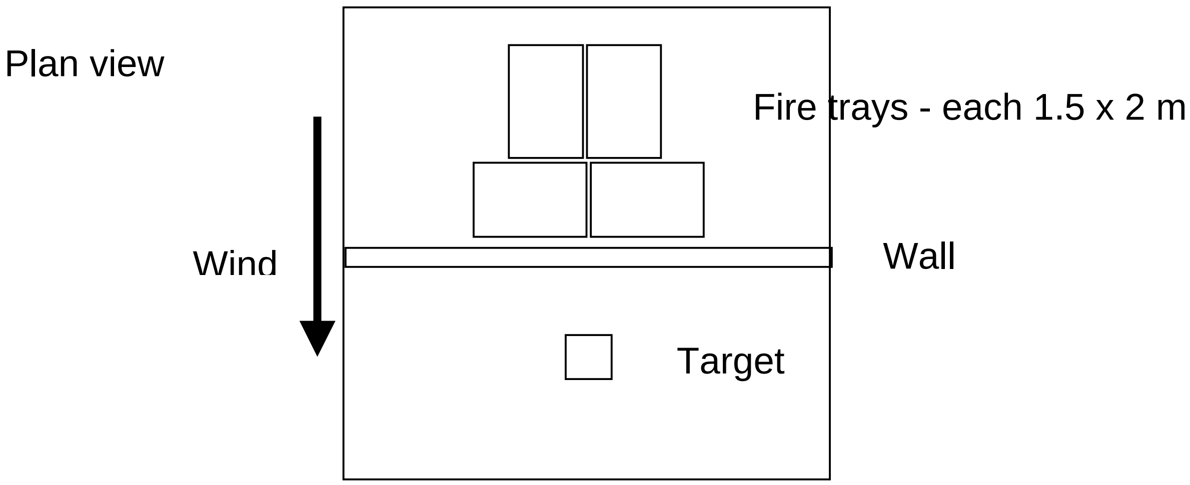


Figure 1b: Schematic (plan view) showing experimental layout

The test area was roughly square with side length 7.5m. The roof height was around 8m. The area was shielded on two sides with profiled steel sheeting.

The fire source used for all the experiments comprised 4 trays each with an area of $3m^2$. Each tray was filled with 160 kg of isopropyl alcohol.

Standard Schutz $1m^3$ MX composite IBCs were used as targets. They were filled with different combinations of liquids in the various tests.

A block-work wall height 2400mm and thickness 400 mm separated the fire source from the target IBCs. The top of the wall was level with the top of the target IBC stack. The separation between the target IBCs and the wall was varied in the test programme. The thickness and method of construction of the wall is not likely to change its effectiveness – so long as it remains standing and retains integrity and insulation for a reasonable period of fire engulfment.

In three of the four tests, a moderate (3-5m/s) wind blew flames over the wall towards the target IBCs. The general set up and flame shape is illustrated in Figure 2.

Figure 2: Experimental set up and flame shape

12.4 INSTRUMENTATION

Measurements of heat flux at the level of the top of the IBC were made calorimetrically in Tests 3 and 4.

The system used involved a controlled flow of water through round copper tubes exposed to radiant heat. The temperature of water was measured at the inlet and (after mixing) at the outlet. The set up is illustrated in Figures 3 and 4.

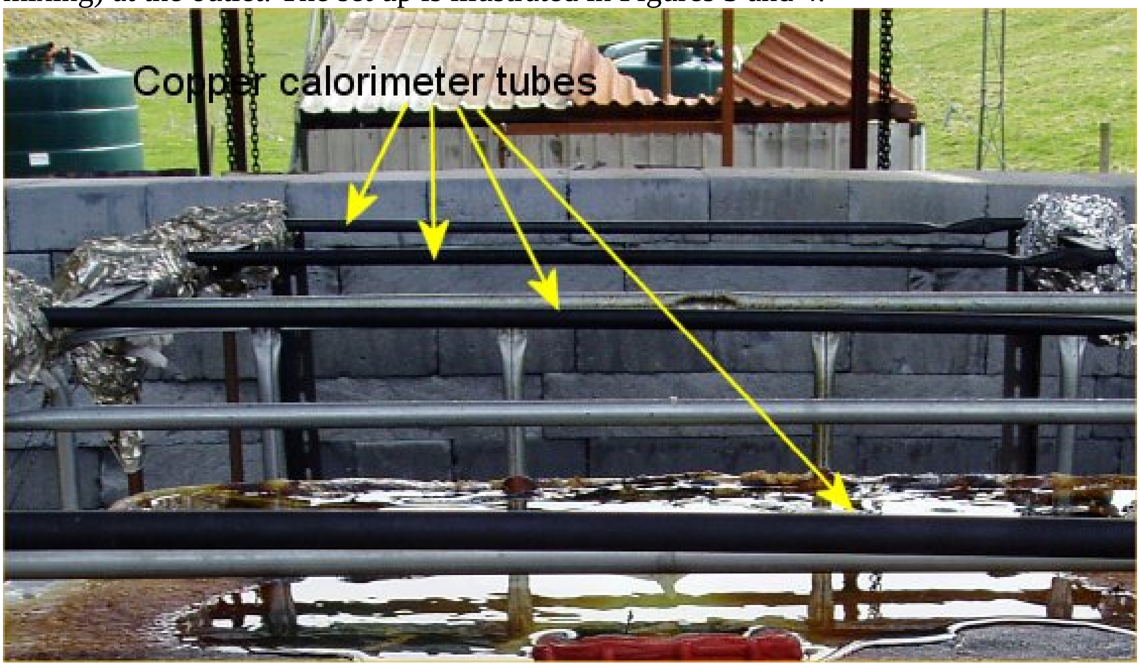


Figure 3: Calorimeter tubes level with the original surface of the IBC inner container

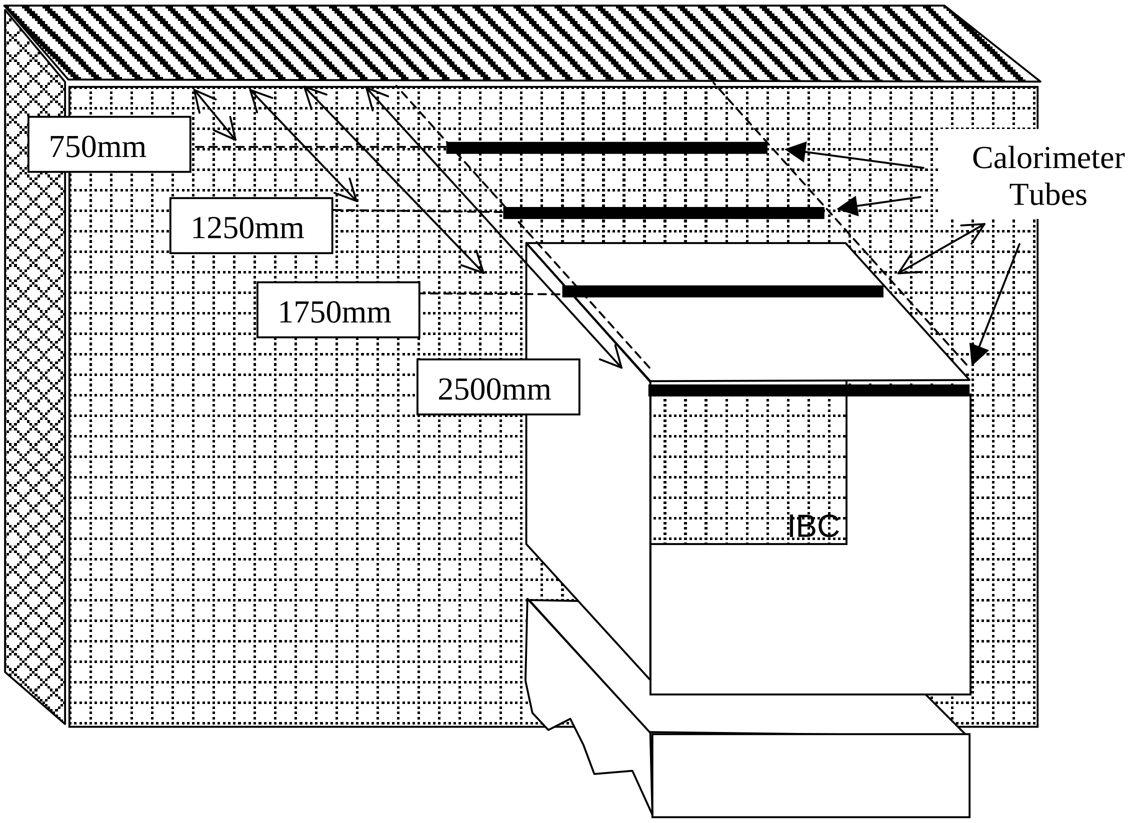


Figure 4: Location of heat flux calorimeters relative to the top of the wall.

In the two earlier tests measurements of ullage pressure and liquid level were made. Results showed extremely low levels of ullage pressurisation prior to holing of the upper surface of the the IBC. Liquid loss was also slow and more conveniently measured by dyeing the liquid contents.

12.5 EXPERIMENTAL PROGRAMME

Table 1 gives details of the target IBC type, location, fill etc.

Test	IBC type	**Minimum distance from wall (mm)**	**Water fill (litres)**	**Other fill**
Test 1	Schutx MX	750	1000	Xylene 2 litres
Test 2	Schutx MX	1500	1000	Xylene 2 litres
Test 3	Schutx MX	1500	1000	Xylene 2 litres
Test 4	Schutx MX	1500	950	Heptane 50 litres

Table 1: Details of the target IBC type, location and fill

Figure 5: Typical view of flame shape relative to target IBC

12.6 EXPERIMENTAL RESULTS

Table 2 gives an over view of the outcome of the four tests

Test	Wind speed	Wind direction	Results
Test 1	Moderate	Towards IBC	Ignition of IBC
Test 2	Low	Variable	IBC unbreached
Test 3	Moderate	Towards IBC	IBC breached. All xylene lost No ignition
Test 4	Moderate	Towards IBC	IBC breached. 15 litres heptane lost No ignition

Table 2: Summary of test outcomes

The results of heat flux measurements in Tests 3 and 4 are shown in Figures 6 and 7.

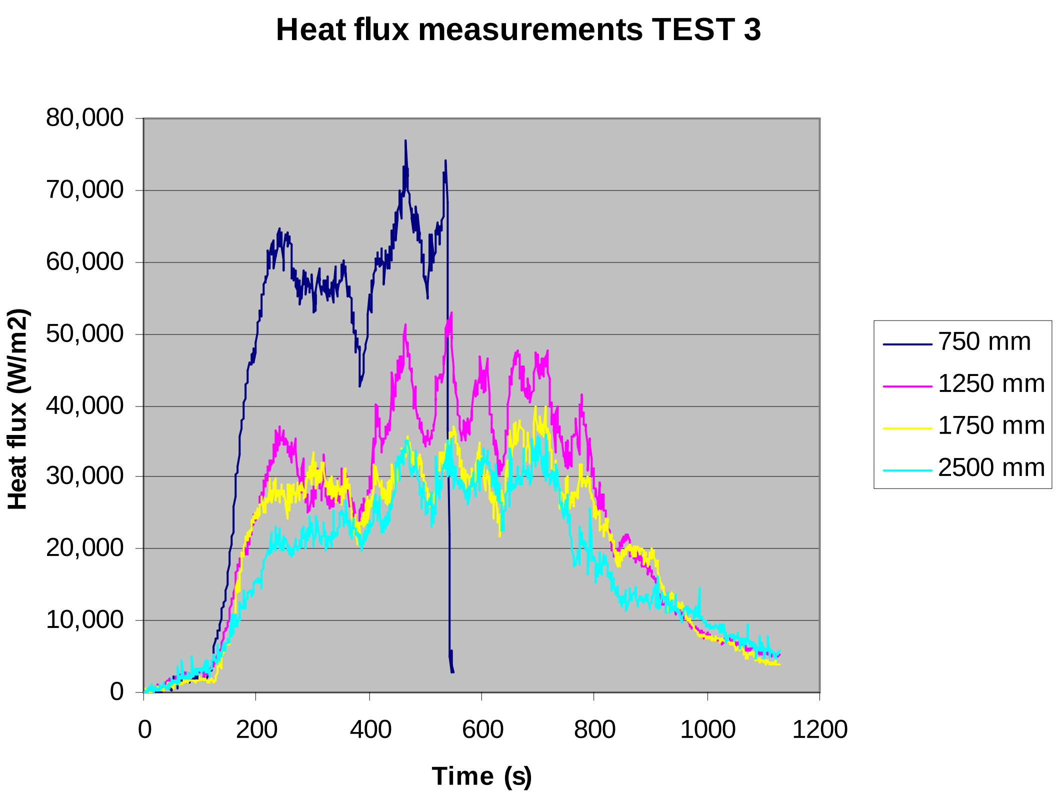


Figure 6: Heat flux measurements in Test 3

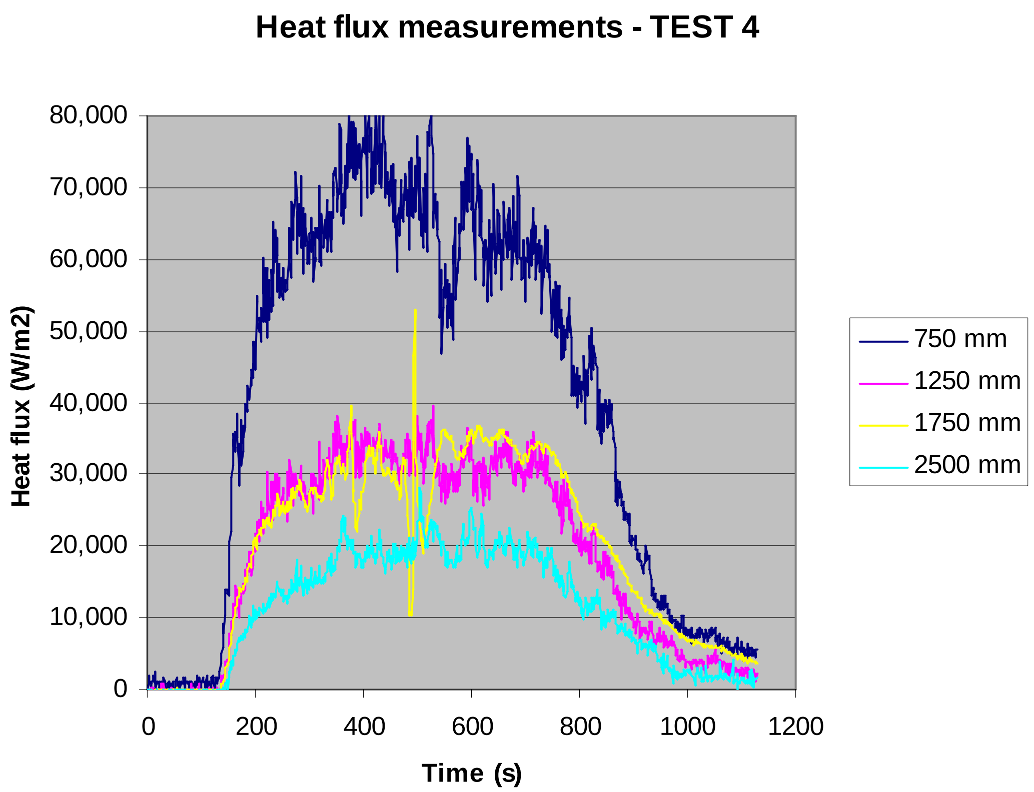


Figure 7: Heat flux measurements in Test 4

All these values are derived based on an effective receiver surface area of πrd – where r and d are the calorimeter tube radius and exposed length.

Boiling made data form the calorimeter closest to the fire in Test 3 was unreliable after about 530 seconds.

Average values of heat flux for the middle part of the tests are shown in Table 3.

Distance from partition Distance from edge of fire	750 mm 1150 mm	1250 mm 1650 mm	1750 mm 2150 mm	2500 mm 2900 mm
Average Heat Flux (kW/m^2) Test 3	58.7	32.9	28.9	24.4
Average Heat Flux (kW/m^2) Test 4	66.4	31.9	31.7	19.8

Table 3: Average heat fluxes during Tests 3 and 4

The data are reasonably consistent between tests. Differences are likely to be caused by variations in wind speed and direction. Wind conditions in Test 4 were more stable and this is reflected in relatively stable heat flux results.

Photographs of the remains of the IBC after tests are shown in Section 12.16.

12.7 DISCUSSION

When the target IBC was positioned with the front face 750 mm from the partition (1150 mm from the edge of the fire) there was spontaneous ignition of plastic closest to the flames after around 300s. Given the rate of irradiation of around 60 kW/m2 at this location, this is not surprising.

When the target IBC was moved to 1500 mm from the partition heat fluxes declined to 30-40 kW/m^2 and there was no ignition. In Test 3 two litres of xylene on the top of the target IBC was vaporised without ignition. In Test 4 fifteen litres of the heptane vaporised - 35 litres remained in the IBC at the end of the test – again there was no ignition.

Videos from two angles are available for the tests. These are particularly useful in showing the heptane vapours released in Test 4.

Heptane fumes could be clearly seen escaping from the IBC and the liquid on top was boiling vigorously. Some at least of these heavy vapours were picked up by and mixed into the strong re-circulating flow on the IBC side of the wall. On several occasions there appeared to be minor vapour/air explosions above the target IBC but none of these resulted in sustained ignition of the liquid heptane.

Figure 8: A sequence of images showing heptane combustion. This event was accompanied by a loud bang.

These experiments suggest that partitioning of IBC storage areas can help control the risk of fire spread even in unfavourable wind conditions and for volatile solvents. Significant separation (>1900 mm) between stored IBCs and the fire side of the partition must be maintained.

The results suggest as a rule of thumb that IBCs are likely to survive (unpiloted) irradiation up to at a level of around 35 kW/m^2. Heat fluxes of 60 kW/m2 are almost certain to cause fire spread.

12.8 NUMERICAL MODELLING

The experimental programme was only able to cover a relatively narrow range of fire sizes and wind speeds.

It is clear that larger fire sizes will produce larger flames, increased view factors and higher heat fluxes to target IBCs. The effect of higher wind speeds is less easy to predict. Flame deflection will increase view factors but more rapid entrainment of air into the flames may reduce flame temperatures and surface emissive powers.

To gain a fuller understanding of the potential limitations of partitions in checking the spread of fire, it was necessary to broaden the analysis to other circumstances. Computational fluid dynamics allows the calculation of heat fluxes caused by fires in a range of circumstances. These fluxes can then be compared with the limiting heat fluxes - below which ignition was not observed

The numerical code chosen was FDS4 (Fire Dynamics Simulator – Version 4) developed by NIST – formerly the American National Bureau of Standards. Full details of the technical content of the numerical scheme and physical sub-models are available on the NIST website.

12.9 COMPARISON WITH EXPERIMENT

Figures 9 and 10 show results from a simulation that corresponds fairly closely to the experimental set up – with a wind speed of 5 m/s. The burning rate of the pool has been taken from the experimental burn time and the known heat content of propyl alcohol.

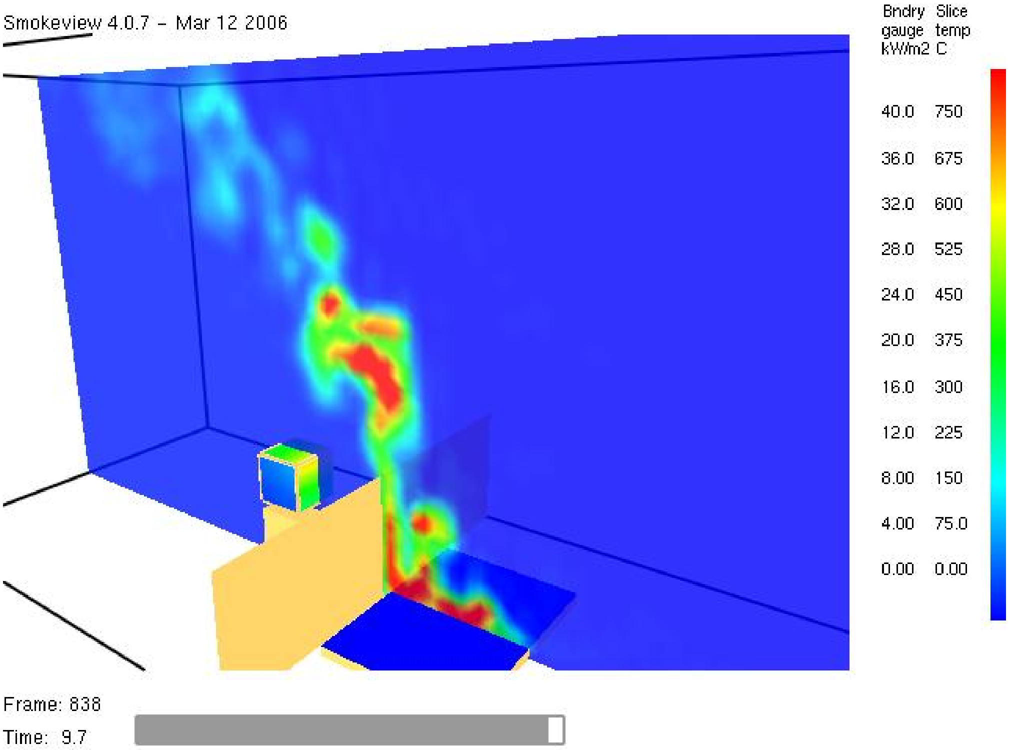


Figure 9: Centreline slice temperatures and heat fluxes to target IBC

The main difference between simulation and experiment is that the wall thickness is zero in the model. This does not change the flow much – as in both cases the flow separates cleanly at the top of the fire side of the wall - but it means that comparisons have to be based on the distance from the target to the fire.

The horizontal and vertical components of heat flux predicted at the front edge of the target IBC (1600mm from the fire in the simulation) are 27 kW/m^2 and 21 kW/m^2 respectively. The magnitude of the total heat flux is the square root of the sum of the squares of horizontal and vertical components. At a distance of 1500mm from the fire the magnitude of the total heat flux is therefore around 34 kW/m^2.

Measurements of heat flux at various distances form the fire are shown in Figure 10. The measured heat flux at 1600mm from the fire is around 35 kW/m2 – which is roughly in agreement with the results of the simulation.

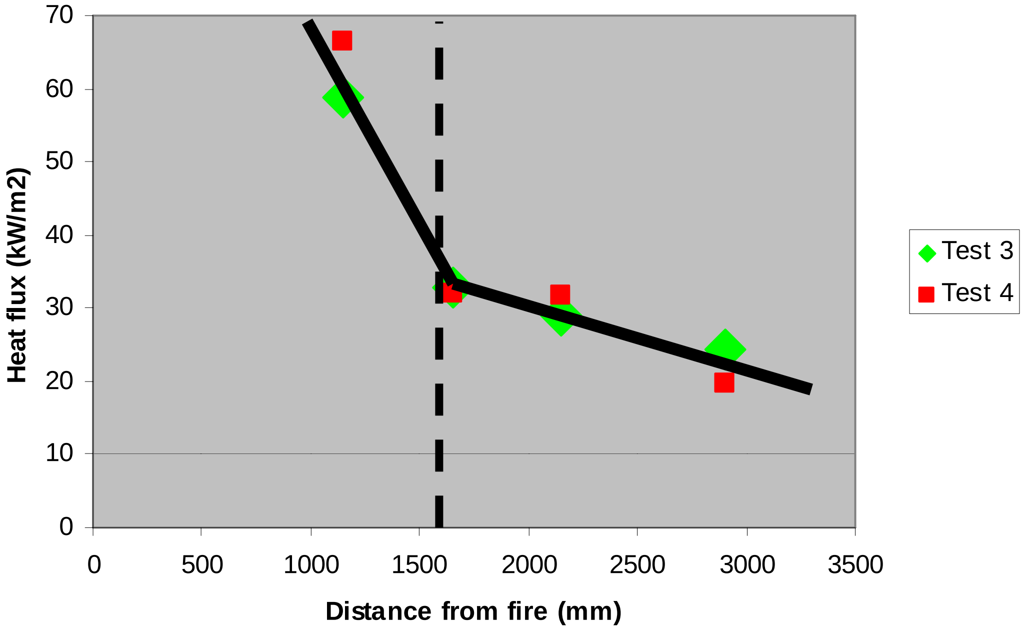


Figure 10: Measurements of heat flux measured at different distances from the fire

These results give some confidence that the modelling can correctly predict heat flux levels and will give sensible guidance on the likelihood of ignition in a range of different wind and fire conditions.

12.10 SCOPE OF EXTENDED NUMERICAL STUDY

In addition to the $12m^2$ open pool fire described above, three other fire geometries have been studied - these are illustrated in Figures 12 to 14. In all cases the simulation includes the blocking effect of a number of IBCs. This can have a significant effect on the flow – especially on the fire side.

All of the simulations have been run using a single central plane of symmetry (Figure 11). This reduces the numerical effort required and run time by a factor of two without reducing the accuracy of the simulation.The model calculates the flow for both halves of the problem (64 IBCs) but only half of the solution is displayed – the other half is a mirror image.

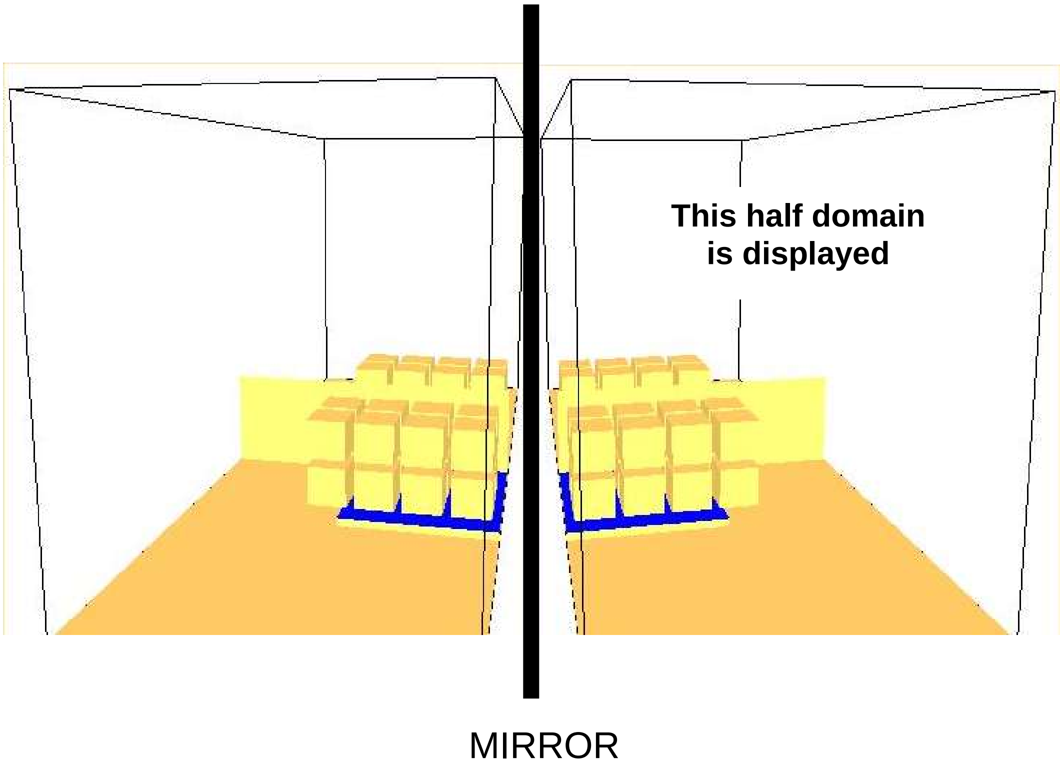


Figure 11: Schematic showing how a plane of symmetry is used to reduce the computational effort required

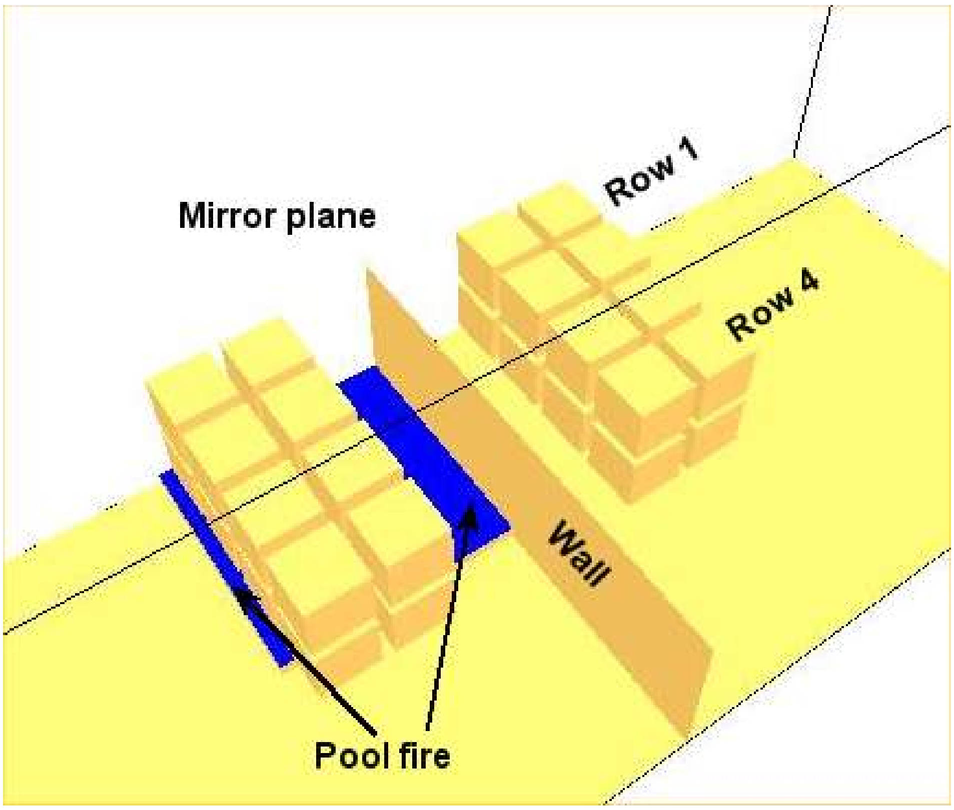


Figure 12: Geometry of the (half) domain used for the “8 x 4 fire”

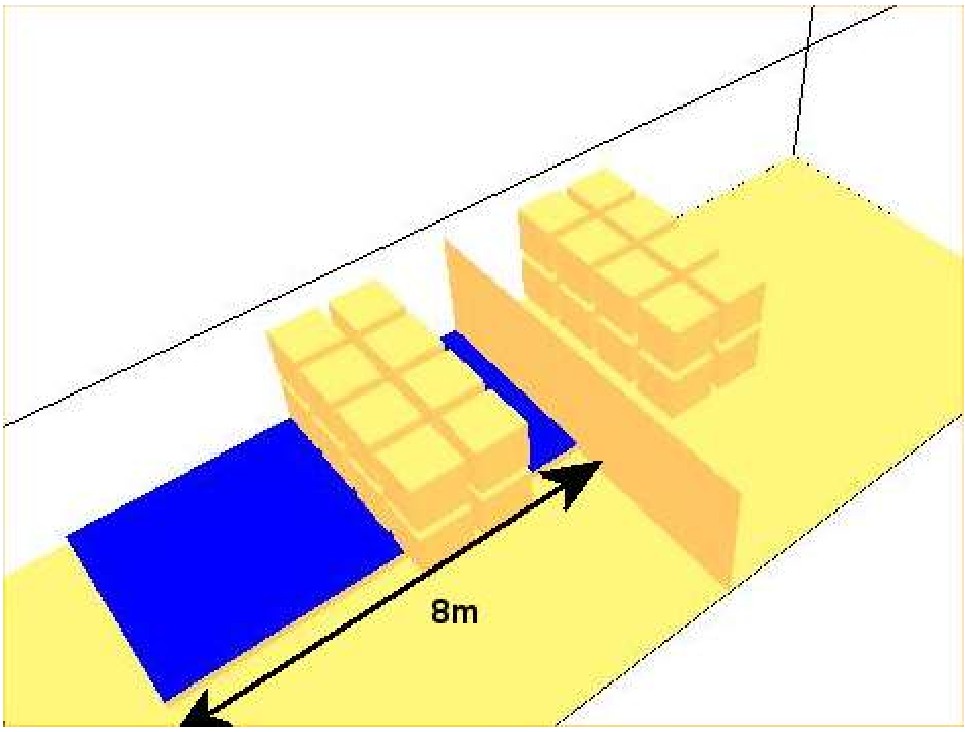


Figure 13: Geometry of the (half) domain used for the “8 x 8 fire”

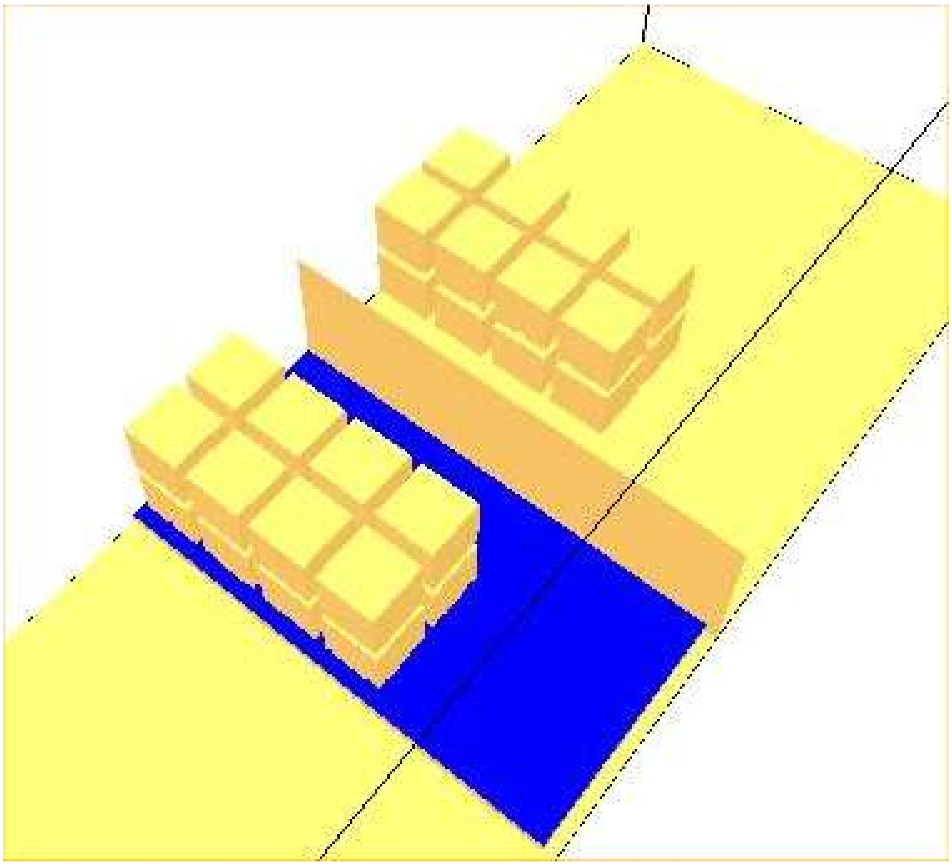


Figure 14: Geometry of the (half) domain used for the “16 x 4 fire”

A uniform cubical grid was used (200,000 cells).

The layout of the grid in the xz plane is illustrated in Figure 15.

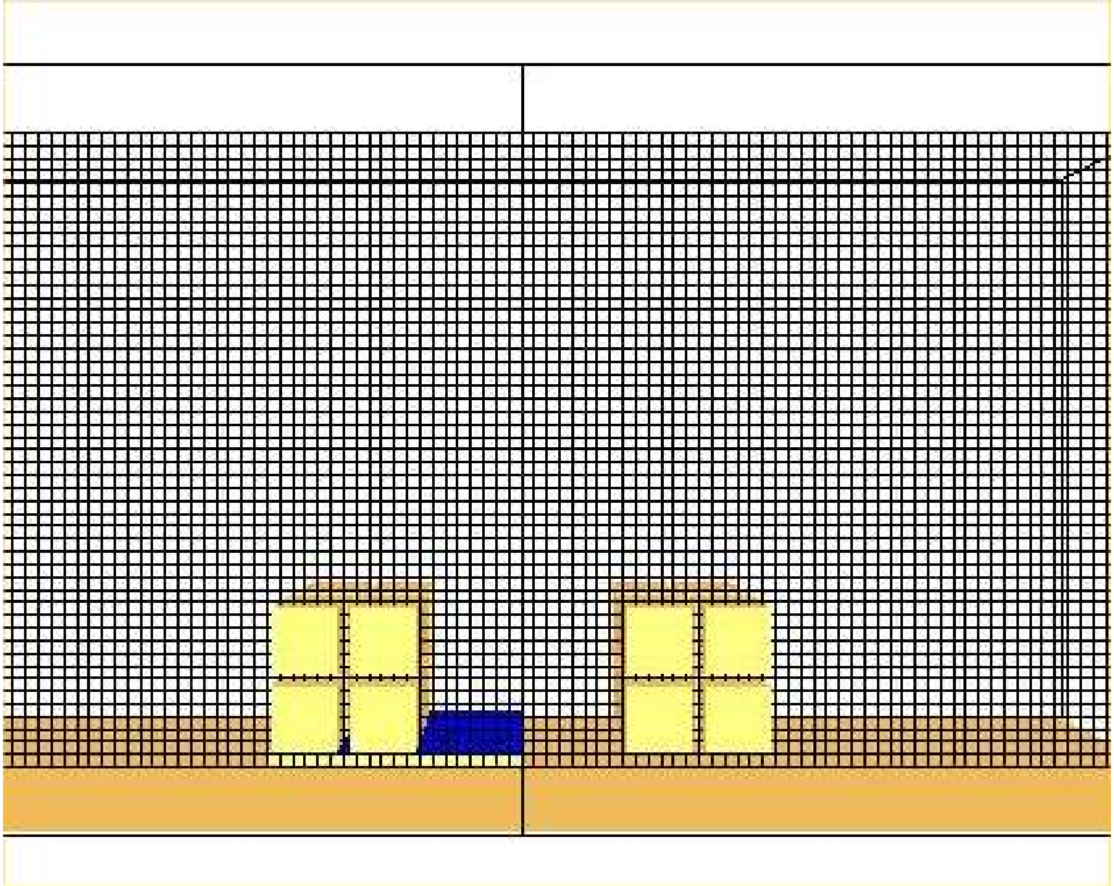


Figure 15: Side view of typical computational grid

A rapid reaction, mixture-fraction combustion model was used.

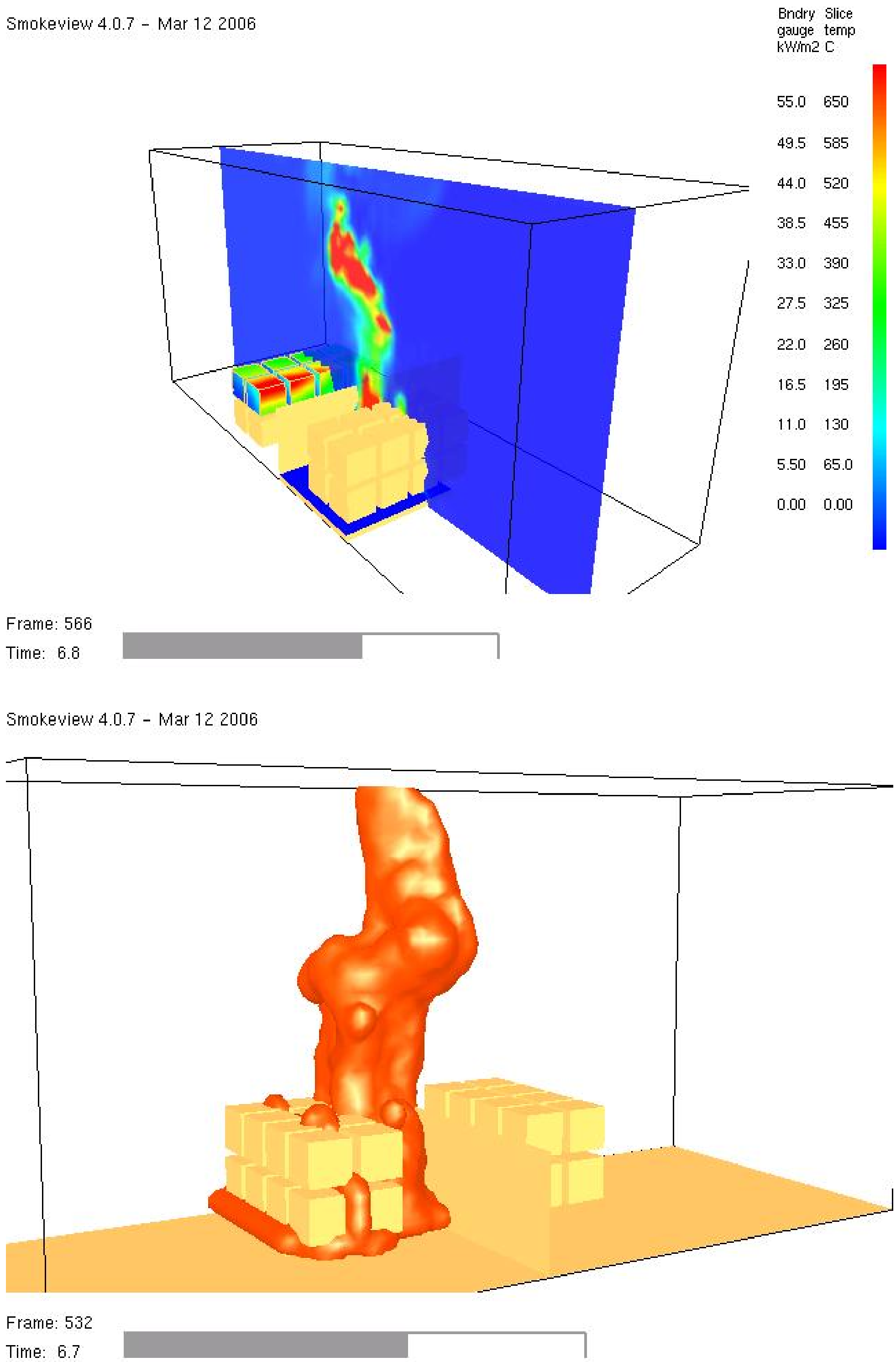
The pool burning rate was 3MW/m2 which is characteristic of a low molecular weight hydrocarbon e.g. hexane.

The surface emissivity of flames was assumed to be characteristic of low molecular weight hydrocarbons. The radiative fluxes for other (strongly sooting) fuels would be lower.

12.11 NUMERICAL RESULTS

Some plots showing the general character of the flow in all of the cases studies are shown in Figures 16 to 23

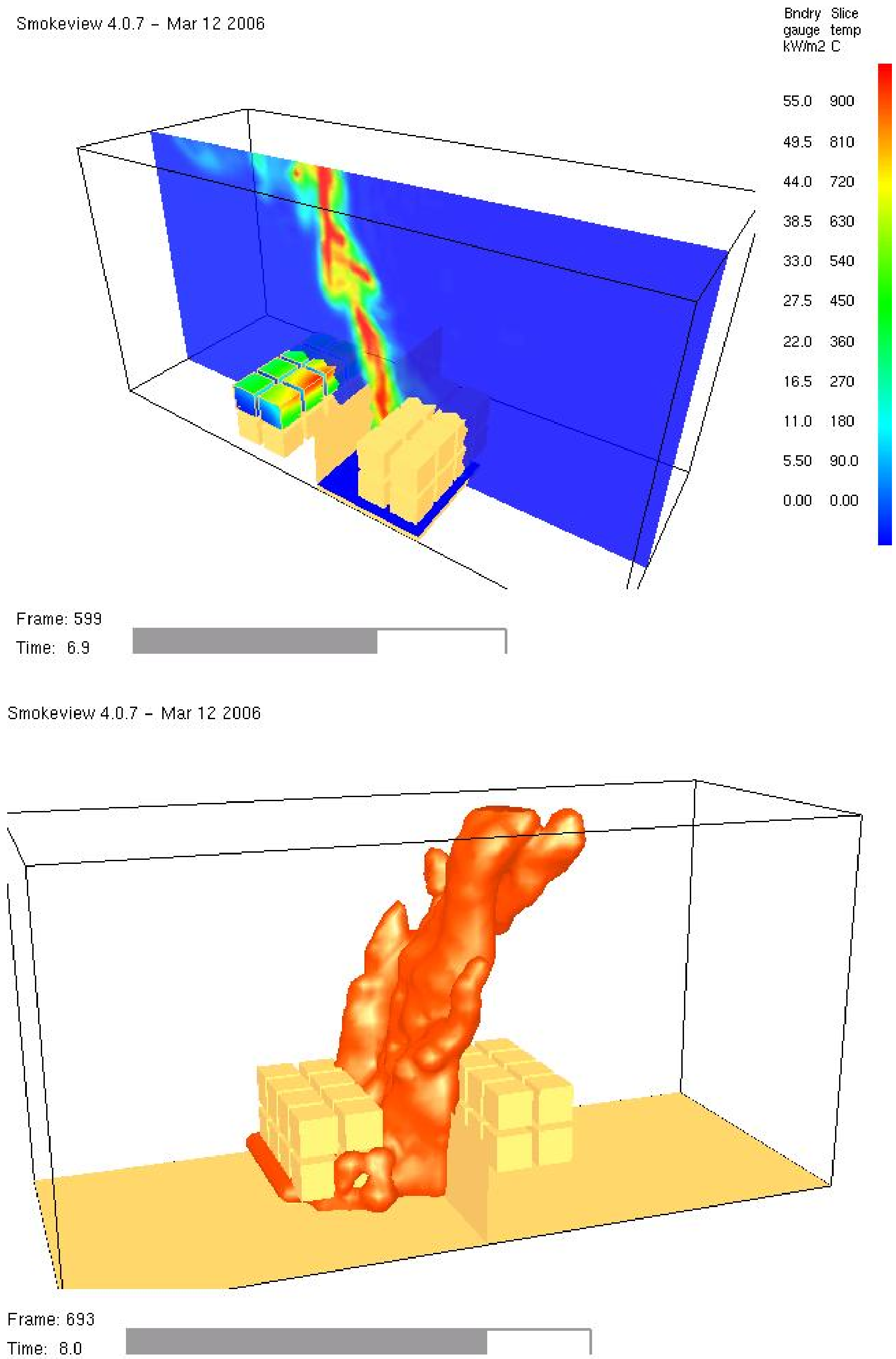
A summary table of total heat flux (as well as vertical and horizontal components) is shown in Table 4. The highest heat fluxes are shown - sometimes these are not found at the centre of the target IBC group. This table indicates which combinations of wind and fire size would lead to fire spread, which would not, and which are marginal.



Fire geometry “8x 4m”
Wind speed 2 m/s

Figure 16 Above - Temperature on a slice through the domain and IBC heat fluxes

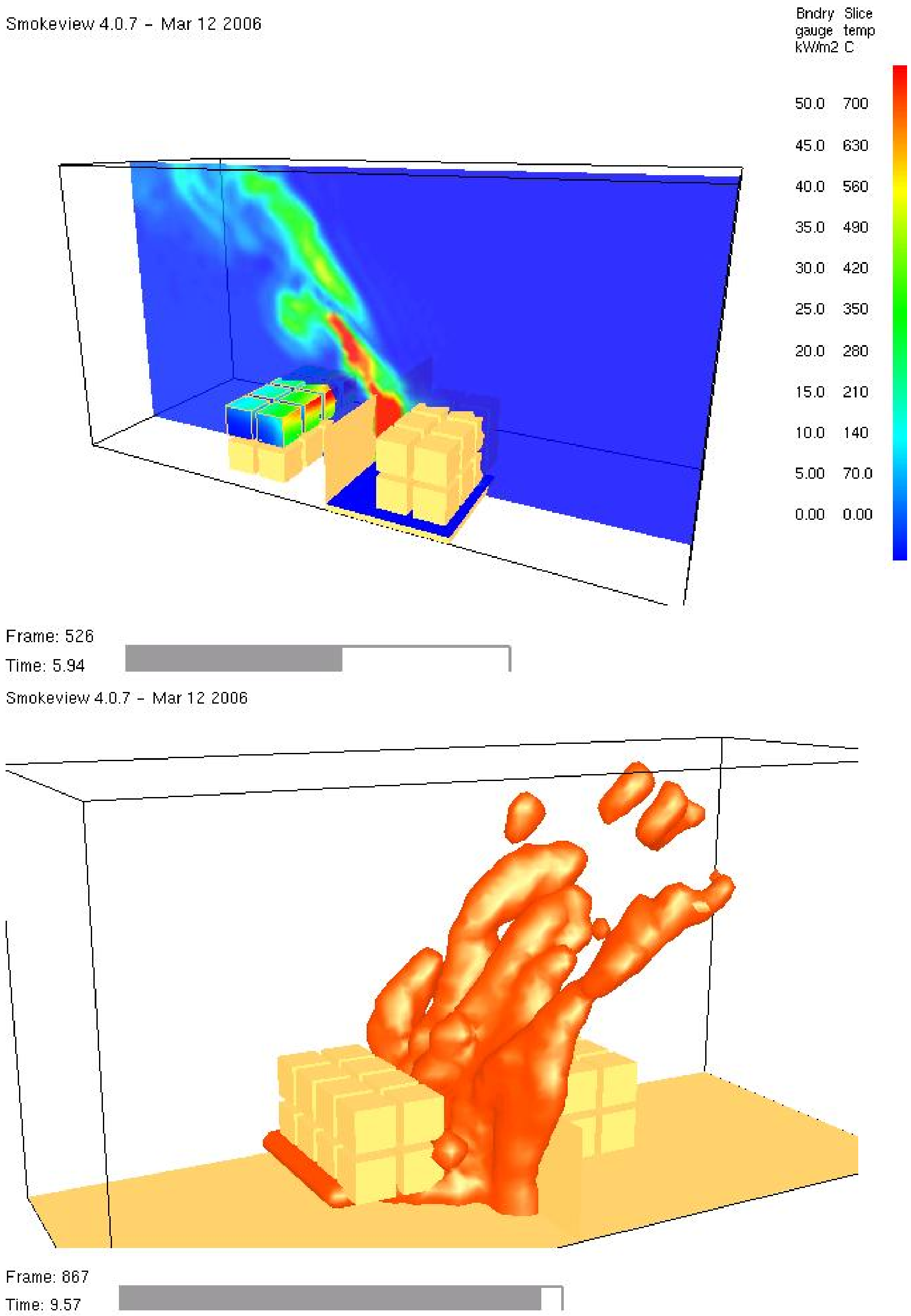
Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.



Fire geometry “8x 4m”
Wind speed 5 m/s

Figure 17 Above - Temperature on a slice through the domain and IBC heat fluxes

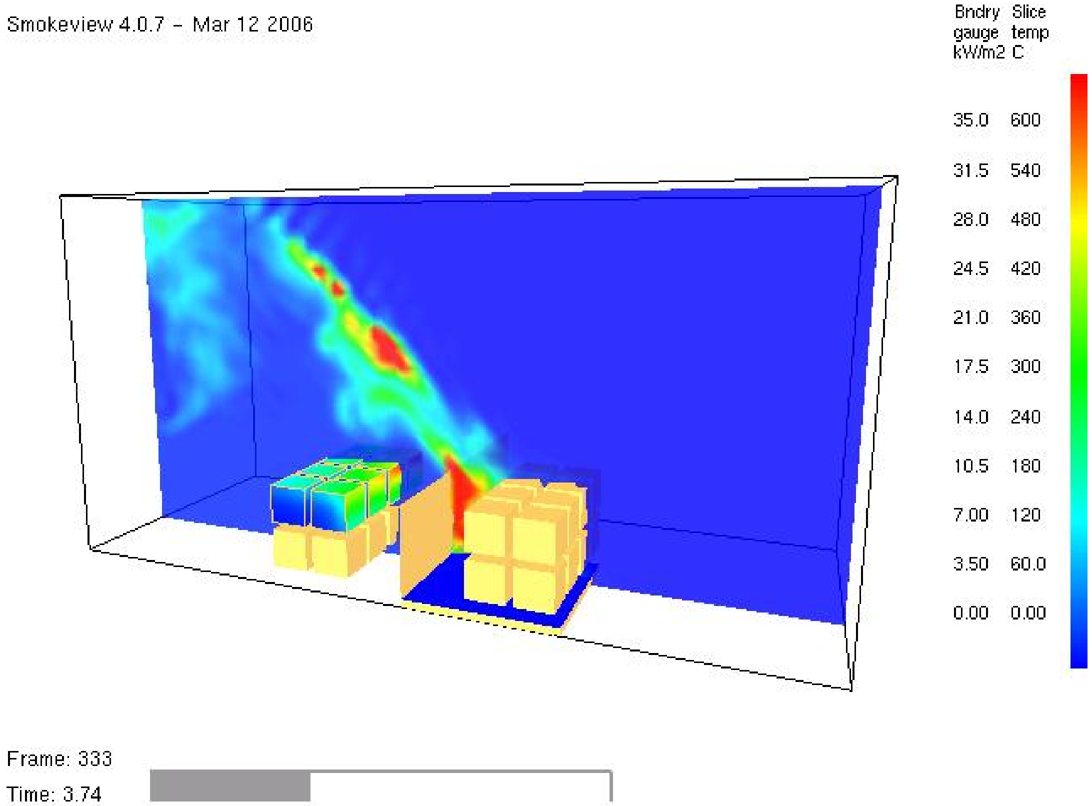
Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.

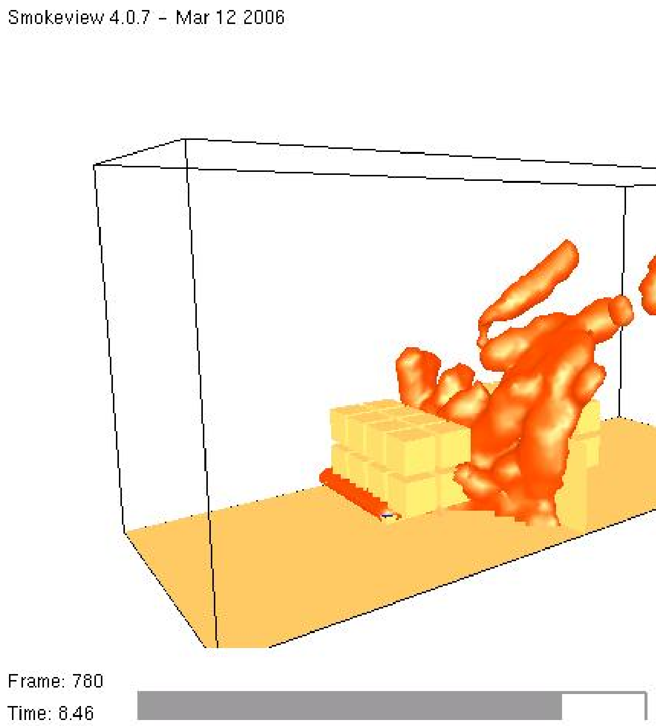


Fire geometry “8x 4m”
Wind speed 10 m/s

Figure 18 Above - Temperature on a slice through the domain and IBC heat fluxes

Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.

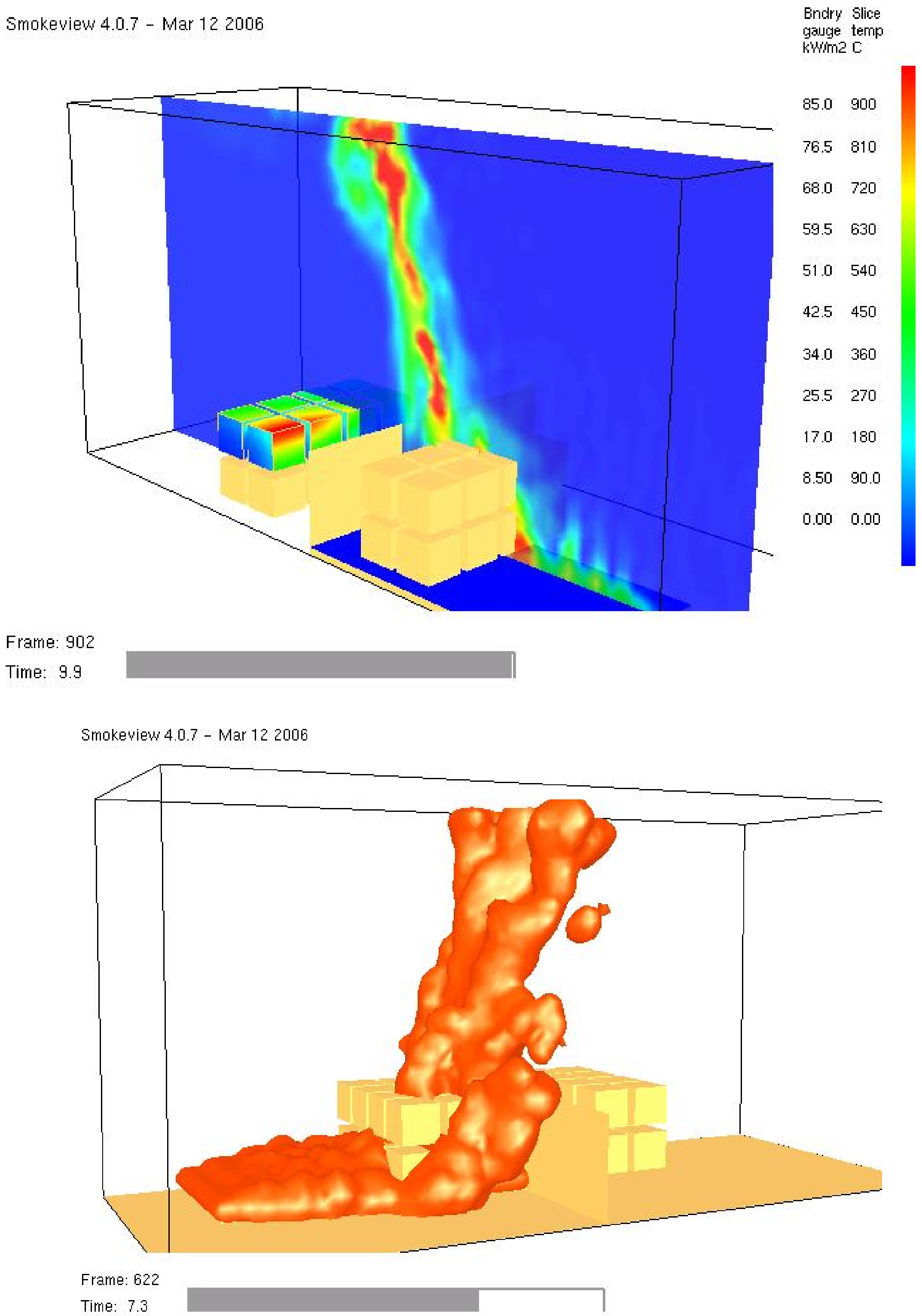




Fire geometry “8x 4m”
Wind speed 15 m/s

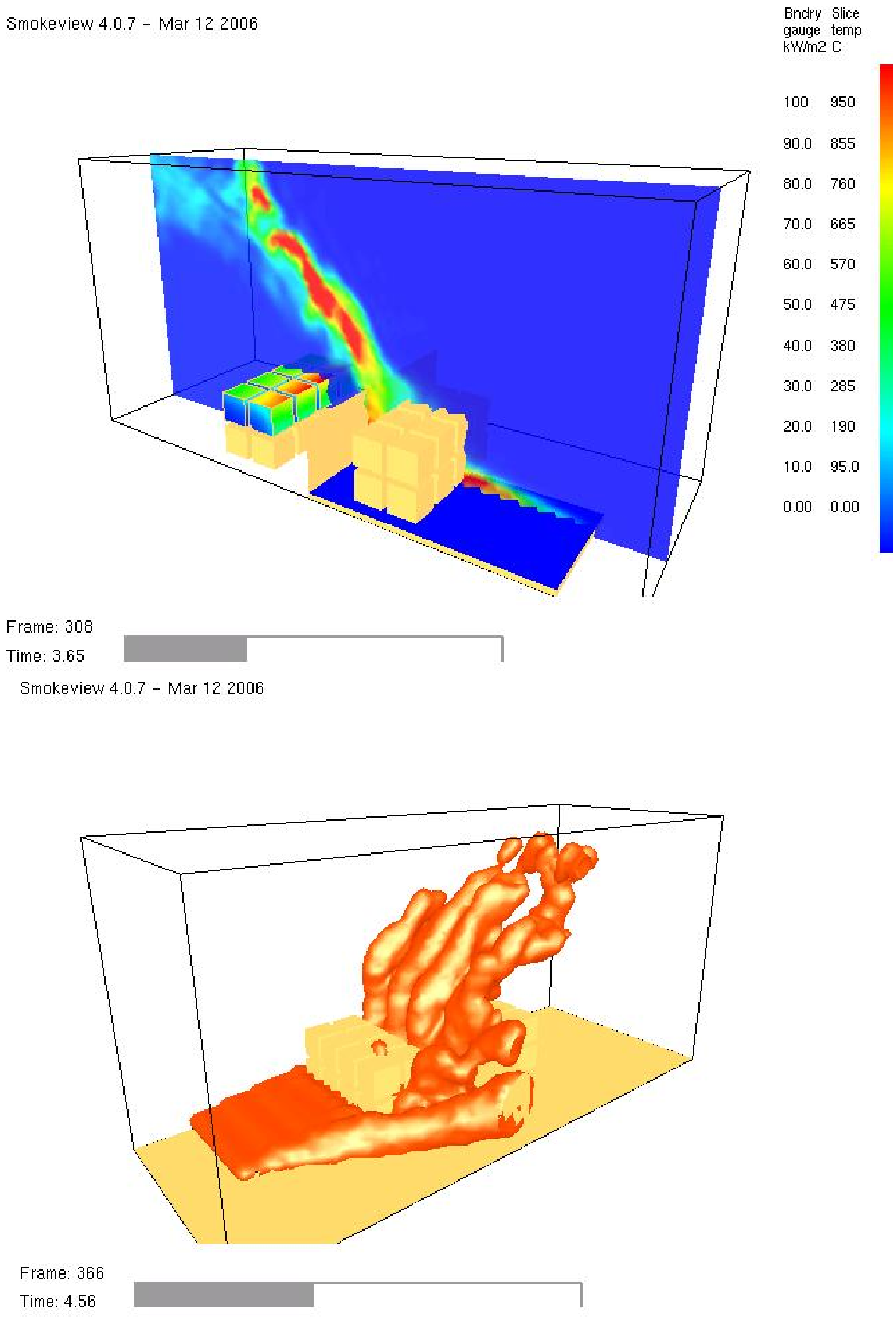
Figure 19 Above - Temperature on a slice through the domain and IBC heat fluxes

Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.



Fire geometry “8 x 8 m”
Wind speed 5 m/s

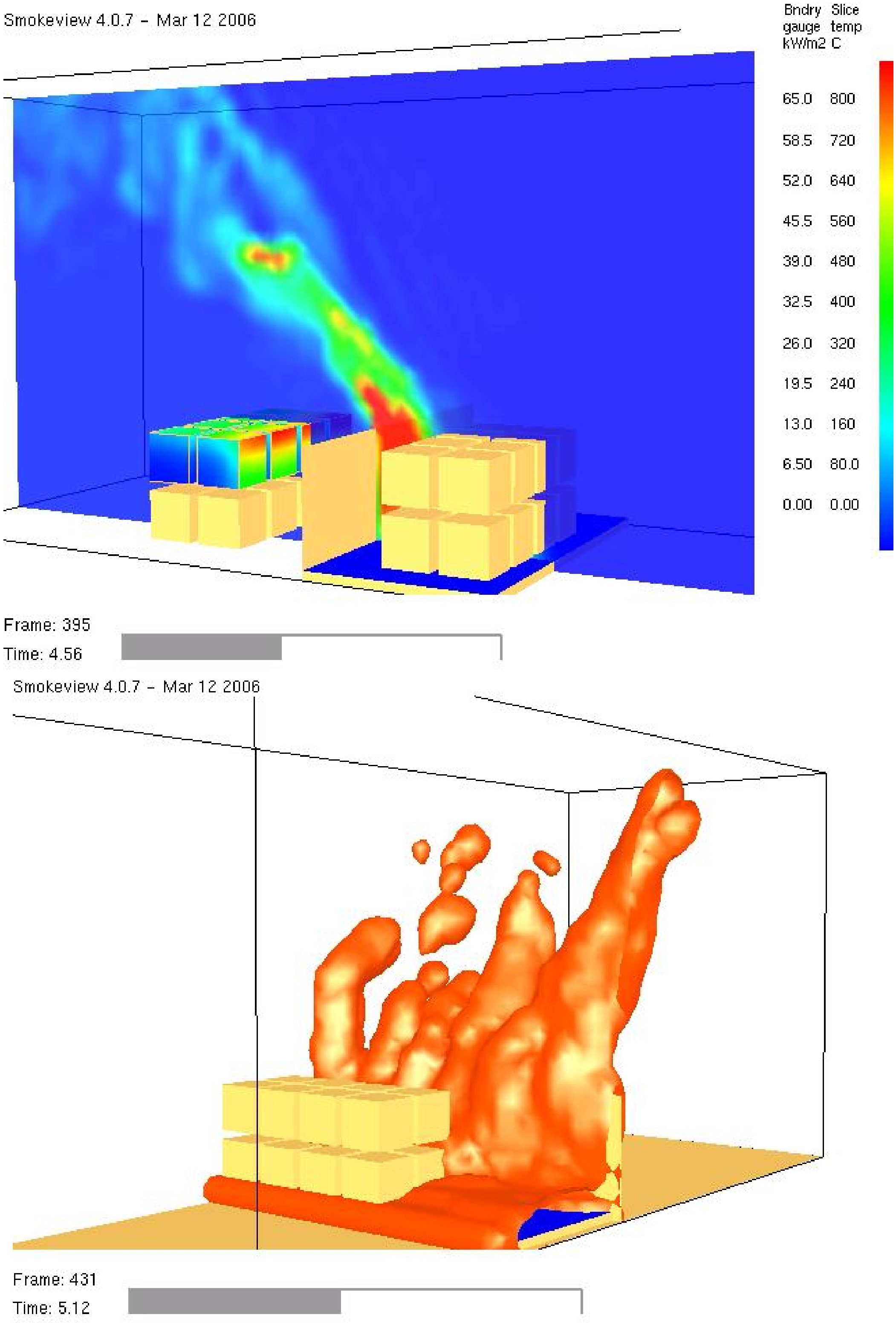
Figure 20 Above - Temperature on a slice through the domain and IBC heat fluxes
Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.



Fire geometry “8 x 4m”
Wind speed 10 m/s

Figure 21 Above - Temperature on a slice through the domain and IBC heat fluxes

Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.



Fire geometry “16 x 4m”
Wind speed 10 m/s

Figure 22 Above - Temperature on a slice through the domain and IBC heat fluxes

Below – Iso contour of heat release rate (114 kW/m^3) – indicates flame shape.

Target IBC 1600 mm from fire					
Fire geometry	Wind speed (m/s)	Fire size (m^2)	Vert.heat flux (kW/m^2)	Horiz. heat flux (kW/m^2)	Total heat flux (kW/m^2)
Alcohol pool	5	12	21	27	**34**
4 x 8 m	2	32	53	57	**77**
4 x 8 m	5	32	47	49	**67**
4 x 8 m	10	32	46	48	**53**
4 x 8 m	15	32	30	38	**48**
8 x 8 m	5	64	96	81	**125**
8 x 8 m	10	64	87	63	**107**
4 x 16 m	10	64	40	51	**65**
Target IBC 2800 mm from fire					
8 x 8 m	10	64	55	58	**80**
4 x 8 m	5	32	40	30	**50**
Target IBC 4400 mm from fire					
8 x 8 m	10	64	34	36	**49**
4 x 8 m	5	32	19	22	**29**
Target IBC 6000 mm from fire					
8 x 8 m	10	64	22	27	**34**
4 x 8 m	5	32	11	15	**18**

Table 4: Summary of results of numerical modelling

(red)	Fire spread certain	(orange)	Fire spread uncertain	(green)	Fire spread unlikely

12.12 DISCUSSION OF NUMERICAL RESULTS

A number of important points come out of the modelling:

Fire size

The primary factor determining whether a fire will spread across a wall partition is the fire size. The extent of the fire perpendicular to the wall is particularly important. For a fire extending 8 metres from the wall, very large (~ 5-6 metre) separations between the partition and target IBCs would be required to prevent fire spread. If the extent of the pool can be limited to around 4 metres from the wall, a separation of around 3-4 metres between the partition and target IBCs should be adequate to prevent fire spread – even if the fire spreads a long way along the wall.

As a preliminary general rule of thumb: if the width of a pool fire can be limited (for example by slopes, kerbs and drains) to a particular distance there has to be a gap of a similar size on the other side of the wall to prevent the fire from spreading. This degree of separation could be reduced if liquids are prevented from running right up to the wall.

Some more numerical work would be useful to explore more fully how different storage designs would work. It would be worth checking how gaps in the IBC storage on the fire-side of the wall affected the flow. It is possible that channelling of flames might occur around such gaps with significant changes to the local flame size and chances of ignition.

Increasing the height of the partition would obvious help in a marginal cases, but is unlikely to reduce heat fluxes to the target significantly for very large pools – where the flame height is large compared with the barrier.

Wind speed

Generally heat fluxes to target IBCs decline as the wind speed increases. These decreases are particularly significant for very high wind speeds (15 m/s).

It is worth noting that without a barrier high wind speeds would lead to extremely high rates of fire spread because flame deflection would lead to direct impingement of flames on IBCs well away from a developing pool.

12.13 PRACTICAL CONSIDERATIONS

Confining the flow of liquid released in a developing IBC storage fire is not necessarily a simple matter. For most organic liquids i.e. solvents, lubricants etc. rapid failure and release of liquid is likely in a developing storage fire. This may result in strong spigot flows of liquid – Figure 24 shows a typical example for an IBC containing diesel.

Figure 24: Spigot flow of diesel from a fire engulfed IBC

This type of release will rapidly cause a large pool fire unless it is very positively channelled into drains.

Design features of a storage /drainage layout with improved resistance to rapid uncontrolled spread of fire are illustrated in Figure 25a. If aqueous and combustible liquids are stored in IBCs in the same area the aqueous materials can be used as part of the fire partitioning strategy. It should be noted that water filled containers will generally empty fairly rapidly during severe fire-engulfment. Aqueous containers will not therefore provide a permanent impermeable barrier. Burning liquid would also run fairly freely under most containers so kerbs or some other form of drainage control are still needed.

The flow of vapour from strongly irradiated (but un-ignited) IBCs close to a partition should be considered further. It is clear from the experiments that some of this vapour is drawn upwards by entrainment into the fire plume – where pockets are periodically ignited. However, it is not clear if some of this heavy vapour would escape from the fire-driven upflow if the downwind side of the wall were obstructed by large numbers of IBC. It is also not clear how such material would disperse. The alcohol pool fire used in the experiments is characterised by low levels of generation of both sparks and small flying brands. Real fires might involve paper or timber or other materials that do produce brands. If there is a low level flow of flammable vapour downwind this could be vulnerable to ignition by brands – which might in turn trigger an established fire past the barrier or even cause a significant explosion.

The rate of release of vapours in a typical situation has been established by the experiments. Modelling of the heavy gas flow from the tops of irradiated IBCs would be worthwhile.

Reflective or insulating covers for the IBCs on the top level closest to partitions would be extremely effective at reducing the risk of ignition.

Metal clad IBCs such as the Schutz SX-EX are commercially available. It would be interesting to examine their resistance to thermal radiation.

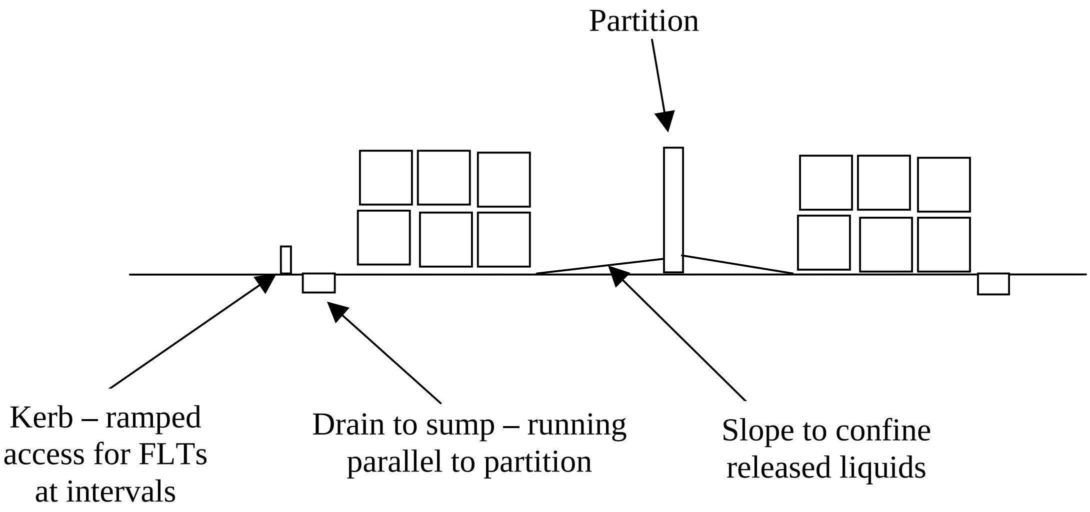


Figure 25a: Schematic showing design features of an IBC storage area (for combustible liquids) with improved fire performance – not to scale

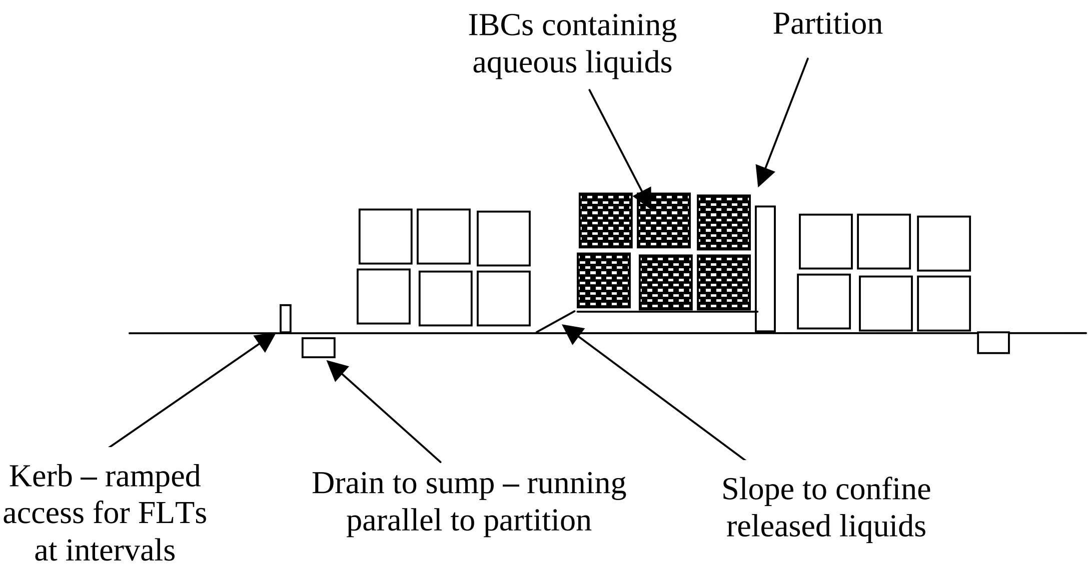


Figure 25b: Schematic showing design features of an IBC storage area for mixed combustible and aqueous liquids – not to scale

Reflective or insulating covers for the IBCs on the top level closest to partitions would be extremely effective at reducing the risk of ignition.

Metal clad IBCs such as the Schutz SX-EX are commercially available. It would be interesting to examine their resistance to thermal radiation.

12.14 FUTURE DEVELOPMENTS

Reducing the probability of 100% loss in IBC storage areas in the case of fire is an important and complex technical challenge. Solutions involving partitioning are likely to be fairly capital intensive and it is important that any design guidelines are carefully validated.

This project has provided some useful data of the levels of thermal radiation that IBCs can sustain without suffering (unpiloted) ignition. A preliminary analysis of the implications of these limits for the design of IBC storage areas has been carried out using fire modelling.

This approach has proved useful but the modelling work was outside the original scope of the project and some more effort is required to develop design guideline that HSE can recommend with confidence.

12.15 CONCLUSIONS AND RECOMMENDATIONS

1. Sufficient evidence has been gathered in this project to encourage the use of partitions to check the spread of fire through an IBC storage area. Any significant reduction in the rate of fire spread gives fire fighters a better chance to control the incident.

2. If fire spread is to be prevented in the long term without intervention by fire fighters, the spread of pool fires around the seat of the fire must be controlled. This could be done using slopes, kerbs and drains.

3. This project has provided some useful data on the levels of thermal radiation that IBCs can sustain without suffering ignition.

4. Fire modelling (outside the original scope of the project) has proved useful in exploring the extent to which partitions can prevent fire spread but some more effort is required to develop design guidelines that HSE can recommend with confidence.

5. Whilst IBCs are very vulnerable to even small flaming ignition sources, the experience gained in this project suggests that they are reasonably resistant to quite high levels of thermal radiation. The guidance given on minimum separation distances to buildings and boundaries given in HSG 51 “The storage of flammable liquids in containers” could be taken over to IBCs – although the guidance currently assumes storage in steel drums.

12.16 VIEWS OF DAMAGED IBCS

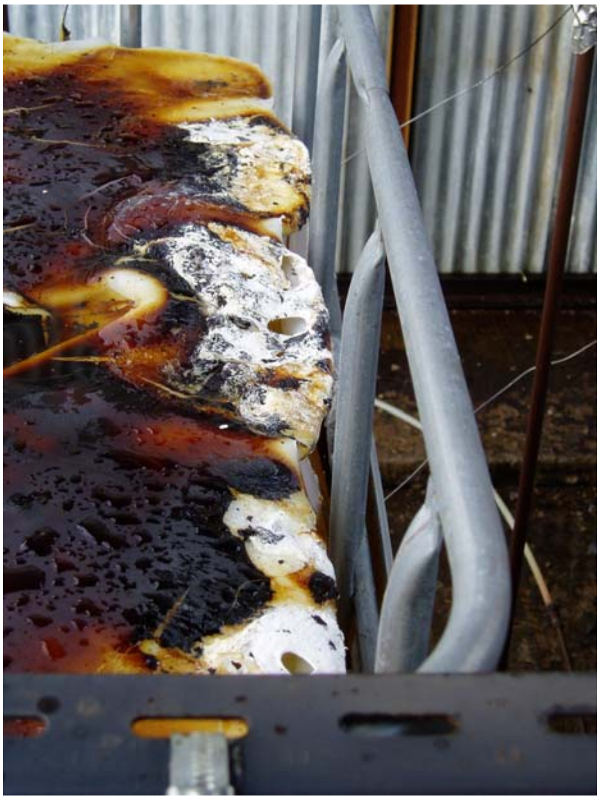


Figure 26:

Damaged IBC after Test 4

Above - overall view
Below – edge closest to fire

Figure 27

Damaged IBC after Test 3 - overall view

The top of the IBC has softened where not in contact with liquid and collapsed to the level of the top of the liquid.

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Health and Safety Executive

Fire performance of composite IBCs

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. Following HSE investigations at the scene of these fires, a research project has been undertaken to provide data to allow more reliable risk assessments for premises using IBCs for liquid storage and to provide a stimulus and direction for change in IBC selection and design.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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